PDAL: Point cloud Data Abstraction Library

Release 2.6.2

Andrew Bell
Brad Chambers
Howard Butler
Michael Gerlek
PDAL Contributors

Jan 24, 2024
## CONTENTS

<table>
<thead>
<tr>
<th>1 News</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 12-11-2023</td>
<td>3</td>
</tr>
<tr>
<td>1.2 11-24-2023</td>
<td>3</td>
</tr>
<tr>
<td>1.3 10-12-2023</td>
<td>3</td>
</tr>
<tr>
<td>1.4 08-18-2023</td>
<td>3</td>
</tr>
<tr>
<td>1.5 06-13-2023</td>
<td>3</td>
</tr>
<tr>
<td>1.6 04-13-2023</td>
<td>4</td>
</tr>
<tr>
<td>1.7 01-13-2023</td>
<td>4</td>
</tr>
<tr>
<td>1.8 06-28-2021</td>
<td>4</td>
</tr>
<tr>
<td>1.9 05-19-2021</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2 About</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 About</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3 Download</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 Download</td>
<td>13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4 Quickstart</th>
<th>19</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1 Quickstart</td>
<td>19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5 Applications</th>
<th>27</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 Applications</td>
<td>27</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6 Community</th>
<th>53</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 Community</td>
<td>53</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7 Drivers</th>
<th>55</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1 Pipeline</td>
<td>55</td>
</tr>
<tr>
<td>7.2 Stages</td>
<td>64</td>
</tr>
<tr>
<td>7.3 Readers</td>
<td>65</td>
</tr>
<tr>
<td>7.4 Writers</td>
<td>139</td>
</tr>
<tr>
<td>7.5 Filters</td>
<td>192</td>
</tr>
</tbody>
</table>
PDAL is a C++ library for translating and manipulating point cloud data (http://en.wikipedia.org/wiki/Point_cloud). It is very much like the GDAL (http://www.gdal.org) library which handles raster and vector data. The About (page 5) page provides high level overview of the library and its philosophy. Visit Readers (page 65) and Writers (page 139) to list data formats it supports, and see Filters (page 192) for filtering operations that you can apply with PDAL.

In addition to the library code, PDAL provides a suite of command-line applications that users can conveniently use to process, filter, translate, and query point cloud data. Applications (page 27) provides more information on that topic.

Finally, PDAL speaks Python by both embedding and extending it. Visit Python (page 369) to find out how you can use PDAL with Python to process point cloud data.

The entire website is available as a single PDF at http://pdal.io/_/downloads/en/latest/pdf/
1.1 12-11-2023
PDAL 2.6.2 was released. Visit Download (page 13) to grab a copy.

1.2 11-24-2023
PDAL 2.6.1 was released. Visit Download (page 13) to grab a copy.

1.3 10-12-2023
PDAL 2.6.0 was released. Visit Download (page 13) to grab a copy.

1.4 08-18-2023
PDAL 2.5.6 was released. Visit Download (page 13) to grab a copy.

1.5 06-13-2023
PDAL 2.5.5 was released. Visit Download (page 13) to grab a copy.
1.6 04-13-2023

PDAL 2.5.3 was released. Visit Download (page 13) to grab a copy.

1.7 01-13-2023

PDAL 2.5.0 was released. Visit Download (page 13) to grab a copy. See it in action in Jupyter by visiting Google Colab at https://colab.research.google.com/drive/1JQpcVFFJYMrrJCfodqP4Nc_B0_w6p5WOV?usp=sharing

1.8 06-28-2021

Howard Butler of Hobu, Inc. (https://hobu.co) was recently interviewed by the MapScaping Podcast (https://mapscaping.com). Listen to the episode where he talks about PDAL and point cloud processing.


1.9 05-19-2021

PDAL 2.2.1 has been released. You can download (page 13) the source code or follow the quickstart (page 19) to get going in a hurry with Conda.
2.1 About

2.1.1 What is PDAL?

PDAL (https://pdal.io/) is Point Data Abstraction Library. It is a C/C++ open source library and applications for translating and processing point cloud data (https://en.wikipedia.org/wiki/Point_cloud). It is not limited to LiDAR (https://en.wikipedia.org/wiki/Lidar) data, although the focus and impetus for many of the tools in the library have their origins in LiDAR.

2.1.2 What is its big idea?

PDAL allows you to compose operations (page 192) on point clouds into pipelines (page 55) of stages. These pipelines can be written in a declarative JSON syntax or constructed using the available API.

Why would you want to do that?

A task might be to load some ASPRS LAS (http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) (the most common LiDAR binary format) data into a database, but you wanted to transform it into a common coordinate system along the way.

One option would be to write a specialized monolithic program that reads LAS data, reprojects it as necessary, and then handles the necessary operations to insert the data in the appropriate format in the database. This approach has a distinct disadvantage in that without careful planning it could quickly spiral out of control as you add new little tweaks and features to the operation. It ends up being very specific, and it does not allow you to easily reuse the component that reads the LAS data separately from the component that transforms the data.
The PDAL approach is to chain together a set of components, each of which encapsulates specific functionality. The components allow for reuse, composition, and separation of concerns. PDAL views point cloud processing operations as a pipeline composed as a series of stages. You might have a simple pipeline composed of a LAS Reader stage, a Reprojection stage, and a PostgreSQL Writer, for example. Rather than writing a single, monolithic specialized program to perform this operation, you can dynamically compose it as a sequence of steps or operations.

![Pipeline Diagram](image)

**Fig. 1:** A simple PDAL pipeline composed of a reader, filter, and writer stages.

A PDAL JSON *Pipeline* that composes this operation to reproject and load the data into PostgreSQL might look something like the following:

```json
{
    "pipeline": [
        {
            "type": "readers.las",
            "filename": "input.las"
        },
        {
            "type": "filters.reprojection",
            "out_srs": "EPSG:3857"
        },
        {
            "type": "writers.pgpointcloud",
            "connection": "host=localhost dbname=lidar user=hobu",
            "table": "output",
            "srid": "3857"
        }
    ]
}
```

PDAL can compose intermediate stages for operations such as filtering, clipping, tiling, transforming into a processing pipeline and reuse as necessary. It allows you to define these pipelines as JSON (https://en.wikipedia.org/wiki/JSON), and it provides a command, *pipeline* (page 41), to allow you to execute them.

**Note:** Raster processing tools often compose operations with this approach. PDAL conceptually steals its pipeline modeling from GDAL (http://gdal.org/)'s Virtual Raster Format.
2.1.3 How is it different than other tools?

**LAStools**

One of the most common open source processing tool suites available for LiDAR processing is LAStools (http://lastools.org) from Martin Isenburg (https://www.cs.unc.edu/~isenburg/). PDAL is different in philosophy in a number of important ways:

1. All components of PDAL are released as open source software under an OSI (https://opensource.org/licenses)-approved license.

2. PDAL allows application developers to provide proprietary extensions that act as stages in processing pipelines. These might be things like custom format readers, specialized exploitation algorithms, or entire processing pipelines.

3. PDAL can operate on point cloud data of any format – not just ASPRS LAS (http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html). LAStools (http://lastools.org) can read and write formats other than LAS, but relates all data to its internal handling of LAS data, limiting it to dimension types provided by the LAS format.

4. PDAL is coordinated by users with its declarative JSON (page 55) syntax. LAStools is coordinated by linking lots of small, specialized command line utilities together with intricate arguments.

5. PDAL is an open source project, with all of its development activities available online at https://github.com/PDAL/PDAL

**PCL**

PCL (http://pointclouds.org) is a complementary, rather than substitute, open source software processing suite for point cloud data. The developer community of the PCL library is focused on algorithm development, robotic and computer vision, and real-time laser scanner processing. PDAL can read and write PCL’s PCD format.
Entwine

Entwine (https://entwine.io) is open source software from Hobu, Inc. that organizes massive point cloud collections into streamable data services. These two software projects allow province-scale LiDAR collections to be organized and served via HTTP clients over the internet. PDAL provides readers.ept (page 72) to allow users to read data from those Entwine Point Tile (https://entwine.io/entwine-point-tile.html) collections that Entwine produces.

Untwine

Untwine (https://github.com/hobuinc/untwine) is open source software from Hobu, Inc. that organizes massive point just like Entwine, but it does so in a bottom-up rather than top-down way.

viewer.copc.io

The Eptium viewer from Hobu, Inc. is a commercial lidar exploitation and visualization platform based on Cesium that can be used to visualize COPC (https://copc.io) and Entwine Point Tile (https://entwine.io/entwine-point-tile.html) content.

Potree

Potree (http://potree.org) is a WebGL (https://en.wikipedia.org/wiki/WebGL) HTML5 point cloud renderer that speaks ASPRS LAS (http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) and LASzip (http://laszip.org) compressed LAS. You can find the software at https://github.com/potree/potree/

Note: See Potree in action using the USGS 3DEP AWS Public Dataset at https://usgs.entwine.io

Others

Other open source point cloud softwares tend to be Desktop GUI, rather than library, focused. They include some processing operations, and sometimes they even embed tools such as PDAL. We’re obviously biased toward PDAL, but you might find useful bits of functionality in them. These other tools include:

- libLAS (http://liblas.org)
- CloudCompare (http://www.danielgm.net/cc/)
• Fusion (http://www.idaholidar.org/tools/fusion-ldv/)
• OrfeoToolbox (https://www.orfeo-toolbox.org/)

Note: The libLAS (http://liblas.org) project is an open source project that predates PDAL, and provides some of the processing capabilities provided by PDAL. It is currently in maintenance mode due to its dependence on LAS, the release of relevant LAStools capabilities as open source, and the completion of Python LAS (https://pypi.python.org/pypi/laspy/1.4.1) software.

2.1.4 Where did PDAL come from?

PDAL takes its cue from another very popular open source project – GDAL (http://gdal.org/). GDAL is Geospatial Data Abstraction Library, and it is used throughout the geospatial software industry to provide translation and processing support for a variety of raster and vector formats. PDAL provides the same capability for point cloud data types.

PDAL evolved out of the development of database storage and access capabilities for the U.S. Army Corps of Engineers CRREL (http://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/476649/remote-sensinggeographic-information-systems-center/) GRiD (http://lidar.io/) project. Functionality that was creeping into libLAS (http://liblas.org/) was pulled into a new library, and it was designed from the ground up to mimic successful extract, transform, and load libraries in the geospatial software domain. PDAL has steadily attracted more contributors as other software developers use it to provide point cloud data translation and processing capability to their software.

How is point cloud data different than raster or vector geo data?

Point cloud data are indeed very much like the typical vector point data type of which many geospatial practitioners are familiar, but their volume causes some significant challenges. Besides their X, Y, and Z locations, each point often has full attribute information of other things like Intensity, Time, Red, Green, and Blue.

Typical vector coverages of point data might max out at a million or so features. Point clouds quickly get into the billions and even trillions, and because of this specialized processing and management techniques must be used to handle so much data efficiently.

The algorithms used to extract and exploit point cloud data are also significantly different than typical vector GIS work flows, and data organization is extremely important to be able to efficiently leverage the available computing. These characteristics demand a library oriented toward these approaches and PDAL achieves it.

Note: Possible point cloud dimension types provided and supported by PDAL can be found at
2.1.5 What tasks are PDAL good at?

PDAL is great at point cloud data translation work flows. It allows users to apply algorithms to data by providing an abstract API to the content – freeing users from worrying about many data format issues. PDAL’s format-free worry does come with a bit of overhead cost. In most cases this is not significant, but for specific processing work flows with specific data, specialized tools will certainly outperform it.

In exchange for possible performance penalty or data model impedance, developers get the freedom to access data over an abstract API, a multitude of algorithms to apply to data within easy reach, and the most complete set of point cloud format drivers in the industry. PDAL also provides a straightforward command line, and it extends simple generic Python processing through Numpy. These features make it attractive to software developers, data managers, and scientists.

2.1.6 What are PDAL’s weak points?

PDAL doesn’t provide a friendly GUI interface, it expects that you have the confidence to dig into the options of Filters (page 192), Readers (page 65), and Writers (page 139). We sometimes forget that you don’t always want to read source code to figure out how things work. PDAL is an open source project in active development, and because of that, we’re always working to improve it. Please visit Community (page 53) to find out how you can participate if you are interested. The project is always looking for contribution, and the mailing list is the place to ask for help if you are stuck.

2.1.7 High Level Overview

PDAL is first and foremost a software library. A successful software library must meet the needs of software developers who use it to provide its software capabilities to their own software. In addition to its use as a software library, PDAL provides some command line applications (page 27) users can leverage to conveniently translate, filter, and process data with PDAL. Finally, PDAL provides Python (http://python.org/) support in the form of embedded operations and Python extensions.
Core C++ Software Library

PDAL provides a C++ API (page 600) software developers can use to provide point cloud processing capabilities in their own software. PDAL is cross-platform C++, and it can compile and run on Linux, OS X, and Windows. The best place to learn how to use PDAL’s C++ API is the test suite (page 590) and its source code (https://github.com/PDAL/PDAL/tree/master/test/unit).

See also:

PDAL software (page 379) development (page 546) tutorials (page 561) have more information on how to use the library from a software developer’s perspective.

Command Line Utilities

PDAL provides a number of applications (page 27) that allow users to coordinate and construct point cloud processing work flows. Some key tasks users can achieve with these applications include:

- Print info (page 38) about a data set
- Data translation (page 50) from one point cloud format to another
- Application of exploitation algorithms
  - Generate a DTM
  - Remove noise
  - Reproject from one coordinate system to another
  - Classify points as ground/not ground (page 33)
- Merge (page 41) or split (page 46) data
- Catalog (page 48) collections of data

Note: The command line utilities are often simply pipeline (page 41) and Pipeline (page 55) collected into a convenient application. In many cases you can replicate the functionality of an application entirely within a single pipeline.
Python API

PDAL supports both embedding Python (http://python.org/) and extending with Python (http://python.org/). These allow you to dynamically interact with point cloud data in a more comfortable and familiar language environment for geospatial practitioners.

See also:

The Python (page 369) document contains information on how to install and use the PDAL Python extension.

Julia Plugin

PDAL supports embedding Julia (https://julialand.org) filters. These allow you to dynamically interact with point cloud data in a more comfortable and familiar language environment for geospatial practitioners, while still maintaining high performance.

Additionally the TypedTables.jl, RoamesGeometry.jl and AcceleratedArrays.jl libraries provide some very high-level interfaces for writing efficient filters.

See also:

The github repo at https://github.com/cognitive-earth/PDAL-julia contains a docker image, build instructions and some sample filters.

Documentation for the stage filters.julia (page 354)

2.1.8 Conclusion

PDAL is an open source project for translating, filtering, and processing point cloud data. It provides a C++ API, command line utilities, and Python extensions. There are many open source software projects for interacting with point cloud data, and PDAL’s niche is in processing, translation, and automation.
CHAPTER THREE

DOWNLOAD

3.1 Download

Contents

• Download (page 13)
  – Current Release(s) (page 13)
  – Past Releases (page 14)
  – Development Source (page 14)
  – Binaries (page 15)
    * Windows (page 15)
    * RPMs (page 16)
    * Alpine (page 16)
    * Conda (page 16)

3.1.1 Current Release(s)

• 2023-11-24 PDAL-2.6.2-src.tar.bz2
  (https://github.com/PDAL/PDAL/releases/download/2.6.2/PDAL-2.6.2-src.tar.bz2)
  Release Notes (https://github.com/PDAL/PDAL/releases/tag/2.6.2) (md5
  (https://github.com/PDAL/PDAL/releases/download/2.6.2/PDAL-2.6.2-src.tar.bz2.md5))
3.1.2 Past Releases

- **2023-11-24** PDAL-2.6.1-src.tar.bz2
  (https://github.com/PDAL/PDAL/releases/download/2.6.1/PDAL-2.6.1-src.tar.bz2)

- **2023-10-12** PDAL-2.6.0-src.tar.bz2
  (https://github.com/PDAL/PDAL/releases/download/2.6.0/PDAL-2.6.0-src.tar.bz2)

- **2023-08-18** PDAL-2.5.6-src.tar.bz2
  (https://github.com/PDAL/PDAL/releases/download/2.5.6/PDAL-2.5.6-src.tar.bz2)

- **2023-01-13** PDAL-2.5.0-src.tar.bz2
  (https://github.com/PDAL/PDAL/releases/download/2.5.0/PDAL-2.5.0-src.tar.bz2)

- **2022-03-18** PDAL-2.4.0-src.tar.bz2
  (https://github.com/PDAL/PDAL/releases/download/2.4.0/PDAL-2.4.0-src.tar.bz2)

- **2021-05-19** PDAL-2.3.0-src.tar.bz2
  (https://github.com/PDAL/PDAL/releases/download/2.3.0/PDAL-2.3.0-src.tar.bz2)

- **2020-08-20** PDAL-2.2.0-src.tar.bz2
  (https://github.com/PDAL/PDAL/releases/download/2.2.0/PDAL-2.2.0-src.tar.bz2)

- **2020-03-20** PDAL-2.1.0-src.tar.bz2
  (https://github.com/PDAL/PDAL/releases/download/2.1.0/PDAL-2.1.0-src.tar.bz2)

- **2019-08-23** PDAL-2.0.1-src.tar.bz2
  (https://github.com/PDAL/PDAL/releases/download/2.0.1/PDAL-2.0.1-src.tar.bz2)

- **2019-05-09** PDAL-1.9.1-src.tar.bz2
  (https://github.com/PDAL/PDAL/releases/download/1.9.1/PDAL-1.9.1-src.tar.bz2)

3.1.3 Development Source

The main repository for PDAL is located on github at https://github.com/PDAL/PDAL.

You can obtain a copy of the active source code by issuing the following command

```
git clone https://github.com/PDAL/PDAL.git
```
3.1.4 Binaries

In this section we list a number of the binary distributions of PDAL. The table below is intended to provide an overview of some of the differences between the various distributions, as not all features can be enabled in every distribution. This table only summarizes the differences between distributions, and there are several plugins that are not built for any of the distributions. These include Delaunay, MATLAB, MBIO, OpenSceneGraph, RDBLIB, and RiVLib. To enable any of these plugins, the reader will need to install any required dependencies and build PDAL from source.

Table 1: PDAL Distribution Feature Comparison

<table>
<thead>
<tr>
<th></th>
<th>Docker</th>
<th>RPMs</th>
<th>Alpine</th>
<th>Conda (page 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platform(s)</td>
<td>linux</td>
<td>linux</td>
<td>linux</td>
<td>win64, linux</td>
</tr>
<tr>
<td>PDAL version</td>
<td>2.5</td>
<td>2.4</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>CPD</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>E57</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>HDF</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>I3S</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Icebridge</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>NITF</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>pgpointcloud</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>SLPK</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>TileDB</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Windows

Windows builds are available via Conda Forge (https://anaconda.org/conda-forge/pdal) (64-bit only). See the Conda (page 16) for more detailed information.
RPMs

RPMs for PDAL are available at https://copr.fedorainfracloud.org/coprs/neteler/pdal/.

Alpine

*Alpine* (page 16) is a Linux distribution that is compact and frequently used with Docker images. Alpine packages for PDAL are available at https://pkgs.alpinelinux.org/packages?name=*pdal*&branch=edge.

Users have a choice of three separate packages.

1. `pdal` will install the PDAL binaries only, and is suitable for users who will be using the PDAL command line applications.

2. `pdal-dev` will install development files which are required for users building their own software that will link against PDAL.

3. `py-pdal` will install the PDAL Python extension.

Note that the PDAL package now resides in Alpine’s `edge/community` repository, which must be added to your Alpine repositories list. Information on adding and updating repositories can be found in the Alpine documentation.

To install one or more packages on Alpine, use the following command.

```bash
apk add [package...]  # example: apk add py-pdal pdal
```

Conda

*Conda* (page 16) can be used on multiple platforms (Windows, macOS, and Linux) to install software packages and manage environments. Conda packages for PDAL are available at https://anaconda.org/conda-forge/pdal.

Conda installation instructions can be found on the Conda website. The instructions below assuming you have a working Conda installation on your system.

Users have a choice of two separate packages.

1. `pdal` will install the PDAL binaries and development files.

2. `python-pdal` will install the PDAL Python extension.

To install one or more Conda packages, use the following command.
Because the PDAL package (and it's dependencies) live in the Conda Forge (https://anaconda.org/conda-forge/pdal) channel, the command to install both the PDAL application and the Python extension is

```conda install -c conda-forge pdal python-pdal gdal```

It is strongly recommended that you make use of Conda's environment management system and install PDAL in a separate environment (i.e., not the base environment). Instructions can be found on the Conda website.
4.1 Quickstart

4.1.1 Introduction

The quickest way to start using PDAL is to leverage builds that were constructed by the PDAL development team using Conda (https://conda.io/docs/).

Directly from the Conda front page,

*Conda is an open source package management system and environment management system that runs on Windows, macOS and Linux. Conda quickly installs, runs and updates packages and their dependencies. Conda easily creates, saves, loads and switches between environments on your local computer.*

This exercise will print the first point of an ASPRS LAS (page 89) file. It will utilize the PDAL command line application (page 27) to inspect the file.

---

**Note:** If you need to compile your own copy of PDAL, see *Compilation* (page 534) for more details.

4.1.2 Install Conda

Conda installation instructions can be found at the following links. Read through them a bit for your platform so you have an idea what to expect.

Note: We will assume you are running on Windows, but the same commands should work in macOS or Linux too – though definition of file paths might provide a significant difference.

Run Conda

On macOS and Linux, all Conda commands are typed into a terminal window. On Windows, commands are typed into the Anaconda Prompt window. Instructions can be found in the Conda Getting Started (https://conda.io/projects/conda/en/latest/user-guide/getting-started.html#starting-conda) guide.

Test Installation

To test your installation, simply run the command `conda list` from your terminal window or the Anaconda Prompt. A list of installed packages should appear.

Install the PDAL Package

A PDAL package based on the latest release, including all recent patches, is pushed to the conda-forge (https://anaconda.org/conda-forge/pdal) channel on anaconda.org with every code change on the PDAL maintenance branch.

Warning: It is a good idea to install PDAL in its own environment (or add it to an existing one). You will NOT want to add it to your default environment named base. Managing environments is beyond the scope of the quickstart, but you can read more about it here (https://conda.io/projects/conda/en/latest/user-guide/getting-started.html#managing-envs).

To install the PDAL package so that we can use it to run PDAL commands, we run the following command to create an environment named `myenv`, installing PDAL from the conda-forge channel.

```bash
conda create --yes --name myenv --channel conda-forge pdal
```

Depending on what packages you may or may not have already installed, the output should look something like:

```plaintext
Solving environment: done
```
environment location: C:\Miniconda3\envs\myenv

added / updated specs:
- pdal

The following packages will be downloaded:

<table>
<thead>
<tr>
<th>package</th>
<th>build</th>
</tr>
</thead>
<tbody>
<tr>
<td>pdal-1.7.2</td>
<td>py35h33f895e_1 8.6 MB conda-forge</td>
</tr>
<tr>
<td>setuptools-39.2.0</td>
<td>py35_0 591 KB conda-forge</td>
</tr>
<tr>
<td>numpy-1.14.3</td>
<td>py35h9fa60d3_2 42 KB</td>
</tr>
</tbody>
</table>

Total: 9.2 MB

The following NEW packages will be INSTALLED:

- boost: 1.66.0-py35_vc14_1 conda-forge [vc14]
- boost-cpp: 1.66.0-vc14_1 conda-forge [vc14]
- ca-certificates: 2018.4.16-0 conda-forge
- cairo: 1.14.10-vc14_0 conda-forge [vc14]
- certifi: 2018.4.16-py35_0 conda-forge
- curl: 7.60.0-vc14_0 conda-forge [vc14]
- expat: 2.2.5-vc14_0 conda-forge [vc14]
- flann: 1.9.1-h0953f56_2 conda-forge
- freexl: 1.0.5-vc14_0 conda-forge [vc14]
- geotiff: 1.4.2-vc14_1 conda-forge [vc14]
- hdf4: 4.2.13-vc14_0 conda-forge [vc14]
- hdf5: 1.10.1-vc14_2 conda-forge [vc14]
- hexer: 1.4.0-vc14_1 conda-forge [vc14]
- icc_rt: 2017.0.4-h97af966_0 conda-forge
- icu: 58.2-vc14_0 conda-forge [vc14]
- intel-openmp: 2018.0.3-0 conda-forge
- jpeg: 9b-vc14_2 conda-forge [vc14]
- kealib: 1.4.7-vc14_4 conda-forge [vc14]
- krb5: 1.14.6-vc14_0 conda-forge [vc14]
- laszip: 3.2.2-vc14_0 conda-forge [vc14]
- laz-perf: 1.2.0-vc14_1 conda-forge [vc14]
- libgdal: 2.2.4-vc14_4 conda-forge [vc14]
libiconv: 1.15-vc14_0 conda-forge [vc14]
libnetcdf: 4.6.1-vc14_2 conda-forge [vc14]
lipng: 1.6.34-vc14_0 conda-forge [vc14]
lippq: 9.6.3-vc14_0 conda-forge [vc14]
lispspatialite: 4.3.0a-vc14_19 conda-forge [vc14]
lis ssh2: 1.8.0-vc14_2 conda-forge [vc14]
litiff: 4.0.9-vc14_0 conda-forge [vc14]
libxml2: 2.9.8-vc14_0 conda-forge [vc14]
litxslt: 1.1.32-vc14_0 conda-forge [vc14]
mkl: 2018.0.3-1
mkl_fft: 1.0.2-py35_0 conda-forge
mkl_random: 1.0.1-py35_0 conda-forge
nitro: 2.7.dev2-vc14_0 conda-forge [vc14]
numpy: 1.14.3-py35h9fa60d3_2
numpy-base: 1.14.3-py35h5c71026_0
openjpeg: 2.3.0-vc14_2 conda-forge [vc14]
openssl: 1.0.2o-vc14_0 conda-forge [vc14]
pcl: 1.8.1-hd76163c_1 conda-forge
pdal: 1.7.2-py35h33f895e_1 conda-forge
pip: 9.0.3-py35_0 conda-forge
pixman: 0.34.0-vc14_2 conda-forge [vc14]
postgresql: 10.3-py35_vc14_0 conda-forge [vc14]
proj4: 4.9.3-vc14_5 conda-forge [vc14]
python: 3.5.5-1 conda-forge
setuptools: 39.2.0-py35_0 conda-forge
sqlite: 3.20.1-vc14_2 conda-forge [vc14]
tiledb: 1.4.1 conda-forge
vc: 14-0 conda-forge
vs2015_runtime: 14.0.25420-0 conda-forge
wheel: 0.31.0-py35_0 conda-forge
wincertstore: 0.2-py35_0 conda-forge
xerces-c: 3.2.0-vc14_0 conda-forge [vc14]
xx: 5.2.3-0 conda-forge
zlib: 1.2.11-vc14_0 conda-forge [vc14]

Downloading and Extracting Packages

pdal-1.7.2 | 8.6 MB | ###################################################
  ↘/ 100%
setuptools-39.2.0 | 591 KB | ###################################################
  ↘/ 100%
numpy-1.14.3 | 42 KB | ###################################################
  ↘/ 100%
Preparing transaction: done
**Note:** PDAL’s Python extension is managed separately from the PDAL package. To install it, replace `pdal` with `python-pdal` in any of the commands in this section. Seeing as how PDAL is a dependency of the Python extension, you will actually get two for the price of one!

To install PDAL to an existing environment names `myenv`, we would run the following command.

```
conda install --name myenv --channel conda-forge pdal
```

Finally, to update PDAL to the latest version, run the following.

```
conda update pdal
```

### 4.1.3 Fetch Sample Data

We need some sample data to play with, so we’re going to download the `autzen.laz` file. Inside your terminal (assuming Windows), issue the following command:

```
explorer.exe https://github.com/PDAL/data/raw/master/autzen/autzen.laz
```

In the download dialog, save the file to your Downloads folder, e.g., `C:\Users\hobu\Downloads`. 
4.1.4 Print the first point

To print the first point only, issue the following command (replacing of course hobu with your user name, or another path altogether, depending on where you saved the file).

```
pdal info C:\Users\hobu\Downloads\autzen.laz -p 0
```

Here’s a summary of what’s going on with that command invocation

1. **pdal**: We’re going to run the `pdal` command.
2. **info**: We want to run `info` (page 38) on the data.
3. **autzen.laz**: The `autzen.laz` file that we want information from.

```
Warning 1: Cannot find datum.csv or gdal_datum.csv
Warning 1: Cannot find ellipsoid.csv
{
    "filename": "C:\Users\hobu\Downloads\autzen.laz",
    "pdal_version": "1.7.2 (git-version: Release)",
    "points":
    {
        "point":
        {
            "Blue": 93,
            "Classification": 1,
            "EdgeOfFlightLine": 0,
            "GpsTime": 245379.3984,
            "Green": 102,
            "Intensity": 4,
            "NumberOfReturns": 1,
            "PointId": 0,
            "PointSourceId": 7326,
            "Red": 84,
            "ReturnNumber": 1,
            "ScanAngleRank": -17,
            "ScanDirectionFlag": 0,
            "UserData": 128,
            "X": 637177.98,
            "Y": 849393.95,
            "Z": 411.19
        }
    }
}
```
4.1.5 What’s next?

- Visit Applications (page 27) to find out how to utilize PDAL applications to process data on the command line yourself.

- Visit Development (page 523) to learn how to embed and use PDAL in your own applications.

- Readers (page 65) lists the formats that PDAL can read, Filters (page 192) lists the kinds of operations you can do with PDAL, and Writers (page 139) lists the formats PDAL can write.

- Tutorials (page 379) contains a number of walk-through tutorials for achieving many tasks with PDAL.

- The PDAL workshop (page 425) contains numerous hands-on examples with screenshots and example data of how to use PDAL Applications (page 27) to tackle point cloud data processing tasks.

- Python (page 369) describes how PDAL embeds and extends Python and how you can leverage these capabilities in your own programs.

See also:

Community (page 53) is a good source to reach out to when you’re stuck.
5.1 Applications

PDAL contains consists of a single application, called pdal. Operations are run by invoking the pdal application along with a command name:

```
$ pdal info myfile.las
$ pdal translate input.las output.las
$ pdal pipeline --stdin < pipeline.json
```

Help for each command can be retrieved via the --help switch. The --drivers and --options switches can tell you more about particular drivers and their options:

```
$ pdal info --help
$ pdal --drivers
$ pdal --options writers.las
```

All commands support the following options:

```
--developer-debug   Enable developer debug (don't trap exceptions).
--label             A string to use as a process label.
--driver            Name of driver to use to override that inferred from file type.
```

Additional driver-specific options may be specified by using a namespace-prefixed option name. For example, it is possible to set the LAS day of year at translation time with the following option:

```
$ pdal translate \   
   --writers.las.creation_doy="42" \   
   input.las \   
   output.las
```
Driver-specific options can be identified using the `pdal <command> --help` invocation.

### 5.1.1 chamfer

**Warning:** As of PDAL v2.6.0, the `chamfer` command is marked as DEPRECATED. It will be removed from the default install in PDAL v2.7 and removed completely in PDAL v2.8.

The following Python code can be used with the PDAL Python bindings to compute the chamfer distance.

```python
import pdal
import numpy as np

def chamfer_distance(arr1, arr2):
    distance_1_to_2 = 0
    distance_2_to_1 = 0

    points1 = np.column_stack((arr1['X'], arr1['Y'], arr2['Z']))
    points2 = np.column_stack((arr2['X'], arr2['Y'], arr2['Z']))

    # Compute distance from each point in arr1 to arr2
    for p1 in points1:
        distances = np.sqrt(np.sum((points2 - p1)**2, axis=1))
        min_distance = np.min(distances)
        distance_1_to_2 += min_distance

    # Compute distance from each point in arr2 to arr1
    for p2 in points2:
        distances = np.sqrt(np.sum((points1 - p2)**2, axis=1))
        min_distance = np.min(distances)
        distance_2_to_1 += min_distance

    return (distance_1_to_2 + distance_2_to_1) / (len(arr1) + len(arr2))

pipeline1 = pdal.Reader("/path/to/input1.laz").pipeline()
pipeline1.execute()
arr1 = pipeline1.array[0]

pipeline2 = pdal.Reader("/path/to/input2.laz").pipeline()
```
pipeline2.execute()
arr2 = pipeline2.array[0]

# Compute Chamfer distance
result = chamfer_distance(arr1, arr2)
print("Chamfer Distance:", result)

Popular Python packages such as scipy and sklearn have functions to compute the pairwise distance between points and can be used to simplify the above somewhat.

Note that the provided code does not match exactly the output of PDAL’s original implementation, which summed the square of the distance to the nearest neighbor. We have elected not to update the PDAL implementation at this time.

The `chamfer` command is used to compute the Chamfer distance between two point clouds. The Chamfer distance is computed by summing the squared distances between nearest neighbor correspondences of two point clouds.

More formally, for two non-empty subsets $X$ and $Y$, the Chamfer distance $d_{CD}(X, Y)$ is

$$d_{CD}(X, Y) = \sum_{x \in X} \min_{y \in Y} ||x - y||^2 + \sum_{y \in Y} \min_{x \in X} ||x - y||^2$$

$pdal$ chamfer <source> <candidate>

```
--source arg Source filename
--candidate arg Candidate filename
```

The algorithm makes no distinction between source and candidate files (i.e., they can be transposed with no affect on the computed distance).

The command returns 0 along with a JSON-formatted message summarizing the PDAL version, source and candidate filenames, and the Chamfer distance. Identical point clouds will return a Chamfer distance of 0.

```
$ pdal chamfer source.las candidate.las
{
   "filenames":
   [ "\path\to\source.las",
     "\path\to\candidate.las"
   ],
   "chamfer": 1.303648726,
   "pdal_version": "1.3.0 (git-version: 191301)"
}
```

5.1. Applications
Note: The Chamfer distance is computed for XYZ coordinates only and as such says nothing about differences in other dimensions or metadata.

5.1.2 delta

Warning: As of PDAL v2.6.0, the delta command is marked as DEPRECATED. It will be removed from the default install in PDAL v2.7 and removed completely in PDAL v2.8.

The delta command is used to select a nearest point from a candidate file for each point in the source file.

$ pdal delta <source> <candidate>

--source source file name
--candidate candidate file name
--detail Output deltas per-point
--alldims Compute diffs for all dimensions (not just X,Y,Z)

Example 1:

$ pdal delta ../../test/data/las/1.2-with-color.las ../../test/data/las/1.2-with-color.las

---

Delta summary for source: '../../test/data/las/1.2-with-color.las'
candidate: '../../test/data/las/1.2-with-color.las'
---

<table>
<thead>
<tr>
<th>Dimension</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Max</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Mean</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
</tbody>
</table>
Example 2:

```bash
$ pdal delta test/data/1.2-with-color.las test/data/1.2-with-color.las --detail
"ID","DeltaX","DeltaY","DeltaZ"
0,0.00,0.00,0.00
1,0.00,0.00,0.00
2,0.00,0.00,0.00
3,0.00,0.00,0.00
4,0.00,0.00,0.00
5,0.00,0.00,0.00
```

5.1.3 density

**Warning:** As of PDAL v2.6.0, the density command is marked as DEPRECATED. It will be removed from the default install in PDAL v2.7 and removed completely in PDAL v2.8.

The density command produces a tessellated hexagonal OGR layer (http://www.gdal.org/ogr_utilities.html) from the output of filters.hexbin (page 331).

```bash
$ pdal density <input> <output>
```

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>--input, -i</td>
<td>Input point cloud file name</td>
</tr>
<tr>
<td>--output, -o</td>
<td>Output vector data source</td>
</tr>
<tr>
<td>--lyr_name</td>
<td>OGR layer name to write into datasource</td>
</tr>
<tr>
<td>--ogrdriver, -f</td>
<td>OGR driver name to use</td>
</tr>
<tr>
<td>--sample_size</td>
<td>Sample size for automatic edge length calculation.</td>
</tr>
<tr>
<td>--threshold</td>
<td>Required cell density [15]</td>
</tr>
<tr>
<td>--hole_cull_tolerance_area</td>
<td>Tolerance area to apply to holes before cull</td>
</tr>
<tr>
<td>--smooth</td>
<td>Smooth boundary output</td>
</tr>
</tbody>
</table>

5.1. Applications
5.1.4 eval

**Warning:** As of PDAL v2.6.0, the `eval` command is marked as DEPRECATED. It will be removed from the default install in PDAL v2.7 and removed completely in PDAL v2.8.

The eval command is used to compare the Classification dimensions of two point clouds.

```
$ pdal eval <predicted> <truth> --labels <labels>
```

```
--predicted arg  Positional argument specifying point cloud filename containing predicted labels.
--truth arg  Positional argument specifying point cloud filename containing truth labels.
--labels arg  Comma-separated list of classification labels to evaluate.
```

The command returns 0 along with a JSON-formatted classification report summarizing various classification metrics.

In the provided example below, the truth and predicted point clouds contain points classified as ground (class 2) and medium vegetation (class 4) in accordance with the LAS specification. Both point clouds also contain some number of classifications that are either unlabeled or do not fall into the specified classes.

```
$ pdal eval predicted.las truth.las --labels 2,4
{
  "confusion_matrix": 
  [[5240537,3860,24102],[268015,3179304,326677],
   [111453,115516,2950315]],
  "f1_score": 0.944,
  "labels": [
    {
      "accuracy": 0.967,
      "f1_score": 0.973,
      "intersection_over_union": 0.947,
      "label": "1",
      "precision": 0.951,
      "sensitivity": 0.995,
      "specificity": 0.929,
      "support": 5268499
    },
    {
      "accuracy": 0.934,
      "f1_score": 0.914,
    }
  ]
}
```

(continues on next page)
Most of the returned metrics will be self explanatory, with scores reported both for individual classes and at a summary level. The returned confusion matrix is presented in row-major order, where each row corresponds to a truth label (the last row is a catch-all for any unlabeled or ignored entries). Similarly, confusion matrix columns correspond to predicted labels where the last column is once again a catch-all for unlabeled entries. Although unlabeled/ignored truth labels are reported in the confusion matrix, they are excluded from all computed scores.

5.1.5 ground

Warning: As of PDAL v2.6.0, the ground command is marked as DEPRECATED. It will be removed from the default install in PDAL v2.7 and removed completely in PDAL v2.8.

The basic pipeline detailed in the kernel is given below in JSON.

```json
[
    "input.laz",
    {
        "type": "filters.assign",
        "value": "Classification=0"
    },
    {
        "type": "filters.outlier"
    },
    {
        "type": "filters.smrf",
        "window": 18.0,
        "threshold": 0.5,
```
"slope": 0.15,
"cell": 1.0,
"cut": 0.0,
"scalar": 1.25,
"returns": "last, only"
},
{
  "type": "filters.expression",
  "expression": "Classification==2"
},
"output.laz"
]

Written programmatically in Python, as shown below, resetting of Classification labels, denoising, and extraction of ground returns only can all be conditionally included.

```python
pipeline = pdal.Reader("input.laz").pipeline()
if reset:
    pipeline |= pdal.Filter.assign(value="Classification=0")
if denoise:
    pipeline |= pdal.Filter.outlier()
    pipeline |= pdal.Filter.smrf(window=18.0, threshold=0.5, slope=0.15, cell=1.0, cut=0.0, scalar=1.25, returns="last, only")
if extract:
    pipeline |= pdal.Filter.expression(expression="Classification==2")
pipeline |= pdal.Writer("output.laz")
pipeline.execute()
```

The `ground` command is used to segment the input point cloud into ground versus non-ground returns using `filters.smrf` (page 197) and `filters.outlier` (page 203).

```
$ pdal ground [options] <input> <output>
```

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>--input, -i</td>
<td>Input filename</td>
</tr>
<tr>
<td>--output, -o</td>
<td>Output filename</td>
</tr>
<tr>
<td>--max_window_size</td>
<td>Max window size</td>
</tr>
<tr>
<td>--slope</td>
<td>Slope</td>
</tr>
</tbody>
</table>

(continues on next page)
--max_distance Max distance
--initial_distance Initial distance
--cell_size Cell size
--extract Extract ground returns?
--reset Reset classifications prior to segmenting?
--denoise Apply statistical outlier removal prior to segmenting?
--returns Include last returns?
--scalar Elevation scalar?
--threshold Elevation threshold?
--cut Cut net size?
--ignore A range query to ignore when processing

5.1.6 hausbodrf

**Warning:** As of PDAL v2.6.0, the hausbodrrf command is marked as DEPRECATED. It will be removed from the default install in PDAL v2.7 and removed completely in PDAL v2.8.

The following Python code can be used with the PDAL Python bindings to compute the Hausdorff distance.

```python
import pdal
import numpy as np

def hausbodrf_distance(arr1, arr2):
    max_min_distance_1_to_2 = 0
    max_min_distance_2_to_1 = 0

    points1 = np.column_stack((arr1['X'], arr1['Y'], arr1['Z']))
    points2 = np.column_stack((arr2['X'], arr2['Y'], arr2['Z']))

    # Compute distance from each point in arr1 to arr2
    for p1 in points1:
        distances = np.sqrt(np.sum((points2 - p1)**2, axis=1))
        min_distance = np.min(distances)
        max_min_distance_1_to_2 = max(max_min_distance_1_to_2, min_distance)

    # Compute distance from each point in arr2 to arr1
    for p2 in points2:
        distances = np.sqrt(np.sum((points1 - p2)**2, axis=1))
```

5.1. Applications
min_distance = np.min(distances)
max_min_distance_2_to_1 = max(max_min_distance_2_to_1, min_distance)

return max(max_min_distance_1_to_2, max_min_distance_2_to_1)

pipeline1 = pdal.Reader("/path/to/input1.laz").pipeline()
pipeline1.execute()
arr1 = pipeline1.arrays[0]

pipeline2 = pdal.Reader("/path/to/input2.laz").pipeline()
pipeline2.execute()
arr2 = pipeline2.arrays[0]

# Compute Hausdorff distance
result = hausdorff_distance(arr1, arr2)
print("Hausdorff Distance:", result)

SciPy can be used to simplify this function even further, as shown below.

import pdal
import numpy as np
from scipy.spatial.distance import directed_hausdorff

def hausdorff_distance(arr1, arr2):
    points1 = np.column_stack((arr1['X'], arr1['Y'], arr2['Z']))
    points2 = np.column_stack((arr2['X'], arr2['Y'], arr2['Z']))

    # Compute directed Hausdorff distances
    d1 = directed_hausdorff(points1, points2)[0]
    d2 = directed_hausdorff(points2, points1)[0]

    return max(d1, d2)

pipeline1 = pdal.Reader("/path/to/input1.laz").pipeline()
pipeline1.execute()
arr1 = pipeline1.array[0]

pipeline2 = pdal.Reader("/path/to/input2.laz").pipeline()
pipeline2.execute()
arr2 = pipeline2.array[0]

# Compute Hausdorff distance
result = hausdorff_distance(arr1, arr2)
The `hausdorff` command is used to compute the Hausdorff distance between two point clouds. In this context, the Hausdorff distance is the greatest of all Euclidean distances from a point in one point cloud to the closest point in the other point cloud.

More formally, for two non-empty subsets $X$ and $Y$, the Hausdorff distance $d_H(X, Y)$ is

$$d_H(X, Y) = \max \left\{ \sup_{x \in X} \inf_{y \in Y} d(x, y), \sup_{y \in Y} \inf_{x \in X} d(x, y) \right\}$$

where sup and inf are the supremum and infimum respectively.

$pdal hausdorff <source> <candidate>$

```
--source arg Source filename
--candidate arg Candidate filename
```

The algorithm makes no distinction between source and candidate files (i.e., they can be transposed with no affect on the computed distance).

The command returns 0 along with a JSON-formatted message summarizing the PDAL version, source and candidate filenames, and the Hausdorff distance. Identical point clouds will return a Hausdorff distance of 0.

```
$ pdal hausdorff source.las candidate.las
{
  "filenames": ["/path/to/source.las", "/path/to/candidate.las"],
  "hausdorff": 1.303648726,
  "pdal_version": "1.3.0 (git-version: 191301)"
}
```

**Note:** The `hausdorff` is computed for XYZ coordinates only and as such says nothing about differences in other dimensions or metadata.
5.1.7 info

Displays information about a point cloud file, such as:

- basic properties (extents, number of points, point format)
- coordinate reference system
- additional metadata
- summary statistics about the points
- the plain text format should be reStructured text if possible to allow a user to retransform the output into whatever they want with ease

```
$ pdal info <input>
```

```
--input, -i Input file name
--all Dump statistics, schema and metadata
--point, -p Point to dump --point="1-5,10,100-200" (0-indexed)
--query Return points in order of distance from the specified location (2D or 3D) --query Xcoord,Ycoord[,Zcoord][/count]
--stats Dump stats on all points (reads entire dataset)
--boundary Compute a hexagonal hull/boundary of dataset
--dimensions Dimensions on which to compute statistics
--enumerate Dimensions whose values should be enumerated
--schema Dump the schema
--pipeline-serialization Output filename for pipeline serialization
--summary Dump summary of the info
--metadata Dump file metadata info
--stdin, -s Read a pipeline file from standard input
```

If no options are provided, --stats is assumed.

**Example 1:**

```
$ pdal info test/data/las/1.2-with-color.las \
  --query="636601.87, 849018.59, 425.10"
```

```
{
  "0":
  {
    "Blue": 134,
    "Classification": 1,
    ...
  }
  ...
}
```

(continues on next page)
"EdgeOfFlightLine": 0,
"GpsTime": 245383.3880801476,
"Green": 104,
"Intensity": 124,
"NumberOfReturns": 1,
"PointSourceId": 7326,
"Red": 134,
"ReturnNumber": 1,
"ScanAngleRank": -4,
"ScanDirectionFlag": 1,
"UserData": 126,
"X": 636601.87,
"Y": 849018.99999999998,
"Z": 425.10000000000002
}

"1":
{
  "Blue": 134,
  "Classification": 2,
  "EdgeOfFlightLine": 0,
  "GpsTime": 246099.17323102333,
  "Green": 106,
  "Intensity": 153,
  "NumberOfReturns": 1,
  "PointSourceId": 7327,
  "Red": 143,
  "ReturnNumber": 1,
  "ScanAngleRank": -10,
  "ScanDirectionFlag": 1,
  "UserData": 126,
  "X": 636606.76000000001,
  "Y": 849018.59999999998,
  "Z": 425.88999999999999
}

...
Example 2:

```
$ pdal info test/data/1.2-with-color.las -p 0-10
{
   "filename": "../..\test\data\las\1.2-with-color.las",
   "pdal_version": "PDAL 1.0.0.b1 (116d7d) with GeoTIFF 1.4.1 GDAL 1.11.
   \-
   2 LASzip 2.2.0",
   "points":
   {
      "point":
      [
         {
            "Blue": 88,
            "Classification": 1,
            "EdgeOfFlightLine": 0,
            "GpsTime": 245380.78254962614,
            "Green": 77,
            "Intensity": 143,
            "NumberOfReturns": 1,
            "PointId": 0,
            "PointSourceId": 7326,
            "Red": 68,
            "ReturnNumber": 1,
            "ScanAngleRank": -9,
            "ScanDirectionFlag": 1,
            "UserData": 132,
            "X": 637012.23999999999,
            "Y": 849028.31000000006,
            "Z": 431.66000000000003
         },
         {
            "Blue": 68,
            "Classification": 1,
            "EdgeOfFlightLine": 0,
            "GpsTime": 245381.45279923646,
            "Green": 66,
            "Intensity": 18,
            "NumberOfReturns": 2,
            "PointId": 1,
            "PointSourceId": 7326,
            "Red": 54,
            "ReturnNumber": 1,
            "ScanAngleRank": -11,
```

(continues on next page)
5.1.8 merge

The `merge` command will combine input files into a single output file.

```bash
$ pdal merge <input> ... <output>
```

--files, -f List of filenames. The last file listed is taken to be the output file.

This command provides simple merging of files. It provides no facility for filtering, reprojection, etc. The file type of the input files may be different from one another and different from that of the output file.

5.1.9 pipeline

The `pipeline` command is used to execute `Pipeline` JSON. By default the pipeline is run in stream mode if possible, otherwise in standard mode. See `Reading with PDAL` (page 379) or `Pipeline` (page 55) for more information.

```bash
$ pdal pipeline <input>
```

--input, -i Input filename
--dims Limit loaded dimensions to this list. Note that X, Y and Z are always loaded.
--pipeline-serialization Output file for pipeline serialization
--validate Validate but do not process the pipeline. Also reports whether a pipeline can be streamed.
--progress Name of file or FIFO to which stages should write progress information. The file/FIFO must exist. PDAL will not create the

(continues on next page)
Substitutions

The pipeline command can accept command-line option substitutions and they replace existing options that are specified in the input JSON pipeline. For example, to set the output and input LAS files for a pipeline that does a translation, the filename for the reader and the writer can be overridden:

```
$ pdal pipeline translate.json --writers.las.filename=output.laz \
   --readers.las.filename=input.las
```

If multiple stages of the same name exist in the pipeline, all stages would be overridden. In the following example, both colorization filters would have their dimensions option overridden to the value “Red:1:1.0, Blue, Green::256.0” by the command shown below:

```
{
   "pipeline": [
      "input.las",
      {
         "type": "filters.colorization",
         "raster": "raster1.tif"
      },
      {
         "type": "filters.colorization",
         "raster": "raster2.tif"
      }
   ],
   "placeholder.laz"
}
```

```
$ pdal pipeline colorize.json --filters.colorization.dimensions=\n   "Red:1:1.0, Blue, Green::256.0"
```

Option substitution can also refer to the tag of an individual stage. This can be done by using the syntax –stage.<tagname>.<option>. This allows options to be set on individual stages, even if there are multiple stages of the same type. For example, if a pipeline contained two LAS
readers with tags las1 and las2 respectively, the following command would allow assignment of different filenames to each stage:

```
{
    "pipeline" : [
        {
            "tag" : "las1",
            "type" : "readers.las"
        },
        {
            "tag" : "las2",
            "type" : "readers.las"
        },
        "placeholder.laz"
    ]
}
```

$ pdal pipeline translate.json --writers.las.filename=output.laz \
 --stage.las1.filename=file1.las --stage.las2.filename=file2.las

Options specified by tag names override options specified by stage types.

### 5.1.10 random

**Warning:** As of PDAL v2.6.0, the random command is marked as DEPRECATED. It will be removed from the default install in PDAL v2.7 and removed completely in PDAL v2.8.

A simply Python script that creates uniformly distributed data and writes the output using PDAL is given below.

```python
import numpy as np
import pdal

def generate_points_uniform(num_points, x_min, x_max, y_min, y_max, z_min, z_max):
    x_coords = np.random.uniform(x_min, x_max, num_points)
    y_coords = np.random.uniform(y_min, y_max, num_points)
    z_coords = np.random.uniform(z_min, z_max, num_points)

dtype = [('X', '<f8'), ('Y', '<f8'), ('Z', '<f8')]
points = np.zeros(num_points, dtype=dtype)
points['X'] = x_coords
points['Y'] = y_coords
```
points['Z'] = z_coords

return points

# Configuration for uniform distribution
num_points_uniform = 100
x_min, x_max = 0, 10
y_min, y_max = 0, 10
z_min, z_max = 0, 10

# Generate points using uniform distribution
points_uniform = generate_points_uniform(num_points_uniform, x_min, x_max, y_min, y_max, z_min, z_max)

pipeline = pdal.Writer("output_uniform.laz").pipeline(points_uniform)
pipeline.execute()

A similar Python script that creates normally distributed data and writes the output using PDAL is given below.

import numpy
import pdal

def generate_points_normal(num_points, x_mean, x_std, y_mean, y_std, z_mean, z_std):
    x_coords = np.random.normal(x_mean, x_std, num_points)
y_coords = np.random.normal(y_mean, y_std, num_points)
z_coords = np.random.normal(z_mean, z_std, num_points)

dtype = [('X', '<f8'), ('Y', '<f8'), ('Z', '<f8')]
points = np.zeros(num_points, dtype=dtype)

points['X'] = x_coords
points['Y'] = y_coords
points['Z'] = z_coords

return points

# Configuration for normal distribution
num_points_normal = 100
x_mean, x_std = 5, 1
y_mean, y_std = 5, 1
z_mean, z_std = 5, 1
The random command is used to create a random point cloud. It uses readers.faux (page 77) to create a point cloud containing count points drawn randomly from either a uniform or normal distribution. For the uniform distribution, the bounds can be specified (they default to a unit cube). For the normal distribution, the mean and standard deviation can both be set for each of the x, y, and z dimensions.

```bash
$ pdal random <output>
```

```
--output, -o  Output file name
--compress, -z Compress output data (if supported by output format)
--count     How many points should we write?
--bounds    Extent (in XYZ to clip output to)
--mean      A comma-separated or quoted, space-separated list of means
            (normal mode): --mean 0.0,0.0,0.0  --mean "0.0 0.0 0.0"
--stdev     A comma-separated or quoted, space-separated list of standard deviations (normal mode): --stdev 0.0,0.0,0.0 --stdev "0.0 0.0 0.0"
--distribution Distribution (uniform / normal)
```

### 5.1.11 sort

The sort command uses filters.mortonorder (page 261) to sort data by XY values.

```bash
$ pdal sort <input> <output>
```

```
--input, -i Input filename
--output, -o Output filename
--compress, -z Compress output data (if supported by output format)
--metadata, -m Forward metadata (VLRs, header entries, etc) from previous stages
```

5.1. Applications
5.1.12 split

The split command will create multiple output files from a single input file. The command takes an input file name and an output filename (used as a template) or output directory specification.

```
$ pdal split <input> <output>
```

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>--input, -i</td>
<td>Input filename</td>
</tr>
<tr>
<td>--output, -o</td>
<td>Output filename</td>
</tr>
<tr>
<td>--length</td>
<td>Edge length for splitter cells</td>
</tr>
<tr>
<td>--capacity</td>
<td>Point capacity of chipper cells</td>
</tr>
<tr>
<td>--origin_x</td>
<td>Origin in X axis for splitter cells</td>
</tr>
<tr>
<td>--origin_y</td>
<td>Origin in Y axis for splitter cells</td>
</tr>
</tbody>
</table>

If neither the --length nor --capacity arguments are specified, an implicit argument of capacity with a value of 100000 is added.

The output argument is a template. If the output argument is, for example, file.ext, the output files created are file_.#.ext where # is a number starting at one and incrementing for each file created.

If the output argument ends in a path separator, it is assumed to be a directory and the input argument is appended to create the output template. The split command never creates directories. Directories must pre-exist.

**Example 1:**

```
$ pdal split --capacity 100000 infile.laz outfile.bpf
```

This command takes the points from the input file infile.laz and creates output files outfile_1.bpf, outfile_2.bpf, ... where each output file contains no more than 100000 points.

5.1.13 tile

The tile command will create multiple output files from input files by generating square tiles of points. The command takes an input file name and an output filename template.

This command is similar to the split (page 46) command, but differs in several ways. The tile command:

- Uses streaming mode to limit the amount of memory consumed by point data.
- Uses a placeholder for filename output.
• Provides for reprojection of data to create consistent output.
• Always creates square tiles that contain all points “covered” by each tile.

$ pdal tile <input> <output>

--input, -i Input filename
--output, -o Output filename
--length Edge length for cells [Default: 1000]
--origin_x Origin in X axis for cells [Default: None]
--origin_y Origin in Y axis for cells [Default: None]
--buffer Size of buffer (overlap) to include around each tile.
[Default: 0]
--out_srs Spatial reference system to which all input points will be reprojected. [Default: None]

The input filename can contain a glob pattern (https://en.wikipedia.org/wiki/Glob_%28programming%29) to allow multiple files as input.

The output filename must contain a placeholder character #. The placeholder character is replaced with an X/Y index of the tile as a part of a cartesian system. For example, if the output filename is specified as out#.las, the tile containing the origin will be named out0_0.las. The tile to its right will be named out1_0.las. The tile above it will be named out0_1.las. The command does not create directories – create any desired directories before running.

If an origin is not supplied with as argument, the first point read is used as the origin.

**Example 1:**

$ pdal tile infile.laz "outfile_.bpf"

This command takes the points from the input file infile.laz and creates output files outfile_0_0.bpf, outfile_0_1.bpf, ... where each output file contains points in the 1000x1000 square units represented by the tile. The X/Y location of the first point is used as the origin of the tile grid.

**Example 2:**

$ pdal tile "/home/me/files/*" "out_.txt" --out_srs="EPSG:4326"

Reads all files in the directory /home/me/files as input and reprojects points to geographic coordinates if necessary. The output is written to a set of text files in the current directory.
5.1.14 tindex

The tindex command is used to create a GDAL (http://www.gdal.org)-style tile index for PDAL-readable point cloud types (see gdaltindex (http://www.gdal.org/gdaltindex.html)).

The tindex command has two modes. The first mode creates a spatial index file for a set of point cloud files. The second mode creates a point cloud file that is the result of merging the points from files referred to in a spatial index file that meet some criteria (usually a geographic region filter).

**tindex Creation Mode**

```
$ pdal tindex create <tindex> <filespec>
```

This command will index the files referred to by filespec and place the result in tindex. The tindex is a vector file or database that will be created by pdal as necessary to store the file index. The type of the index file can be specified by specifying the OGR code for the format using the --ogrdriver option. If no driver is specified, the format defaults to “ESRI Shapefile”. Any filetype that can be handled by OGR (http://www.gdal.org/ogr_formats.html) is acceptable.

In vector file-speak, each file specified by filespec is stored as a feature in a layer in the index file. The filespec is a glob pattern (http://man7.org/linux/man-pages/man7/glob.7.html) and normally needs to be quoted to prevent shell expansion of wildcard characters.
## tindex Merge Mode

$ pdal tindex merge <tindex> <filespec>

This command will read the existing index file `tindex` and merge the points in the indexed files that pass any filter that might be specified, writing the output to the point cloud file specified in `filespec`. The type of the output file is determined automatically from the filename extension.

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>--index</td>
<td>OGR-readable/writeable tile index output</td>
</tr>
<tr>
<td>--filespec</td>
<td>Build: Pattern of files to index. Merge: Output filename</td>
</tr>
<tr>
<td>--lyr_name</td>
<td>OGR layer name to write into datasource</td>
</tr>
<tr>
<td>--tindex_name</td>
<td>Tile index column name</td>
</tr>
<tr>
<td>--ogrdriver, -f</td>
<td>OGR driver name to use</td>
</tr>
<tr>
<td>--bounds</td>
<td>Extent (in XYZ) to clip output to</td>
</tr>
<tr>
<td>--polygon</td>
<td>Well-known text of polygon to clip output</td>
</tr>
<tr>
<td>--t_srs</td>
<td>Spatial reference of the clipping geometry.</td>
</tr>
</tbody>
</table>

### Example 1:

Find all LAS files via `find`, send that file list via STDIN to `pdal tindex`, and write a SQLite tile index file with a layer named `pdal`:

$ find las/ -iname "*.las" | pdal tindex create index.sqlite -f "SQLite" \
   --stdin --lyr_name pdal

### Example 2:

Glob a list of LAS files, output the SRS for the index entries to EPSG:4326, and write out an SQLite (http://www.sqlite.org) file.

$ pdal tindex create index.sqlite "*.las" -f "SQLite" --lyr_name "pdal" \
   --t_srs "EPSG:4326"
5.1.15 translate

The translate command can be used for simple conversion of files based on their file extensions. It can also be used for constructing pipelines directly from the command-line. By default, processing is done in stream mode if possible, standard mode if not.

```
$ pdal translate [options] input output [filter]
```

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>--input, -i</td>
<td>Input filename</td>
</tr>
<tr>
<td>--output, -o</td>
<td>Output filename</td>
</tr>
<tr>
<td>--filter, -f</td>
<td>Filter type</td>
</tr>
<tr>
<td>--json</td>
<td>PDAL pipeline from which to extract filters.</td>
</tr>
<tr>
<td>--pipeline, -p</td>
<td>Pipeline output</td>
</tr>
<tr>
<td>--metadata, -m</td>
<td>Dump metadata output to the specified file</td>
</tr>
<tr>
<td>--reader, -r</td>
<td>Reader type</td>
</tr>
<tr>
<td>--writer, -w</td>
<td>Writer type</td>
</tr>
<tr>
<td>--dims</td>
<td>Limit loaded dimensions to this list. Note that X, Y, and Z are always loaded.</td>
</tr>
<tr>
<td>--stream</td>
<td>Run in stream mode. If not possible, exit.</td>
</tr>
<tr>
<td>--nostream</td>
<td>Run in standard mode.</td>
</tr>
</tbody>
</table>

The --input and --output file names are required options.

If provided, the --pipeline option will write the pipeline constructed from the command-line arguments to the specified file. The translate command will not actually run when this argument is given.

The --json flag can use used to specify a PDAL pipeline from which filters will be extracted. If a reader or writer exist in the pipeline, they will be removed and replaced with the input and output provided on the command line. If a reader/writer stage references tags in the provided pipeline, the overriding files will assume those tags. If the argument to the --json option references an existing file, it is assumed that the file contains the pipeline to be processed. If the argument value is not a filename, it is taken to be a literal JSON string that is the pipeline. The flag can’t be used if filters are listed on the command line or explicitly with the --filter option.

The --filter flag is optional. It is used to specify drivers used to filter the data. --filter accepts multiple arguments if provided, thus constructing a multi-stage filtering operation. Filters can’t be specified using this method and with the --json flag.

The --metadata flag accepts a filename for the output of metadata associated with the execution of the translate operation.

If no --reader or --writer type are given, PDAL will attempt to infer the correct drivers from the input and output file name extensions respectively.
Example 1:

The `translate` command can be augmented by specifying fully specified options at the command-line invocation. For example, the following invocation will translate `1.2-with-color.las` to `output.laz` while doing the following:

- Setting the creation day of year to 42
- Setting the creation year to 2014
- Setting the LAS point format to 1
- Cropping the file with the given polygon

```bash
$ pdal translate
   --writers.las.creation_doy="42" \
   --writers.las.creation_year="2014" \
   --writers.las.format="1" \
   --filters.crop.polygon="POLYGON ((636889.412951239268295 851528.
   ↗512293258565478 422.7001953125,636899.14233423944097 851475.
   ↗00686757150106 422.4697265625,636899.14233423944097 851475.
   ↗00686757150106 422.4697265625,636928.33048324030824 851494.
   ↗459452757611871 422.5400390625,636928.33048324030824 851494.
   ↗459452757611871 422.5400390625,636976.977398241520859 851513.
   ↗918218758190051 424.150390625,636976.977398241520859 851513.
   ↗918218758190051 424.150390625,637069.406536744092591 851475.
   ↗00686757150106 438.7099609375,637132.647526245797053 851445.
   ↗812537756282836 425.9501953125,637132.647526245797053 851445.
   ↗812537756282836 425.9501953125,637336.964569251285866 851411.
   ↗759697255445644 425.8203125,637336.964569251285866 851411.
   ↗759697255445644 425.8203125,637473.175931254867464 851158.
   ↗7957397248627797 435.6298828125,637589.928527257987298 850711.
   ↗244121236610226 420.509765625,637244.535430748714134 850511.
   ↗791769731207751 420.7998046875,636758.066280735656619 850667.
   ↗461897735483944 434.609735,636539.155163229792379 851056.
   ↗63271774588339 422.6396484375,636889.412951239268295 851528.
   ↗512293258565478 422.7001953125))" \
   .//test/data/1.2-with-color.las \ 
   output.laz \ 
   filters.crop
```
Example 2:

Given these tools, we can now construct a custom pipeline on-the-fly. The example below uses a simple LAS reader and writer, but stages a voxel grid filter, followed by the SMRF filter and a range filter. We can even set stage-specific parameters as shown.

```bash
$ pdal translate input.las output.las voxelcenternearestneighbor smrf
  --range
  --filters.range.limits="Classification[2:2]"
```

Example 3:

This command reads the input text file “myfile” and writes an output LAS file “output.las”, processing the data through the stats filter. The metadata output (including the output from the stats filter) is written to the file “meta.json”.

```bash
$ pdal translate myfile output.las --metadata=meta.json -r readers.text
  --json="{ "pipeline": [ { "type":"filters.stats" } ] }"
```

Example 4:

This command reprojects the points in the file “input.las” to another spatial reference system and writes the result to the file “output.las”.

```bash
$ pdal translate input.las output.las -f filters.reprojection
  --filters.reprojection.out_srs="EPSG:4326"
```
6.1 Community

PDAL’s community interacts through Mailing List (page 53), GitHub (page 54), Gitter (https://gitter.im/PDAL/PDAL) and IRC (page 54). Please feel welcome to ask questions and participate in all of the venues. The Mailing List (page 53) communication channel is for general questions, development discussion, and feedback. The GitHub (page 54) communication channel is for development activities, bug reports, and testing. The IRC (page 54) and Gitter (https://gitter.im/PDAL/PDAL) channels are for real-time chat activities such as meetings and interactive debugging sessions.

6.1.1 Mailing List

Developers and users of PDAL participate on the PDAL mailing list. It is OK to ask questions about how to use PDAL, how to integrate PDAL into your own software, and report issues that you might have.

http://lists.osgeo.org/mailman/listinfo/pdal

Note: Please remember that an email to the PDAL list is going to 100s of individuals. Do your diligence the best you can on your question before asking, but don’t be afraid to ask. We won’t bite. Promise.
6.1.2 GitHub

Visit http://github.com/PDAL/PDAL to file issues you might be having with the software. GitHub is also where you can obtain a current development version of the software in the git (https://en.wikipedia.org/wiki/Git_(software)) revision control system. The PDAL project is eager to take contributions in all forms, and we welcome those who are willing to roll up their sleeves and start filing tickets, pushing code, generating builds, and answering questions.

See also:

Development (page 523) provides more information on how the PDAL software development activities operate.

6.1.3 Gitter

Some PDAL developers are active on Gitter (https://gitter.im/PDAL/PDAL) and you can use that mechanism for asking questions and interacting with the developers in a mode that is similar to IRC (page 54). Gitter uses your GitHub (page 54) credentials for access, so you will need an account to get started.

6.1.4 Keybase

Some PDAL developers are available via Keybase’s pdal chat. See https://keybase.io/blog/keybase-chat for more details.

6.1.5 IRC

You can find some PDAL developers on IRC on #pdal at Freenode (http://freenode.net). This mechanism is usually reserved for active meetings and other outreach with the community. The Mailing List (page 53) and GitHub (page 54) avenues are going to be more productive communication channels in most situations.
CHAPTER
SEVEN

DRIVERS

7.1 Pipeline

Pipelines define the processing of data within PDAL. They describe how point cloud data are read, processed and written. PDAL internally constructs a pipeline to perform data translation operations using translate (page 50), for example. While specific applications (page 27) are useful in many contexts, a pipeline provides useful advantages for many workflows:

1. You have a record of the operation(s) applied to the data
2. You can construct a skeleton of an operation and substitute specific options (filenames, for example)
3. You can construct complex operations using the JSON (http://www.json.org/) manipulation facilities of whatever language you want.

Note: pipeline (page 41) is used to invoke pipeline operations via the command line.

7.1.1 Introduction

A PDAL processing pipeline is represented in JSON. The structure may either:

- a JSON object, with a key called pipeline whose value is an array of inferred or explicit PDAL Stage Objects (page 59) representations.
- a JSON array, being the array described above without being encapsulated by a JSON object.
**Simple Example**

A simple PDAL pipeline, inferring the appropriate drivers for the reader and writer from filenames, and able to be specified as a set of sequential steps:

```
[     "input.las",
     {
         "type": "filters.crop",
         "bounds": "([0,100],[0,100])"
     },
     "output.bpf"
]
```

Fig. 1: A simple pipeline to convert **LAS** (page 89) to **BPF** (page 66) while only keeping points inside the box \([0 \leq x \leq 100, 0 \leq y \leq 100]\).

**Reprojection Example**

A more complex PDAL pipeline reprojects the stage tagged A1, merges the result with B, and writes the merged output to a GeoTIFF file with the **writers.gdal** (page 156) writer:

```
[     {
         "filename": "A.las",
         "spatialreference": "EPSG:26916"
     },
     {
         "type": "filters.reprojection",
         "in_srs": "EPSG:26916",
         "out_srs": "EPSG:4326",
         "tag": "A2"
     },
     {
         "filename": "B.las",
         "tag": "B"
     }
]
```

(continues on next page)
Fig. 2: A more complex pipeline that merges two inputs together but uses `filters.reprojection` (page 275) to transform the coordinate system of file B.las from UTM (http://spatialreference.org/ref/epsg/nad83-utm-zone-16n/) to Geographic (http://spatialreference.org/ref/epsg/4326/).

**Point Views and Multiple Outputs**

Some filters produce sets of points as output. `filters.splitter` (page 322), for example, creates a point set for each tile (rectangular area) in which input points exist. Each of these output sets is called a point view. Point views are carried through a PDAL pipeline individually. Some writers can produce separate output for each input point view. These writers use a placeholder character (#) in the output filename which is replaced by an incrementing integer for each input point view.

The following pipeline provides an example of writing multiple output files from a single pipeline. The crop filter creates two output point views (one for each specified geometry) and the writer creates output files ‘output1.las’ and ‘output2.las’ containing the two sets of points:
7.1.2 Processing Modes

PDAL process data in one of two ways: standard mode or stream mode. With standard mode, all input is read into memory before it is processed. Many algorithms require standard mode processing because they need access to all points. Operations that do sorting or require neighbors of points, for example, require access to all points.

For operations that don’t require access to all points, PDAL provides stream mode. Stream mode processes points through a pipeline in chunks, which reduces memory requirements.

When using `pdal translate` (page 50) or `pdal pipeline` (page 41) PDAL uses stream mode if possible. If stream mode can’t be used the applications fall back to standard mode processing. Streamable stages are tagged in the stage documentation with a blue bar. Users can explicitly choose to use standard mode by using the `--nostream` option. Users of the PDAL API can explicitly control the selection of the PDAL processing mode.

7.1.3 Pipelines

Pipeline Array

PDAL JSON pipelines are an array of stages.

**Note:** In versions of PDAL prior to 1.9, the array of stages needed to be the value of a key named “pipeline” which was encapsulated in an object. The earlier format is still accepted for backward compatibility.

Old format:

```json
{
   "pipeline" :
   [ 
    "inputfile",
    "outputfile"
   ]
}
```
Equivalent new format:

```
[  
  "inputfile",
  "outputfile"
]
```

- The pipeline array may have any number of string or *Stage Objects* (page 59) elements.
- String elements shall be interpreted as filenames. PDAL will attempt to infer the proper driver from the file extension and position in the array. A writer stage will only be created if the string is the final element in the array.

### Stage Objects

For more on PDAL stages and their options, check the PDAL documentation on *Readers* (page 65), *Writers* (page 139), and *Filters* (page 192).

- A stage object may have a member with the name `tag` whose value is a string. The purpose of the tag is to cross-reference this stage within other stages. Each `tag` must be unique.
- A stage object may have a member with the name `inputs` whose value is an array of strings. Each element in the array is the tag of another stage to be set as input to the current stage.
- Stages are processed sequentially in the order listed. An empty default input list is created when interpretation of the pipeline begins.
- Reader stages will disregard the `inputs` member. When the current stage is a reader it is added to the default input list.
- If `inputs` is specified for a writer or filter, those inputs are used for the current stage. The default input list is replaced with the current stage.
- If `inputs` is not specified for a writer or filter, the default input list is used for the current stage. The default input list is replaced with the current stage.
- A `tag` mentioned in another stage’s `inputs` must have been previously defined in the pipeline array.
- A reader or writer stage object may have a member with the name `type` whose value is a string. The `type` must specify a valid PDAL reader or writer name.
• A filter stage object must have a member with the name type whose value is a string. The type must specify a valid PDAL filter name.

• A stage object may have additional members with names corresponding to stage-specific option names and their respective values. Values provided as JSON objects or arrays will be stringified and parsed within the stage. Some options allow multiple inputs. In those cases, provide the option values as a JSON array.

• A user_data option can be added to any stage object and it will be carried through to any serialized pipeline output.

• All stages support the option_file option that allows options to be placed in a separate file. See Option Files (page 60) for details.

Filename Globbing

• A filename may contain the wildcard character * to match any string of characters. This can be useful if working with multiple input files in a directory (e.g., merging all files).

Filename globbing ONLY works in pipeline file specifications. It doesn’t work when a filename is provided as an option through a command-line application like pdal pipeline or pdal translate.

Option Files

All stages accept the option file option that allows extra options for a stage to be placed in a separate file. The value of the option is the filename in which the additional options are located.

Option files can be written using either JSON syntax or command line syntax. When using the JSON syntax, the format is a block of options just as if the options were placed in a pipeline:

```json
{
   "minor_version": 4,
   "out_srs": "EPSG_4326"
}
```

When using the command line syntax, the options are specified as they would be on the command line without the need to qualify the option names with the stage name:

```
--minor_version=4 --out_srs="EPSG_4326"
```
7.1.4 Extended Examples

BPF to LAS

The following pipeline converts the input file from BPF (page 66) to LAS (page 161), inferring both the reader and writer type, and setting a number of options on the writer stage.

```
[ 
  "utm15.bpf",
  {
    "filename": "out2.las",
    "scale_x": 0.01,
    "offset_x": 311898.23,
    "scale_y": 0.01,
    "offset_y": 4703909.84,
    "scale_z": 0.01,
    "offset_z": 7.385474
  }
]
```

Python HAG

In our next example, the reader and writer types are once again inferred. After reading the input file, the ferry filter is used to copy the Z dimension into a new height above ground (HAG) dimension. Next, the filters.python (page 348) is used with a Python script to compute height above ground values by comparing the Z values to a surface model. These height above ground values are then written back into the Z dimension for further analysis. See the Python code at hag.py (https://raw.githubusercontent.com/PDAL/PDAL/master/test/data/autzen/hag.py.in).

See also:

filters.hag_nn (page 215) describes using a specific filter to do this job in more detail.

```
[
  "autzen.las",
  {
    "type": "filters.ferry",
    "dimensions": "Z=>HAG"
  },
  {
    "type": "filters.python",
    "script": "hag.py",
    "function": "filter",
    "module": "anything"
  }
]
```
A common task is to create a digital terrain model (DTM) from the input point cloud. This pipeline infers the reader type, applies an approximate ground segmentation filter using \texttt{filters.smrf} (page 197), filters out all points but the ground returns (classification value of 2) using the \texttt{filters.range} (page 313), and then creates the DTM using the \texttt{writers.gdal} (page 156).

\begin{verbatim}
[ "autzen-full.las",
  {
    "type":"filters.smrf",
    "window":33,
    "slope":1.0,
    "threshold":0.15,
    "cell":1.0
  },
  {
    "type":"filters.range",
    "limits":"Classification[2:2]"
  },
  {
    "type":"writers.gdal",
    "filename":"autzen-surface.tif",
    "output_type":"min",
    "gdaldriver":"GTiff",
    "window_size":3,
    "resolution":1.0
  }
]
\end{verbatim}
Decimate & Colorize

This example still infers the reader and writer types while applying options on both. The pipeline decimates the input LAS file by keeping every other point, and then colorizes the points using the provided raster image. The output is written as ASCII text.

```
[  
  {  
    "filename": "1.2-with-color.las",
    "spatialreference": "EPSG:2993"
  },  
  {  
    "type": "filters.decimation",
    "step": 2,
    "offset": 1
  },  
  {  
    "type": "filters.colorization",
    "raster": "autzen.tif",
    "dimensions": ["Red:1:1", "Green:2:1", "Blue:3:1"]
  },  
  {  
    "filename": "junk.txt",
    "delimiter": ",",
    "write_header": false
  }
]
```

Reproject

Our first example with multiple readers, this pipeline infers the reader types, and assigns spatial reference information to each. `filters.reprojection` (page 275) filter reprojects data to the specified output spatial reference system.

```
[  
  {  
    "filename": "1.2-with-color.las",
    "spatialreference": "EPSG:2027"
  },  
  {  
    "filename": "1.2-with-color.las",
    "spatialreference": "EPSG:2027"
  }
]
```
Globbed Inputs

Finally, we capture another merge pipeline demonstrating the ability to glob multiple input LAS files from a given directory.

```
[  
"/path/to/data/*.las",
"output.las"
]
```

See also:

The PDAL source tree contains a number of example pipelines that are used for testing. You might find these inspiring. Go to https://github.com/PDAL/PDAL/tree/master/test/data/pipeline to find more.

Note: Issuing the command `pdal info --options` will list all available stages and their options. See `info` (page 38) for more.

### 7.2 Stages

The stages of a PDAL Pipeline (page 55) are divided into Readers (page 65), Filters (page 192) and Writers (page 139). Stages may support streaming mode (page 58) or not, depending on their functionality or particular implementation. Many stages are built into the base PDAL library (the file pdalcpp.so on Unix, pdalcpp.dylib on OSX and pdalcpp.dll on Windows). PDAL can also load stages that have been built separately. These stages are called plugins.

Stages are usually created as plugins for one of several reasons. First, a user may wish to create a stage for their own purposes. In this case a user has no need to build their stage into the PDAL library itself. Second, a stage may depend on some third-party library that cannot be distributed with PDAL. Providing the stage as a plugin eliminates the direct dependency on a library and can simplify licensing issues. Third, a stage may be little used and its addition would unnecessarily increase the size of the PDAL library.
PDAL will automatically load plugins when necessary. PDAL plugins have a specific naming pattern:

```
libpdal_plugin_<plugin type>_<plugin name>.<shared library extension>
```

Where `<plugin type>` is “reader”, “writer” or “filter” and `<shared library extension>` is “.dll” on Windows, “.dylib” on OSX and “.so” on UNIX systems.

The `<plugin name>` must start with a letter or number, which can be followed by letters, numbers, or an underscore (‘_’).

PDAL looks for plugins in the directory that contains the PDAL library itself, as well as the directories `./lib`, `../lib`, `./bin`, `../bin`. Those paths are relative to the current working directory. These locations can be overridden by setting the environment variable `PDAL_DRIVER_PATH` to a list of directories delimited by `;` on Windows and `:` on other platforms.

You can use `pdal --drivers` to show stages that PDAL is able to load. Verify the above if you are having trouble loading specific plugins.

### 7.3 Readers

Readers provide *Dimensions* (page 359) to *Pipeline* (page 55). PDAL attempts to normalize common dimension types, like X, Y, Z, or Intensity, which are often found in LiDAR point clouds. Not all dimension types need to be fixed, however. Database drivers typically return unstructured lists of dimensions. A reader might provide a simple file type, like `readers.text` (page 130), a complex database like `readers.pgpointcloud` (page 106), or a network service like `readers.ept` (page 72).

#### 7.3.1 readers.arrow

**Dynamic Plugin**

This stage requires a dynamic plugin to operate

**Streamable Stage**

This stage supports streaming operations

The Arrow reader supports reading Arrow and Parquet-formatted data as written by `writers.arrow` (page 139), although it should support point clouds written by other writers too if
they follow either the GeoArrow (https://github.com/geoarrow/geoarrow/) or GeoParquet (https://github.com/opengeospatial/geoparquet/) specification.

Caveats:

- Which schema is read is chosen by the file name extension, but can be overridden with the format option set to geoarrow or geoparquet

Options

filename
Arrow GeoArrow or GeoParquet file to read [Required]

format
geoarrow or geoparquet option to override any filename extension hinting of data type [Optional]

count
Maximum number of points to read. [Default: unlimited]

override_srs
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

default_srs
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

7.3.2 readers.bpf

BPF is an NGA specification (https://nsgreg.nga.mil/doc/view?i=4220&month=8&day=30&year=2016) for point cloud data. The BPF reader supports reading from BPF files that are encoded as version 1, 2 or 3.

This BPF reader only supports Zlib compression. It does NOT support the deprecated compression types QuickLZ and FastLZ. The reader will consume files containing ULEM frame data and polarimetric data, although these data are not made accessible to PDAL; they are essentially ignored.

Data that follows the standard header but precedes point data is taken to be metadata and is UTF-encoded and added to the reader’s metadata.

Default Embedded Stage

This stage is enabled by default
Streamable Stage

This stage supports streaming operations

Example

```
[  
    "inputfile.bpf",
    {
        "type":"writers.text",
        "filename":"outputfile.txt"
    }
]
```

Options

- **filename**
  - BPF file to read [Required]

- **fix_dims**
  - BPF files may contain dimension names that aren’t allowed by PDAL. When this option is ‘true’, invalid characters in dimension names are replaced by ‘_’ in order to make the names valid. [Default: true]

- **count**
  - Maximum number of points to read. [Default: unlimited]

- **override_srs**
  - Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

- **default_srs**
  - Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]
7.3.3 readers.buffer

The *readers.buffer* (page 68) stage is a special stage that allows you to read data from your own PointView rather than fetching the data from a specific reader. In the *Writing with PDAL* (page 546) example, it is used to take a simple listing of points and turn them into an LAS file.

**Default Embedded Stage**

This stage is enabled by default

**Example**

See *Writing with PDAL* (page 546) for an example usage scenario for *readers.buffer* (page 68).

**Options**

- **count**
  Maximum number of points to read. [Default: unlimited]

- **override_srs**
  Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

- **default_srs**
  Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

7.3.4 readers.copc

The COPC Reader supports reading from COPC format (https://copc.io/) files. A COPC file is a LASzip (http://laszip.org) (compressed LAS) file that organizes its data spatially, allowing for incremental loading and spatial filtering.

**Note:** LAS stores X, Y and Z dimensions as scaled integers. Users converting an input LAS file to an output LAS file will frequently want to use the same scale factors and offsets in the output file as existed in the input file in order to maintain the precision of the data. Use the *forward* option of *writers.las* (page 161) to facilitate transfer of header information from source COPC files to destination LAS/LAZ files.
Note: COPC files can contain datatypes that are actually arrays rather than individual dimensions. Since PDAL doesn’t support these datatypes, it must map them into datatypes it supports. This is done by appending the array index to the name of the datatype. For example, datatypes 11 - 20 are two dimensional array types and if a field had the name Foo for datatype 11, PDAL would create the dimensions Foo0 and Foo1 to hold the values associated with LAS field Foo. Similarly, datatypes 21 - 30 are three dimensional arrays and a field of type 21 with the name Bar would cause PDAL to create dimensions Bar0, Bar1 and Bar2. See the information on the extra bytes VLR in the LAS Specification (http://www.asprs.org/wp-content/uploads/2019/07/LAS_1_4_r15.pdf) for more information on the extra bytes VLR and array datatypes.

Warning: COPC files that use the extra bytes VLR and datatype 0 will be accepted, but the data associated with a dimension of datatype 0 will be ignored (no PDAL dimension will be created).

Default Embedded Stage
This stage is enabled by default

Streamable Stage
This stage supports streaming operations

Example

```
[
  {
    "type": "readers.copc",
    "filename": "inputfile.copc.laz"
  },
  {
    "type": "writers.text",
    "filename": "outputfile.txt"
  }
]
```

7.3. Readers
Options

filename
  COPC file to read. Remote file specifications (http, AWS, Google, Azure, Dropbox) are supported. [Required]

count
  Maximum number of points to read. [Default: unlimited]

override_srs
  Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

default_srs
  Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

bounds
  The extent of the data to select in 2 or 3 dimensions, expressed as a string, e.g.: ([xmin, xmax], [ymin, ymax], [zmin, zmax]). If omitted, the entire dataset will be selected. The bounds specification can be followed by a slash (‘/’) and a spatial reference specification to apply to the bounds specification.

polygon
  A clipping polygon, expressed in a well-known text string, e.g.: POLYGON((0 0, 5000 10000, 10000 0, 0 0)). This option can be specified more than once. Multiple polygons will be treated as a single multipolygon. The polygon specification can be followed by a slash (‘/’) and a spatial reference specification to apply to the polygon.

ogr
  A JSON object representing an OGR query to fetch polygons to use for filtering. The polygons fetched from the query are treated exactly like those specified in the polygon option. The JSON object is specified as follows:

  ```json
  {
    "drivers": "OGR drivers to use",
    "openoptions": "Options to pass to the OGR open function",
    "layer": "OGR layer from which to fetch polygons [optional]",
    "sql": "SQL query to use to filter the polygons in the layer",
    "options": {
      "geometry", "WKT or GeoJSON geomtry used to filter query"
    }
  }
  ```
requests
The number of worker threads processing data. The optimal number depends on your system and your network connection, but more is not necessarily better. A reasonably fast network connection can often fetch data faster than it can be processed, leading to memory consumption and slower performance. [Default: 15]

resolution
Limit the pyramid levels of data to fetch based on the expected resolution of the data. Units match that of the data. [Default: no resolution limit]

header
HTTP headers to forward for remote endpoints. Specify as a JSON object of key/value string pairs.

query
HTTP query parameters to forward for remote endpoints. Specify as a JSON object of key/value string pairs.

las
Read LAS VLRs and import as metadata. [Default: false]

keep_alive
The number of chunks to keep active in memory while reading [Default: 10]

fix_dims
Make invalid dimension names valid by converting disallowed characters to ‘_’. Only applies to names specified in an extra-bytes VLR. [Default: true]

srs_consume_preference
Preference order to read SRS VLRs. [Default: ‘wkt1, wkt2, projjson’]

nosrs
Don’t read the SRS VLRs. The data will not be assigned an SRS. This option is for use only in special cases where processing the SRS could cause performance issues. [Default: false]

7.3.5 readers.draco
Draco (https://github.com/google/draco) is a library for compressing and decompressing 3D geometric meshes and point clouds and was designed and built for compression efficiency and speed. The code supports compressing points, connectivity information, texture coordinates, color information, normals, and any other generic attributes associated with geometry.
Example

```json
[
  {
    "type": "readers.draco",
    "filename": "color.las"
  }
]
```

Options

**filename**
Input file name. [Required]

**count**
Maximum number of points to read. [Default: unlimited]

**override_srs**
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

**default_srs**
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

### 7.3.6 readers.ept

Entwine Point Tile (https://entwine.io/entwine-point-tile.html) (EPT) is a hierarchical octree-based point cloud format suitable for real-time rendering and lossless archival. Entwine (https://entwine.io/) is a producer of this format. The EPT Reader supports reading data from the EPT format, including spatially accelerated queries and file reconstruction queries.

Sample EPT datasets of hundreds of billions of points in size may be viewed with Potree (http://potree.entwine.io/data/nyc.html).

**Default Embedded Stage**
This stage is enabled by default

**Streamable Stage**
This stage supports streaming operations
Example

This example downloads a small area around the Statue of Liberty from the New York City data set (4.7 billion points) which can be viewed in its entirety in Potree (http://potree.entwine.io/data/nyc.html).

```json
[
  {
    "type": "readers.ept",
    "filename": "http://na.entwine.io/nyc/ept.json",
    "bounds": "([-8242669, -8242529], [4966549, 4966674])"
  },
  "statue-of-liberty.las"
]
```

Additional attributes created by the EPT addon writer (page 149) can be referenced with the addon option. Here is an example that overrides the Classification dimension with an addon dimension derived from the original dataset:

```json
[
  {
    "type": "readers.ept",
    "filename": "http://na.entwine.io/autzen/ept.json",
    "addons": {
      "Classification": "~/entwine/addons/autzen/smrf"
    }
  },
  {
    "type": "writers.las",
    "filename": "autzen-ept-smrf.las"
  }
]
```

For more details about addon dimensions and how to produce them, see writers.ept_addon (page 149).

Options

filename

Path to the EPT resource from which to read, ending with ept.json. For example, /Users/connor/entwine/autzen/ept.json or http://na.entwine.io/autzen/ept.json. [Required]

spatialreference

Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. [Default: none]
bounds
The extents of the resource to select in 2 or 3 dimensions, expressed as a string, e.g.: ([xmin, xmax], [ymin, ymax], [zmin, zmax]). If omitted, the entire dataset will be selected. The bounds can be followed by a slash ('/') and a spatial reference specification to apply to the bounds.

resolution
A point resolution limit to select, expressed as a grid cell edge length. Units correspond to resource coordinate system units. For example, for a coordinate system expressed in meters, a resolution value of 0.1 will select points up to a ground resolution of 100 points per square meter.

The resulting resolution may not be exactly this value: the minimum possible resolution that is at least as precise as the requested resolution will be selected. Therefore the result may be a bit more precise than requested.

addons
A mapping of assignments of the form DimensionName: AddonPath, which assigns dimensions from the specified paths to the named dimensions. These addon dimensions are created by the EPT addon writer (page 149). If the dimension names already exist in the EPT Schema (https://entwine.io/entwine-point-tile.html#schema) for the given resource, then their values will be overwritten with those from the appropriate addon.

Addons may used to override well-known dimension (page 359). For example, an addon assignment of "Classification": "~/addons/autzen/MyGroundDimension/" will override an existing EPT Classification dimension with the custom dimension.

origin
EPT datasets are lossless aggregations of potentially multiple source files. The origin option can be used to select all points from a single source file. This option may be specified as a string or an integral ID.

The string form of this option selects a source file by its original file path. This may be a substring instead of the entire path, but the string must uniquely select only one source file (via substring search). For example, for an EPT dataset created from source files one.las, two.las, and two.bpf, “one” is a sufficient selector, but “two” is not.

The integral form of this option selects a source file by its OriginId dimension, which can be determined from the file’s position in EPT metadata file entwine-files.json.

Note: When using pdal info --summary, using the origin option will cause the resulting bounds to be clipped to those of the selected origin, and the resulting number of points to be an upper bound for this selection.

correction
The clipping polygon, expressed in a well-known text string, e.g.: POLYGON((0 0, 5000 10000, 10000 0, 0 0)). This option can be specified more than once by
placing values in an array, in which case all of them will be unioned together, acting as a single multipolygon. The polygon definition can be followed by a slash (‘/’) and a spatial reference specification to apply to the polygon.

**Note:** When using `pdal info --summary`, using the `polygon` option will cause the resulting bounds to be clipped to the maximal extents of all provided polygons, and the resulting number of points to be an upper bound for this polygon selection.

**Note:** When both the `bounds` and `polygon` options are specified, only the points that fall within *both* the bounds and the polygon(s) will be returned.

### ogr

A JSON object representing an OGR query to fetch polygons to use for filtering. The polygons fetched from the query are treated exactly like those specified in the `polygon` option. The JSON object is specified as follows:

```
{
    "drivers": "OGR drivers to use",
    "openoptions": "Options to pass to the OGR open function [optional]",
    "layer": "OGR layer from which to fetch polygons [optional]",
    "sql": "SQL query to use to filter the polygons in the layer [optional]",
    "options": {
        "geometry": "WKT or GeoJSON geometry used to filter query [optional]"
    }
}
```

### requests

Maximum number of simultaneous requests for EPT data. [Minimum: 4] [Default: 15]

### header

HTTP headers to forward for remote EPT endpoints, specified as a JSON object of key/value string pairs.

### query

HTTP query parameters to forward for remote EPT endpoints, specified as a JSON object of key/value string pairs.

### ignore_unreadable

If set to true, ignore errors for missing or unreadable point data nodes.

7.3. Readers
7.3.7 readers.e57

The **E57 Reader** supports reading from E57 files.
The reader supports E57 files with Cartesian point clouds.

**Note:** E57 files can contain multiple point clouds stored in a single file. If that is the case, the reader will read all the points from all of the internal point clouds as one. Only dimensions present in all of the point clouds will be read.

**Note:** Point clouds stored in spherical format are not supported.

**Note:** The E57 `cartesianInvalidState` dimension is mapped to the Omit PDAL dimension. A range filter can be used to filter out the invalid points.

**Dynamic Plugin**
This stage requires a dynamic plugin to operate

**Streamable Stage**
This stage supports streaming operations

**Example 1**

```
[
    {
        "type": "readers.e57",
        "filename": "inputfile.e57"
    },
    {
        "type": "writers.text",
        "filename": "outputfile.txt"
    }
]
```
Example 2

```
[
    {
        "type": "readers.e57",
        "filename": "inputfile.e57"
    },
    {
        "type": "filters.range",
        "limits": "Omit[0:0]"
    },
    {
        "type": "writers.text",
        "filename": "outputfile.txt"
    }
]
```

Options

**filename**
E57 file to read [Required]

**count**
Maximum number of points to read. [Default: unlimited]

**override_srs**
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

**default_srs**
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

### 7.3.8 readers.faux

The faux reader is used for testing pipelines. It does not read from a file or database, but generates synthetic data to feed into the pipeline.

The faux reader requires a mode argument to define the method in which points should be generated. Valid modes are as follows:

**constant**
The values provided as the minimums to the bounds argument are used for the X, Y and Z value, respectively, for every point.

7.3. Readers
random
   Random values are chosen within the provided bounds.

ramp
   Value increase uniformly from the minimum values to the maximum values.

uniform
   Random values of each dimension are uniformly distributed in the provided ranges.

normal
   Random values of each dimension are normally distributed in the provided ranges.

grid
   Creates points with integer-valued coordinates in the range provided (excluding the upper bound).

---

Default Embedded Stage

This stage is enabled by default

---

Streamable Stage

This stage supports streaming operations

---

Example

```json
[
  {
    "type": "readers.faux",
    "bounds": "([0,1000000],[0,1000000],[0,100])",
    "count": "10000",
    "mode": "random"
  },
  {
    "type": "writers.text",
    "filename": "outputfile.txt"
  }
]
```
Options

bounds
The spatial extent within which points should be generated. Specified as a string in the form “([xmin,xmax],[ymin,ymax],[zmin,zmax])”. [Default: unit cube]

count
The number of points to generate. [Required, except when mode is ‘grid’]

override_srs
Spatial reference to apply to data. [Optional]

mean_x|y|z
Mean value in the x, y, or z dimension respectively. (Normal mode only) [Default: 0]

stdev_x|y|z
Standard deviation in the x, y, or z dimension respectively. (Normal mode only) [Default: 1]

mode
“constant”, “random”, “ramp”, “uniform”, “normal” or “grid” [Required]

7.3.9 readers.fbi

The FBI Reader supports reading from FastBinary format files. FastBinary is the internal format for TerraScan. This driver allows to read FBI files in version 1 of the FBI specification.

Note: Support for all point attributes in LAS 1.2 format so data can be converted between LAS 1.2 and Fast Binary formats without any loss of point attribute information.

Default Embedded Stage
This stage is enabled by default

Streamable Stage
This stage supports streaming operations

7.3. Readers
**Example**

```
[
  {
    "type":"readers.fbi",
    "filename":"inputfile.fbi"
  },
  {
    "type":"writers.text",
    "filename":"outputfile.txt"
  }
]
```

**Options**

**filename**

FBI file to read [Required]

### 7.3.10 readers.gdal

The GDAL (http://gdal.org) reader reads GDAL readable raster (http://www.gdal.org/formats_list.html) data sources as point clouds.

Each pixel is given an X and Y coordinate (and corresponding PDAL dimensions) that are center pixel, and each band is represented by “band-1”, “band-2”, or “band-n”. Using the ‘header’ option allows naming the band data to standard PDAL dimensions.

**Default Embedded Stage**

This stage is enabled by default

**Basic Example**

Simply writing every pixel of a JPEG to a text file is not very useful.

```
[
  {
    "type":"readers.gdal",
    "filename":"./pdal/test/data/autzen/autzen.jpg"
  },
  ...
]
```
LAS Example

The following example assigns the bands from a JPG to the RGB values of an ASPRS LAS (http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) file using writers.las (page 161).

```
[{
    "type": "readers.gdal",
    "filename": "/pdal/test/data/autzen/autzen.jpg",
    "header": "Red, Green, Blue"
  },
  {
    "type": "writers.las",
    "filename": "outputfile.las"
  }
]
```

Note: readers.gdal (page 80) is quite sensitive to GDAL’s cache settings. See the GDAL_CACHMAX value at https://gdal.org/user/configoptions.html for more information.

Options

filename

GDALOpen

GDALOpen
(https://gdal.org/api/raster_c_api.html#gdal_8h_a0a05455472359964151f9c891d678d5e) ‘able raster file to read [Required]

count

Maximum number of points to read. [Default: unlimited]

override_srs

Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]
default_srs
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

header
A comma-separated list of dimension (page 359) IDs to map bands to. The length of the list must match the number of bands in the raster.

memorycopy
Use the GDAL MEM driver (https://gdal.org/drivers/raster/mem.html) to copy the entire raster into memory before converting to points. This is useful if the raster driver has a lot of per-block overhead or you are willing to trade memory for performance.

gdalopts
A list of key/value options to pass directly to the GDAL driver. The format is name=value,name=value,… The option may be specified any number of times.

7.3.11 readers.hdf

The HDF reader reads data from files in the HDF5 format. (https://www.hdfgroup.org/solutions/hdf5/) You must explicitly specify a mapping of HDF datasets to PDAL dimensions using the dimensions parameter. ALL dimensions must be scalars and be of the same length. Compound types are not supported at this time.

Dynamic Plugin
This stage requires a dynamic plugin to operate

Streamable Stage
This stage supports streaming operations

Example
This example reads from the Autzen HDF example with all dimension properly mapped and then outputs a LAS file.

```json
[
  {
    "type": "readers.hdf",
    "filename": "test/data/hdf/autzen.h5",
    "dimensions":
```
Note: All dimensions must be simple numeric HDF datasets with equal lengths. Compound types, enum types, string types, etc. are not supported.

Warning: The HDF reader does not set an SRS.
Common Use Cases

A possible use case for this driver is reading NASA’s ICESat-2 (https://icesat-2.gsfc.nasa.gov/) data. This example reads the X, Y, and Z coordinates from the ICESat-2 ATL03 (https://icesat-2.gsfc.nasa.gov/sites/default/files/page_files/ICESat2_ATL03_ATBD_r002.pdf) format and converts them into a LAS file.

**Note:** ICESat-2 data use EPSG:7912 (https://epsg.io/7912). ICESat-2 Data products documentation can be found here (https://icesat-2.gsfc.nasa.gov/science/data-products)

```json
[
  {
    "type": "readers.hdf",
    "filename": "ATL03_20190906201911_10800413_002_01.h5",
    "dimensions":
      {
        "X" : "gt1l/heights/lon_ph",
        "Y" : "gt1l/heights/lat_ph",
        "Z" : "gt1l/heights/h_ph"
      }
  },
  {
    "type" : "writers.las",
    "filename": "output.las"
  }
]
```

**Options**

`count`  
Maximum number of points to read. [Default: unlimited]

`override_srs`  
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

`default_srs`  
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

`dimensions`  
A JSON map with PDAL dimension names as the keys and HDF dataset paths as the values.
7.3.12 readers.i3s

Indexed 3d Scene Layer (I3S) ([link](https://github.com/Esri/i3s-spec/blob/master/format/Indexed%203d%20Scene%20Layer%20Format%20Specification.md)) is a specification created by Esri as a format for their 3D Scene Layer and scene services. The I3S reader handles RESTful webservices in an I3S file structure/format.

**Default Embedded Stage**

This stage is enabled by default

**Streamable Stage**

This stage supports streaming operations

**Example**

This example will download the Autzen dataset from the ArcGIS scene server and output it to a las file. This is done through PDAL’s command line interface or through the pipeline.

```json
[
  {
    "type": "readers.i3s",
    "filename": "https://tiles.arcgis.com/tiles/8cv2FuXuWSfF0nbL/arcgis/rest/services/AUTZEN_LiDAR/SceneServer",
    "obb": {
      "center": [
        636590,
        849216,
        460
      ],
      "halfSize": [
        590,
        281,
        60
      ],
      "quaternion": [
        0,
        0,
        0
      ]
    }
  }
]
```

(continues on next page)
pdal translate i3s://https://tiles.arcgis.com/tiles/8cv2FuXuWSfF0nbL/arcgis/rest/services/AUTZEN_LiDAR/SceneServer autzen.las --readers.i3s.threads=64

Options

**count**
Maximum number of points to read. [Default: unlimited]

**override_srs**
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

**default_srs**
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

**filename**
I3S file stored remotely. These must be prefaced with an “i3s://”.

Example remote file: pdal translate i3s://https://tiles.arcgis.com/tiles/arcgis/rest/services/AUTZEN_LiDAR/SceneServer autzen.las

**threads**
This specifies the number of threads that you would like to use while reading. The default number of threads to be used is 8. This affects the speed at which files are fetched and added to the PDAL view.

Example: --readers.i3s.threads=64

**obb**
An oriented bounding box used to filter the data being retrieved. The obb is specified as JSON exactly as described by the I3S specification (https://github.com/Esri/i3s-spec/blob/master/docs/2.0/obb.cmn.md).

**dimensions**
Comma-separated list of dimensions that should be read. Specify the Esri name, rather than the PDAL dimension name.
<table>
<thead>
<tr>
<th>Esri</th>
<th>PDAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTENSITY</td>
<td>Intensity</td>
</tr>
<tr>
<td>CLASS_CODE</td>
<td>ClassFlags</td>
</tr>
<tr>
<td>FLAGS</td>
<td>Flag</td>
</tr>
<tr>
<td>RETURNS</td>
<td>NumberOfReturns</td>
</tr>
<tr>
<td>USER_DATA</td>
<td>UserData</td>
</tr>
<tr>
<td>POINT_SRC_ID</td>
<td>PointSourceId</td>
</tr>
<tr>
<td>GPS_TIME</td>
<td>GpsTime</td>
</tr>
<tr>
<td>SCAN_ANGLE</td>
<td>ScanAngleRank</td>
</tr>
<tr>
<td>RGB</td>
<td>Red</td>
</tr>
</tbody>
</table>

Example: `--readers.i3s.dimensions="returns, rgb"`

**min_density and max_density**

This is the range of density of the points in the nodes that will be selected during the read. The density of a node is calculated by the vertex count divided by the effective area of the node. Nodes do not have a uniform density across depths in the tree, so some sections may be more or less dense than others. The default values for these parameters will pull all the leaf nodes (the highest resolution).

Example: `--readers.i3s.min_density=2 --readers.i3s.max_density=2.5`

### 7.3.13 readers.ilvis2

The ILVIS2 reader read from files in the ILVIS2 format. See the product spec (https://nsidc.org/data/ilvis2) for more information.

---

**Default Embedded Stage**

This stage is enabled by default

---

**Streamable Stage**

This stage supports streaming operations
The IceBridge L1S Level-2 Georeferenced Surface Elevation Product ASCII text format data files contain fields as described in Table 2.

### Table 2. ASCII Text File Parameter Description

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVIS_LFID</td>
<td>LVIS file identification, including date and time of collection and file number. The second through sixth values in the first field represent the Modified Julian Date of data collection.</td>
<td>n/a</td>
</tr>
<tr>
<td>SHOTNUMBER</td>
<td>Laser shot assigned during collection</td>
<td>n/a</td>
</tr>
<tr>
<td>TIME</td>
<td>UTC decimal seconds of the day</td>
<td>Seconds</td>
</tr>
<tr>
<td>LONGITUDE_CENTROID</td>
<td>Refers to the centroid longitude of the corresponding LVIS Level-1B waveform.</td>
<td>Degrees east</td>
</tr>
<tr>
<td>LATITUDE_CENTROID</td>
<td>Refers to the centroid latitude of the corresponding LVIS Level-1B waveform.</td>
<td>Degrees north</td>
</tr>
<tr>
<td>ELEVATION_CENTROID</td>
<td>Refers to the centroid elevation of the corresponding LVIS Level-1B waveform.</td>
<td>Meters</td>
</tr>
<tr>
<td>LONGITUDE_LOW</td>
<td>Longitude of the lowest detected mode within the waveform</td>
<td>Degrees east</td>
</tr>
<tr>
<td>LATITUDE_LOW</td>
<td>Latitude of the lowest detected mode within the waveform</td>
<td>Degrees north</td>
</tr>
<tr>
<td>ELEVATION_LOW</td>
<td>Mean elevation of the lowest detected mode within the waveform</td>
<td>Meters</td>
</tr>
<tr>
<td>LONGITUDE_HIGH</td>
<td>Longitude of the center of the highest mode in the waveform</td>
<td>Degrees east</td>
</tr>
<tr>
<td>LATITUDE_HIGH</td>
<td>Latitude of the center of the highest mode in the waveform</td>
<td>Degrees north</td>
</tr>
<tr>
<td>ELEVATION_HIGH</td>
<td>Elevation of the center of the highest mode in the waveform</td>
<td>Meters</td>
</tr>
</tbody>
</table>

Fig. 3: Dimensions provided by the ILVIS2 reader

**Example**

```json
[
  {
    "type": "readers.ilvis2",
    "filename": "ILVIS2_GL2009_0414_R1401_042504.TXT",
    "metadata": "ILVIS2_GL2009_0414_R1401_042504.xml"
  },
  {
    "type": "writers.las",
    "filename": "outputfile.las"
  }
]
```
Options

filename
   File to read from [Required]

count
   Maximum number of points to read. [Default: unlimited]

override_srs
   Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

default_srs
   Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

mapping
   Which ILVIS2 field type to map to X, Y, Z dimensions ‘LOW’, ‘CENTROID’, or ‘HIGH’ [Default: ‘CENTROID’]

metadata
   XML metadata file to coincidentally read [Optional]

7.3.14 readers.las

The **LAS Reader** supports reading from **LAS format** (http://asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) files, the standard interchange format for LIDAR data. The reader does NOT support point formats containing waveform data (4, 5, 9 and 10).

The reader also supports compressed LAS files, known as LAZ files or **LASzip** (http://laszip.org) files. In order to use compressed LAS (LAZ), your version of PDAL must be built with one of the two supported decompressors, **LASzip** (http://laszip.org) or **LAZperf** (https://github.com/verma/laz-perf). See the compression (page 91) option below for more information.

**Note:** LAS stores X, Y and Z dimensions as scaled integers. Users converting an input LAS file to an output LAS file will frequently want to use the same scale factors and offsets in the output file as existed in the input file in order to maintain the precision of the data. Use the forward option on the **writers.las** (page 161) to facilitate transfer of header information from source to destination LAS/LAZ files.

**Note:** LAS 1.4 files can contain datatypes that are actually arrays rather than individual dimensions. Since PDAL doesn’t support these datatypes, it must map them into datatypes it supports. This is done by appending the array index to the name of the datatype. For example,
datatypes 11 - 20 are two dimensional array types and if a field had the name Foo for datatype 11, PDAL would create the dimensions Foo0 and Foo1 to hold the values associated with LAS field Foo. Similarly, datatypes 21 - 30 are three dimensional arrays and a field of type 21 with the name Bar would cause PDAL to create dimensions Bar0, Bar1 and Bar2. See the information on the extra bytes VLR in the LAS Specification (http://www.asprs.org/a/society/committees/standards/LAS_1_4_r13.pdf) for more information on the extra bytes VLR and array datatypes.

**Warning:** LAS 1.4 files that use the extra bytes VLR and datatype 0 will be accepted, but the data associated with a dimension of datatype 0 will be ignored (no PDAL dimension will be created).

**Default Embedded Stage**

This stage is enabled by default

**Streamable Stage**

This stage supports streaming operations

**Example**

```json
[
    {
        "type": "readers.las",
        "filename": "inputfile.las"
    },
    {
        "type": "writers.text",
        "filename": "outputfile.txt"
    }
]
```
Options

filename
LAS file to read [Required]

count
Maximum number of points to read. [Default: unlimited]

override_srs
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

default_srs
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

start
Point at which reading should start (0-indexed). Useful in combination with ‘count’ option to read a subset of points. [Default: 0]

extra_dims
Extra dimensions to be read as part of each point beyond those specified by the LAS point format. The format of the option is <dimension_name>=<type>[, ...]. Any valid PDAL type (page 367) can be specified.

Note: The presence of an extra bytes VLR when reading a version 1.4 file or a version 1.0 - 1.3 file with use_eb_vlr set causes this option to be ignored.

use_eb_vlr
If an extra bytes VLR is found in a version 1.0 - 1.3 file, use it as if it were in a 1.4 file. This option has no effect when reading a version 1.4 file. [Default: false]

compression
May be set to “lazperf” or “laszip” to choose either the LazPerf decompressor or the LASzip decompressor for LAZ files. PDAL must have been built with support for the decompressor being requested. The LazPerf decompressor doesn’t support version 1 LAZ files or version 1.4 of LAS. [Default: ‘none’]

ignore_vlr
A comma-separated list of “userid/record_id” pairs specifying VLR records that should not be loaded.

fix_dims
Make invalid dimension names valid by converting disallowed characters to ‘_’. Only applies to names specified in an extra-bytes VLR. [Default: true]

nosrs
Don’t read the SRS VLRs. The data will not be assigned an SRS. This option is for use

7.3. Readers
only in special cases where processing the SRS could cause performance issues.

[Default: false]

### 7.3.15 readers.matlab

The Matlab Reader supports readers Matlab `.mat` files. Data must be in a Matlab struct (https://www.mathworks.com/help/matlab/ref/struct.html), with field names that correspond to `dimension` (page 359) names. No ability to provide a name map is yet provided.

Additionally, each array in the struct should ideally have the same number of points. The reader takes its number of points from the first array in the struct. If the array has fewer elements than the first array in the struct, the point’s field beyond that number is set to zero.

**Note:** The Matlab reader requires the Mat-File API from MathWorks, and it must be explicitly enabled at compile time with the `BUILD_PLUGIN_MATLAB=ON` variable

---

**Dynamic Plugin**

This stage requires a dynamic plugin to operate

---

**Streamable Stage**

This stage supports streaming operations

---

**Example**

```json
[
  {
    "type": "readers.matlab",
    "struct": "PDAL",
    "filename": "autzen.mat"
  },
  {
    "type": "writers.las",
    "filename": "output.las"
  }
]
```
Options

filename
Input file name. [Required]

count
Maximum number of points to read. [Default: unlimited]

override_srs
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

default_srs
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

struct
Array structure name to read. [Default: ‘PDAL’]

7.3.16 readers.memoryview

The memoryview reader is a special stage that allows the reading of point data arranged in rows directly from memory – each point needs to have dimension data arranged at a fixed offset from a base address of the point. Before each point is read, the memoryview reader calls a function that should return the point’s base address, or a null pointer if there are no points to be read.

Note that the memoryview reader does not currently work with columnar data (data where individual dimensions are packed into arrays).

Usage

The memoryview reader cannot be used from the command-line. It is for use by software using the PDAL API.

After creating an instance of the memoryview reader, the user should call pushField() for every dimension that should be read from memory. pushField() takes a single argument, a MemoryViewReader::Field, that consists of a dimension name, a type and an offset from the point base address:

```cpp
struct Field
{
    std::string m_name;
    Dimension::Type m_type;
    size_t m_offset;
};
```

Usage

7.3. Readers
The user should also call `setIncrementer()`, a function that takes a single argument, a `std::function` that receives the ID of the point to be added and should return the base address of the point data, or a null pointer if there are no more points to be read.

```cpp
using PointIncrementer = std::function<char *(PointId)>;

void setIncrementer(PointIncrementer inc);
```

**Options**

None.

### 7.3.17 readers.mbio

The mbio reader allows sonar bathymetry data to be read into PDAL and treated as data collected using LIDAR sources. PDAL uses the MB-System (https://www.mbari.org/products/research-software/mb-system/) library to read the data and therefore supports all formats (http://www3.mbari.org/products/mbsystem/html/mbsystem_formats.html) supported by that library. Some common sonar systems are NOT supported by MB-System, notably Kongsberg, Reson and Norbit. The mbio reader reads each “beam” of data after averaging and processing by the MB-System software and stores the values for the dimensions ‘X’, ‘Y’, ‘Z’ and ‘Amplitude’. X and Y use longitude and latitude for units and the Z values are in meters (negative, being below the surface). Units for ‘Amplitude’ is not specified and may vary.

**Dynamic Plugin**

This stage requires a dynamic plugin to operate

**Streamable Stage**

This stage supports streaming operations
Example

This reads beams from a sonar data file and writes points to a LAS file.

```json
[
  {
    "type": "readers.mbio",
    "filename": "shipdata.m57",
    "format": "MBF_EM3000RAW"
  },
  {
    "type": "writers.las",
    "filename": "outputfile.las"
  }
]
```

Options

**filename**
Filename to read from [Required]

**count**
Maximum number of points to read. [Default: unlimited]

**override_srs**
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

**default_srs**
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

**format**
Name of number of format of file being read. See MB-System documentation for a list of [all formats](http://www3.mbari.org/products/mbsystem/html/mbsystem_formats.html). [Required]

**datatype**
Type of data to read. Either ‘multibeam’ or ‘sidescan’. [Default: ‘multibeam’]

**timegap**
The maximum number of seconds that can elapse between pings before the end of the data stream is assumed. [Default: 1.0]

**speedmin**
The minimum speed that the ship can be moving to before the end of the data stream is assumed. [Default: 0]
7.3.18 readers.nitf

The NITF (http://en.wikipedia.org/wiki/National_Imagery_Transmission_Format) format is used primarily by the US Department of Defense and supports many kinds of data inside a generic wrapper. The NITF 2.1 (http://www.gwg.nga.mil/ntb/baseline/docs/2500c/index.html) version added support for LIDAR point cloud data, and the NITF file reader supports reading that data, if the NITF file supports it.

- The file must be NITF 2.1
- There must be at least one Image segment (“IM”).
- There must be at least one DES segment (http://jitc.fhu.disa.mil/cgi/nitf/registers/desreg.aspx) (“DE”) named “LIDARA”.
- Only LAS or LAZ data may be stored in the LIDARA segment

The dimensions produced by the reader match exactly to the LAS dimension names and types for convenience in file format transformation.

**Note:** Only LAS or LAZ data may be stored in the LIDARA segment. PDAL uses the readers.las (page 89) and writers.las (page 161) to actually read and write the data.

**Note:** PDAL uses a fork of the NITF Nitro (http://nitro-nitf.sourceforge.net/wikka.php?wakka=HomePage) library available at https://github.com/hobu/nitro for NITF read and write support.

**Default Embedded Stage**

This stage is enabled by default

**Streamable Stage**

This stage supports streaming operations
Example

```
[
  {
    "type": "readers.nitf",
    "filename": "mynitf.nitf"
  },
  {
    "type": "writers.las",
    "filename": "outputfile.las"
  }
]
```

Options

**filename**
Filename to read from [Required]

**count**
Maximum number of points to read. [Default: unlimited]

**override_srs**
Spatial reference to apply to the data. overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

**default_srs**
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

**extra_dims**
Extra dimensions to be read as part of each point beyond those specified by the LAS point format. The format of the option is <dimension_name>=<type>[, ...]. Any PDAL type (page 367) can be specified.

Note: The presence of an extra bytes VLR when reading a version 1.4 file or a version 1.0 - 1.3 file with use_eb_vlr set causes this option to be ignored.

**use_eb_vlr**
If an extra bytes VLR is found in a version 1.0 - 1.3 file, use it as if it were in a 1.4 file. This option has no effect when reading a version 1.4 file. [Default: false]

**compression**
May be set to “lazperf” or “laszip” to choose either the LazPerf decompressor or the LASzip decompressor for LAZ files. PDAL must have been built with support for the
decompressor being requested. The LazPerf decompressor doesn’t support version 1 LAZ files or version 1.4 of LAS. [Default: “none”]

### 7.3.19 readers.numpy

PDAL has support for processing data using *filters.python* (page 348), but it is also convenient to read data from Numpy (http://www.numpy.org/) for processing in PDAL.

Numpy (http://www.numpy.org/) supports saving files with the `save` method, usually with the extension `.npy`. As of PDAL 1.7.0, `.npz` files were not yet supported.

**Warning:** It is untested whether problems may occur if the versions of Python used in writing the file and for reading the file don’t match.

#### Array Types

readers.numpy supports reading data in two forms:

- As a structured array (https://docs.scipy.org/doc/numpy/user/basics.rec.html) with specified field names (from laspy (https://github.com/laspy/laspy) for example)
- As a standard array that contains data of a single type.

#### Structured Arrays

Numpy arrays can be created as structured data, where each entry is a set of fields. Each field has a name. As an example, laspy (https://github.com/laspy/laspy) provides its `.points` as an array of named fields:

```python
import laspy
f = laspy.file.File('test/data/autzen/autzen.las')
print(f.points[0:1])
```

```python
array([[ (63608330, 84939865, 40735, 65, 73, 1, -11, 126, 7326, 245385.60820904),]],&
dtype=[('point', [(X', '<i4'), ('Y', '<i4'), ('Z', '<i4'), ('intensity', '<u2'), ('flag_byte', 'u1'), ('raw_classification', 'u1'), ('scan_angle_rank', 'i1'), ('user_data', 'u1'), ('pt_src_id', '<u2'), ('gps_time', '<f8')]])
```
The numpy reader supports reading these Numpy arrays and mapping field names to standard PDAL dimension (page 359) names. If that fails, the reader retries by removing _, -, or space in turn. If that also fails, the array field names are used to create custom PDAL dimensions.

**Standard (non-structured) Arrays**

Arrays without field information contain a single datatype. This datatype is mapped to a dimension specified by the dimension option.

```python
f = open('./perlin.npy', 'rb')
data = np.load(f,)

data.shape
(100, 100)
data.dtype
dtype('float64')
```

```
pdal info perlin.npy --readers.numpy.dimension=Intensity --readers.numpy.assign_z=4
```

```json
{
    "filename": "..	est\data\plang\perlin.npy",
    "pdal_version": "1.7.1 (git-version: 399e19)",
    "stats":
    {
        "statistic":
        [
            {
                "average": 49.5,
                "count": 10000,
                "maximum": 99,
                "minimum": 0,
                "name": "X",
                "position": 0,
                "stddev": 28.86967866,
                "variance": 833.4583458
            },
            {
                "average": 49.5,
                "count": 10000,
                "maximum": 99,
                "minimum": 0,
```
X, Y and Z Mapping

Unless the X, Y or Z dimension is specified as a field in a structured array, the reader will create dimensions X, Y and Z as necessary and populate them based on the position of each item of the array. Although Numpy arrays always contain contiguous, linear data, that data can be seen to be arranged in more than one dimension. A two-dimensional array will cause dimensions X and Y to be populated. A three dimensional array will cause X, Y and Z to be populated. An array of more than three dimensions will reuse the X, Y and Z indices for each dimension over three.

When reading data, X Y and Z can be assigned using row-major (C) order or column-major (Fortran) order by using the order option.

Dynamic Plugin

This stage requires a dynamic plugin to operate

Streamable Stage

This stage supports streaming operations
Loading Options

readers.numpy (page 98) supports two modes of operation - the first is to pass a reference to a .npy file to the filename argument. It will simply load it and read.

The second is to provide a reference to a .py script to the filename argument. It will then invoke the Python function specified in module and function with the fargs that you provide.

Loading from a Python script

A reference to a Python function that returns a Numpy array can also be used to tell readers.numpy (page 98) what to load. The following example itself loads a Numpy array from a Python script

Python Script

```
import numpy as np

def load(filename):
    array = np.load(filename)
    return array
```

Command Line Invocation

Using the above Python file with its load function, the following pdal info (page 38) invocation passes in the reference to the filename to load.

```
pdal info threedim.py \
    --readers.numpy.function=load \
    --readers.numpy.fargs=threedim.npy \
    --driver readers.numpy
```
Pipeline

An example *Pipeline* (page 55) definition would follow:

```json
[
  {
    "function": "load",
    "filename": "threedim.py",
    "fargs": "threedim.npy",
    "type": "readers.numpy"
  },
  ...
]
```

Options

**filename**

npy file to read or optionally, a .py file that defines a function that returns a Numpy array using the module, function, and fargs options. [Required]

**count**

Maximum number of points to read. [Default: unlimited]

**override_srs**

Spatial reference to apply to the data.Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

**default_srs**

Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

**dimension**

*Dimension* (page 359) name to map raster values

**order**

Either ‘row’ or ‘column’ to specify assigning the X,Y and Z values in a row-major or column-major order. [Default: matches the natural order of the array.]

**module**

The Python module name that is holding the function to run.

**function**

The function name in the module to call.

**fargs**

The function args to pass to the function
**Note:** The functionality of the ‘assign_z’ option in previous versions is provided with
filters.assign (page 253)

The functionality of the ‘x’, ‘y’, and ‘z’ options in previous versions are generally handled with
the current ‘order’ option.

---

### 7.3.20 readers.obj

The **OBJ reader** reads data from files in the OBJ format. This reader constructs a mesh from
the faces specified in the OBJ file, ignoring vertices that are not associated with any face.
Faces, vertices, vertex normals and vertex textures are read, while all other obj elements (such
as lines and curves) are ignored.

**Dynamic Plugin**

This stage requires a dynamic plugin to operate

---

**Example**

This pipeline reads from an example OBJ file outputs the vertices as a point to a LAS file.

```json
[
  {
    "type": "readers.obj",
    "filename": "test/data/obj/1.2-with-color.obj"
  },
  {
    "type": "writers.las",
    "filename": "output.las",
    "scale_x": 1.0e-5,
    "scale_y": 1.0e-5,
    "scale_z": 1.0e-5,
    "offset_x": "auto",
    "offset_y": "auto",
    "offset_z": "auto"
  }
]
```
PDAL: Point cloud Data Abstraction Library, Release 2.6.2

Options

**count**
Maximum number of points to read. [Default: unlimited]

**override_srs**
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

**default_srs**
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

**filename**
File to read. [Required]

7.3.21 readers.optech

The **Optech reader** reads Corrected Sensor Data (.csd) files. These files contain scan angles, ranges, IMU and GNSS information, and boresight calibration values, all of which are combined in the reader into XYZ points using the WGS84 reference frame.

Default Embedded Stage

This stage is enabled by default

Example

```
[
  {
    "type":"readers.optech",
    "filename":"input.csd"
  },
  {
    "type":"writers.text",
    "filename":"outputfile.txt"
  }
]
```
Options

filename

csd file to read [Required]

count

Maximum number of points to read. [Default: unlimited]

override_srs

Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

default_srs

Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

7.3.22 readers.pcd

The PCD Reader supports reading from Point Cloud Data (PCD) (https://pcl-tutorials.readthedocs.io/en/latest/pcd_file_format.html) formatted files, which are used by the Point Cloud Library (PCL) (http://pointclouds.org).

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example

```json
[
    {
        "type": "readers.pcd",
        "filename": "inputfile.pcd"
    },
    {
        "type": "writers.text",
        "filename": "outputfile.txt"
    }
]
```

7.3. Readers
Options

filename
   PCD file to read [Required]

count
   Maximum number of points to read. [Default: unlimited]

override_srs
   Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

default_srs
   Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

7.3.23 readers.pgpointcloud

The **PostgreSQL Pointcloud Reader** allows you to read points from a PostgreSQL database with PostgreSQL Pointcloud ([https://github.com/pramsey/pointcloud](https://github.com/pramsey/pointcloud)) extension enabled. The Pointcloud extension stores point cloud data in tables that contain rows of patches. Each patch in turn contains a large number of spatially nearby points.

The reader pulls patches from a table, potentially sub-setting the query with a “where” clause.

Dynamic Plugin

This stage requires a dynamic plugin to operate

Example

```json
[
   {
      "type": "readers.pgpointcloud",
      "connection": "dbname='lidar' user='user'",
      "table": "lidar",
      "column": "pa",
      "spatialreference": "EPSG:26910",
      "where": "PC_Intersects(pa, ST_MakeEnvelope(560037.36, 5114846.45, 562667.31, 5118943.24, 26910))"
   },
   {
      "type": "writers.text",
      (continues on next page)"}
]"
Options

```json
"filename": "output.txt"
```

count
Maximum number of points to read. [Default: unlimited]

override_srs
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

default_srs
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

connection
PostgreSQL connection string. In the form "host=hostname dbname=database user=username password=pw port=5432" [Required]

table
Database table to read from. [Required]

schema
Database schema to read from. [Default: public]

column
Table column to read patches from. [Default: pa]

7.3.24 readers.ply

The ply reader reads points and vertices from the polygon file format (http://paulbourke.net/dataformats/ply/), a common file format for storing three dimensional models. The ply reader can read ASCII and binary ply files.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

7.3. Readers
This stage supports streaming operations

**Example**

```json
[
    {
        "type": "readers.ply",
        "filename": "inputfile.ply"
    },
    {
        "type": "writers.text",
        "filename": "outputfile.txt"
    }
]
```

**Options**

- **filename**
  - Ply file to read [Required]

- **count**
  - Maximum number of points to read. [Default: unlimited]

- **override_srs**
  - Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

- **default_srs**
  - Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

**7.3.25 readers.pts**

The **PTS reader** reads data from Leica Cyclone PTS files. It infers dimensions from points stored in a text file.

**Default Embedded Stage**

This stage is enabled by default
Example Pipeline

```
[
    {
        "type": "readers.pts",
        "filename": "test.pts"
    },
    {
        "type": "writers.text",
        "filename": "outputfile.txt"
    }
]
```

Options

**filename**

File to read. [Required]

**count**

Maximum number of points to read. [Default: unlimited]

**override_srs**

Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

**default_srs**

Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

### 7.3.26 readers.ptx

The PTX reader reads data from Leica Cyclone PTX (http://paulbourke.net/dataformats/ptx/) files. It infers dimensions from points stored in a text file.

**Note:** PTX files can contain multiple point clouds stored in a single file. If that is the case, the reader will read all the points from all of the internal point clouds as one.

---

**Default Embedded Stage**

This stage is enabled by default
Example Pipeline

```
[
    {
        "type": "readers.ptx",
        "filename": "test.ptx"
    },
    {
        "type": "writers.text",
        "filename": "outputfile.txt"
    }
]
```

Options

**filename**
File to read. [Required]

**count**
Maximum number of points to read. [Default: unlimited]

**override_srs**
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

**default_srs**
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

**discard_missing_points**
Each point cloud in a PTX file is “fully populated”, in that the point cloud will contain missing points with XYZ values of “0 0 0”. When this option is enabled, we will skip over any missing input points. [Default: true]

### 7.3.27 readers.qfit

The **QFIT reader** read from files in the **QFIT format** (http://nsidc.org/data/docs/daac/icebridge/ilatm1b/docs/ReadMe.qfit.txt) originated for the Airborne Topographic Mapper (ATM) project at NASA Goddard Space Flight Center.

**Default Embedded Stage**
This stage is enabled by default
Example

```
[
  {
    "type":"readers.qfit",
    "filename":"inputfile.qi",
    "flip_coordinates":"false",
    "scale_z":"1.0"
  },
  {
    "type":"writers.las",
    "filename":"outputfile.las"
  }
]
```

Options

**filename**
File to read from [Required]

**count**
Maximum number of points to read. [Default: unlimited]

**override_srs**
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

**default_srs**
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

**flip_coordinates**
Flip coordinates from 0-360 to -180-180 [Default: true]

**scale_z**
Z scale. Use 0.001 to go from mm to m. [Default: 1]

**little_endian**
Are data in little endian format? This should be automatically detected by the driver. [Optional]
7.3.28 readers.rdb

The RDB reader reads from files in the RDB format, the in-house format used by RIEGL Laser Measurement Systems GmbH (http://www.riegl.com).

Dynamic Plugin

This stage requires a dynamic plugin to operate

Streamable Stage

This stage supports streaming operations

Installation

To build PDAL with rdb support, set rdb_DIR to the path of your local rdlib installation. rdlib can be obtained from the RIEGL download pages (http://www.riegl.com/members-area/software-downloads/libraries/) with a properly enabled user account. The rdlib files do not need to be in a system-level directory, though they could be (e.g. they could be in /usr/local, or just in your home directory somewhere). For help building PDAL with optional libraries, see the optional library documentation (http://pdal.io/compilation/unix.html#configure-your-optional-libraries).

Note:

• Minimum rdlib version required to build the driver and run the tests: 2.1.6
• This driver was developed and tested on Ubuntu 17.10 using GCC 7.2.0.

Example

This example pipeline reads points from a RDB file and stores them in LAS format. Only points classified as “ground points” are read since option filter is set to “riegl.class == 2” (see line 5).

```json
[
  {
    "type": "readers.rdb",
    "filename": "autzen-thin-srs.rdbx",
    "filter": "riegl.class == 2"
  }
]
```

(continues on next page)
Options

filename
Name of file to read [Required]

count
Maximum number of points to read. [Default: unlimited]

override_srs
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

default_srs
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

filter
Point filter expression string (see RDB SDK documentation for details) [Optional] [Default: empty string (= no filter)]

extras
Read all available dimensions (true) or known PDAL dimensions only (false) [Optional] [Default: false]
Dimensions

The reader maps following default RDB point attributes to PDAL dimensions (if they exist in the RDB file):

<table>
<thead>
<tr>
<th>RDB attribute</th>
<th>PDAL dimension(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>riegl.id</td>
<td>Id::PointId</td>
</tr>
<tr>
<td>riegl.source_cloud_id</td>
<td>Id::OriginId</td>
</tr>
<tr>
<td>riegl.timestamp</td>
<td>Id::InternalTime</td>
</tr>
<tr>
<td>riegl.xyz</td>
<td>Id::X, Id::Y, Id::Z</td>
</tr>
<tr>
<td>riegl.intensity</td>
<td>Id::Intensity</td>
</tr>
<tr>
<td>riegl.amplitude</td>
<td>Id::Amplitude</td>
</tr>
<tr>
<td>riegl.reflectance</td>
<td>Id::Reflectance</td>
</tr>
<tr>
<td>riegl.deviation</td>
<td>Id::Deviation</td>
</tr>
<tr>
<td>riegl.pulse_width</td>
<td>Id::PulseWidth</td>
</tr>
<tr>
<td>riegl.background_radiation</td>
<td>Id::BackgroundRadiation</td>
</tr>
<tr>
<td>riegl.target_index</td>
<td>Id::ReturnNumber</td>
</tr>
<tr>
<td>riegl.target_count</td>
<td>Id::NumberOfReturns</td>
</tr>
<tr>
<td>riegl.scan_direction</td>
<td>Id::ScanDirectionFlag</td>
</tr>
<tr>
<td>riegl.scan_angle</td>
<td>Id::ScanAngleRank</td>
</tr>
<tr>
<td>riegl.class</td>
<td>Id::Classification</td>
</tr>
<tr>
<td>riegl.rgba</td>
<td>Id::Red, Id::Green, Id::Blue</td>
</tr>
<tr>
<td>riegl.surface_normal</td>
<td>Id::NormalX, Id::NormalY, Id::NormalZ</td>
</tr>
</tbody>
</table>

All other point attributes that may exist in the RDB file are ignored unless the option extras is set to true. If so, a custom dimension is defined for each additional point attribute, whereas the dimension name is equal to the point attribute name.

**Note**: Point attributes are read “as-is”, no scaling or unit conversion is done by the reader. The only exceptions are point coordinates (riegl.xyz) and surface normals (riegl.surface_normal) which are transformed to the RDB file’s SRS by applying the matrix defined in the (optional) RDB file metadata object riegl.geo_tag.

Metadata

The reader adds following objects to the stage’s metadata node:
Object “database”

Contains basic information about the RDB file such as the bounding box, number of points and the file ID.

Listing 1: Example:

```
{
    "bounds": {
        "maximum": {
            "X": -2504493.762,
            "Y": -3846841.252,
            "Z": 4413210.394
        },
        "minimum": {
            "X": -2505882.459,
            "Y": -3848231.393,
            "Z": 4412172.548
        }
    },
    "points": 10653,
    "uuid": "637de54d-7e6b-4004-b6ab-b6bc588ec9ea"
}
```

List “dimensions”

List of point attribute description objects.

Listing 2: Example:

```
[{
    "compression_options": "shuffle",
    "default_value": 0,
    "description": "Cartesian point coordinates wrt. application coordinate system (0: X, 1: Y, 2: Z)",
    "invalid_value": ",",
    "length": 3,
    "maximum_value": 535000,
    "minimum_value": -535000,
    "name": "riegl.xyz",
    "resolution": 0.00025,
    "scale_factor": 1,
    "storage_class": "variable",
```

(continues on next page)
"title": "XYZ",
"unit_symbol": "m"
},
{
  "compression_options": "shuffle",
  "default_value": 0,
  "description": "Target surface reflectance",
  "invalid_value": "",
  "length": 1,
  "maximum_value": 327.67,
  "minimum_value": -327.68,
  "name": "riegl.reflectance",
  "resolution": 0.01,
  "scale_factor": 1,
  "storage_class": "variable",
  "title": "Reflectance",
  "unit_symbol": "dB"
}
]

Details about the point attribute properties see RDB SDK documentation.

Object “metadata”

Contains one sub-object for each metadata object stored in the RDB file.

Listing 3: Example:
"crs": {
  "epsg": 4956,
  "wkt": "GEOCCS["NAD83(HARN) \ Geocentric"],DATUM["NAD83(HARN)\n    \rightarrow "HARN"],SPHEROID["GRS 1980"],6378137.000,298.257222101,AUTHORITY["EPSG","7019"]],AUTHORITY["EPSG","6152"],PRIMEM["Greenwich",0.
    \rightarrow 0000000000000000,AUTHORITY["EPSG","8901"]],UNIT["Meter",1.
    \rightarrow 00000000000000000000,AUTHORITY["EPSG","9001"]],AXIS["Y",EAST],AXIS["Z",NORTH],AUTHORITY["EPSG","4956"]]
  "pose": [
    0.837957447, 0.379440385, -0.392240121, -2505819.156,
    -0.545735575, 0.582617132, -0.602270669, -3847595.645,
    0.000000000, 0.718736580, 0.695282481, 4412064.882,
    0.000000000, 0.000000000, 0.000000000, 1.000
  ]
}

The riegl.geo_tag object defines the Spatial Reference System (SRS) of the file. The point coordinates are actually stored in a local coordinate system (usually horizontally leveled) which is based on the SRS. The transformation from the local system to the SRS is defined by the 4x4 matrix pose which is stored in row-wise order. Point coordinates (riegl.xyz) and surface normals (riegl.surface_normal) are automatically transformed to the SRS by the reader.

Details about the metadata objects see RDB SDK documentation.

**List “transactions”**

List of transaction objects describing the history of the file.

Listing 4: Example:

```json
{
  "agent": "RDB Library 2.1.6-1677 (x86_64-windows, Apr 5 2018, 10:58:39)",
  "comments": "",
  "id": 1,
  "rdb": "RDB Library 2.1.6-1677 (x86_64-windows, Apr 5 2018, 10:58:39)",
  "settings": {
    "cache_size": 524288000,
    "chunk_size": 65536,
    "chunk_size_lod": 20
  }
}
```

(continues on next page)
"compression_level": 10,
"primary_attribute": {
  "compression_options": "shuffle",
  "default_value": 0,
  "description": "Cartesian point coordinates wrt. application coordinate system (0: X, 1: Y, 2: Z)",
  "invalid_value": "",
  "length": 3,
  "maximum_value": 535000,
  "minimum_value": -535000,
  "name": "riegl.xyz",
  "resolution": 0.00025,
  "scale_factor": 1,
  "storage_class": "variable",
  "title": "XYZ",
  "unit_symbol": "m"
},
"start": "2018-04-06 10:10:39.336",
"stop": "2018-04-06 10:10:39.336",
"title": "Database creation"
},
{
  "agent": "rdbconvert",
  "comments": "",
  "id": 2,
  "rdb": "RDB Library 2.1.6-1677 (x86_64-windows, Apr 5 2018, 10:58:39)",
  "settings": "",
  "stop": "2018-04-06 10:10:39.380",
  "title": "Import"
},
{
  "agent": "RiSCAN PRO 64 bit v2.6.3",
  "comments": "",
  "id": 3,
  "rdb": "RDB Library 2.1.6-1677 (x86_64-windows, Apr 5 2018, 10:58:39)",
  "settings": "",
  "start": "2018-04-06 10:10:41.666",
  "stop": "2018-04-06 10:10:41.666",
  "title": "Meta data saved"
Details about the transaction objects see RDB SDK documentation.

7.3.29 readers.rxp

The RXP reader read from files in the RXP format, the in-house streaming format used by RIEGL Laser Measurement Systems GmbH (http://www.riegl.com).

**Warning:** This software has not been developed by RIEGL, and RIEGL will not provide any support for this driver. Please do not contact RIEGL with any questions or issues regarding this driver. RIEGL is not responsible for damages or other issues that arise from use of this driver. This driver has been tested against RiVLib version 1.39 on a Ubuntu 14.04 using gcc43.

**Dynamic Plugin**

This stage requires a dynamic plugin to operate

**Streamable Stage**

This stage supports streaming operations

**Installation**

To build PDAL with rxp support, set RiVLib_DIR to the path of your local RiVLib installation. RiVLib can be obtained from the RIEGL download pages (http://www.riegl.com/members-area/software-downloads/libraries/) with a properly enabled user account. The RiVLib files do not need to be in a system-level directory, though they could be (e.g. they could be in /usr/local, or just in your home directory somewhere).
Example

This example rescales the points, given in the scanner’s own coordinate system, to values that can be written to a las file. Only points with a valid gps time, as determined by a pps pulse, are read from the rxp, since the sync_to_pps option is “true”. Reflectance values are mapped to intensity values using sensible defaults.

```
[
  {
    "type": "readers.rxp",
    "filename": "120304_204030.rxp",
    "sync_to_pps": "true",
    "reflectance_as_intensity": "true"
  },
  {
    "type": "writers.las",
    "filename": "outputfile.las",
    "discard_high_return_numbers": "true"
  }
]
```

We set the discard_high_return_numbers option to true on the writers.las (page 161). RXP files can contain more returns per shot than is supported by las, and so we need to explicitly tell the las writer to ignore those high return number points. You could also use filters.python (page 348) to filter those points earlier in the pipeline.

Options

filename
File to read from, or rdtp URI for network-accessible scanner. [Required]

count
Maximum number of points to read. [Default: unlimited]

override_srs
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

default_srs
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

rdtp
Boolean to switch from file-based reading to RDTP-based. [Default: false]

sync_to_pps
If “true”, ensure all incoming points have a valid pps timestamp, usually provided by
some sort of GPS clock. If “false”, use the scanner’s internal time. [Default: true]

**reflectance_as_intensity**
If “true”, in addition to storing reflectance values directly, also stores the values as Intensity by mapping the reflectance values in the range from \( \text{min\_reflectance} \) to \( \text{max\_reflectance} \) to the range 0-65535. Values less than \( \text{min\_reflectance} \) are assigned the value 0. Values greater \( \text{max\_reflectance} \) are assigned the value 65535. [Default: true]

**min\_reflectance**
The low end of the reflectance-to-intensity map. [Default: -25.0]

**max\_reflectance**
The high end of the reflectance-to-intensity map. [Default: 5.0]

7.3.30 readers.sbet

The SBET reader read from files in the SBET format, used for exchange data from inertial measurement units (IMUs). SBET files store angles as radians, but by default this reader converts all angle-based measurements to degrees. Set angles_as_degrees to false to disable this conversion.

---

**Default Embedded Stage**
This stage is enabled by default

---

**Streamable Stage**
This stage supports streaming operations

---

**Example**

```
[  "sbetfile.sbet",
   "output.las"
]
```
Options

filename
File to read from [Required]

count
Maximum number of points to read. [Default: unlimited]

override_srs
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

default_srs
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

angles_as_degrees
Convert all angles to degrees. If false, angles are read as radians. [Default: true]

7.3.31 readers.smrmsg

The SMRMSG reader read from POSPac MMS post-processed accuracy files, used to describes the accuracy of the post-processed solution (SBET file) and contains the position, orientation and velocity RMS after smoothing. See writers.sbet (page 181).

Default Embedded Stage
This stage is enabled by default

Streamable Stage
This stage supports streaming operations

Example

```python
[
    "smrmsg_xxx.out",
    "output.txt"
]
```
Options

filename
  File to read from [Required]

count
  Maximum number of points to read. [Default: unlimited]

override_srs
  Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

default_srs
  Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

7.3.3.2 readers.slpk

Scene Layer Packages (SLPK) (https://github.com/Esri/i3s-spec/blob/master/format/Indexed%203d%20Scene%20Layer%20Format%20Specification.md#_8_1) is a specification created by Esri as a format for their 3D Scene Layer and scene services. SLPK is a format that allows you to package all the necessary I3S (page 85) files together and store them locally rather than find information through REST.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example

This example will unarchive the slpk file, store it in a temp directory, and traverse it. The data will be output to a las file. This is done through PDAL’s command line interface or through the pipeline.

```
[
  {
    "type": "readers.slpk",
    "filename": "PDAL/test/data/i3s/SMALL_AUTZEN_LAS_All.slpk",
    (continues on next page)```
"obb": {
  "center": [
    636590,
    849216,
    460
  ],
  "halfSize": [
    590,
    281,
    60
  ],
  "quaternion": [
    0,
    0,
    0,
    1
  ]
}

```
pdal translate PDAL/test/data/i3s/SMALL_AUTZEN_LAS_All.slpk autzen.las
```

### Options

**filename**

SLPK file must have a file extension of .slpk. Example: `pdal translate /PDAL/test/data/i3s/SMALL_AUTZEN_LAS_ALL.slpk output.las`

**count**

Maximum number of points to read. [Default: unlimited]

**override_srs**

Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

**default_srs**

Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

**obb**

An oriented bounding box used to filter the data being retrieved. The obb is specified as
JSON exactly as described by the **I3S specification**
(https://github.com/Esri/i3s-spec/blob/master/docs/2.0/obb.cmn.md).

**dimensions**
Comma-separated list of dimensions that should be read. Specify the Esri name, rather than the PDAL dimension name.

<table>
<thead>
<tr>
<th>Esri</th>
<th>PDAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTENSITY</td>
<td>Intensity</td>
</tr>
<tr>
<td>CLASS_CODE</td>
<td>ClassFlags</td>
</tr>
<tr>
<td>FLAGS</td>
<td>Flag</td>
</tr>
<tr>
<td>RETURNS</td>
<td>NumberOfReturns</td>
</tr>
<tr>
<td>USER_DATA</td>
<td>UserData</td>
</tr>
<tr>
<td>POINT_SRC_ID</td>
<td>PointSourceId</td>
</tr>
<tr>
<td>GPS_TIME</td>
<td>GpsTime</td>
</tr>
<tr>
<td>SCAN_ANGLE</td>
<td>ScanAngleRank</td>
</tr>
<tr>
<td>RGB</td>
<td>Red</td>
</tr>
</tbody>
</table>

Example: `--readers.slpk.dimensions="rgb, intensity"`

**min_density and max_density**
This is the range of density of the points in the nodes that will be selected during the read. The density of a node is calculated by the vertex count divided by the effective area of the node. Nodes do not have a uniform density across depths in the tree, so some sections may be more or less dense than others. Default values for these parameters will select all leaf nodes (the highest resolution).

Example: `--readers.slpk.min_density=2 --readers.slpk.max_density=2.5`

### 7.3.33 readers.stac

Spatio Temporal Access Catalog (STAC) (https://stacspec.org/en) is a common language to describe geospatial information, so it can more easily be worked with, indexed, and discovered. The STAC reader will read Catalogs and Features. For Catalogs, the reader will iterate through items available in the Links key, creating a list of reads to accomplish.

**Default Embedded Stage**
This stage is enabled by default
Example

```
[
  {
    "type": "readers.stac",
    "filename": "https://s3-us-west-2.amazonaws.com/usgs-lidar-stac/ept/catalog.json",
    "reader_args": [{"type": "readers.ept", "resolution": 100}],
    "items": ["MD_GoldenBeach_2012"],
    "catalogs": ["3dep"],
    "properties": { "pc:type": ["lidar", "sonar"], "pc:encoding": "ept" },
    "asset_name": "ept.json",
    "date_ranges": [
      ["2022-11-11T0:00:0Z", "2022-11-30T0:00:0Z"
    ],
    "validate_schema": true
  }
]
```

```
pdal info --input https://s3-us-west-2.amazonaws.com/usgs-lidar-stac/ept/MD_GoldenBeach_2012.json \
  --driver readers.stac --asset_name ept.json --summary
```

Options

**filename**

STAC endpoint, local or remote, that corresponds to a Catalog, Feature or ItemCollection.

**asset_names**

The list of asset names that should be looked at to find the source data. The default is ‘data’.

**date_ranges**

A list of date ranges to prune Features by. Example: `--readers.stac.date_ranges '[["2022-11-11T0:00:0Z","2022-11-30T0:00:0Z"],...]'

**bounds**

Bounds to prune Features by. Form: ([minx,maxx],[miny,maxy],[minz,maxz])
Example: `--readers.stac.bounds '([-79.0,74.0],[38.0,39.0])'`
items
List of Regular Expression (https://en.cppreference.com/w/cpp/regex) strings to prune
STAC Item IDs by. Example: --readers.stac.items
'"MD_GoldenBeach_2012", "USGS_LPC\\w{0,}"'

catalogs
List of Regular Expression (https://en.cppreference.com/w/cpp/regex) strings to prune
STAC Catalog IDs by. Root catalog IDs are always included in the list. Example:
--readers.stac.catalogs '"3dep-test", "USGS"'

collections
List of Regular Expression (https://en.cppreference.com/w/cpp/regex) strings to prune
STAC Collection IDs by. This will filter by the collections key in a STAC Item and the id
key of the STAC Collection. Example: --readers.stac.collections
'"3dep-test", "USGS"'

validate_schema
Boolean value determining if the reader should validate the supplied STAC as it’s being
read using JSON schema and the publicly available STAC schemas and list of STAC
extension schemas.

properties
A key value mapping (JSON) of properties and the desired values to prune Features by.
Different keys will be AND’d together, and list of values will OR’d together. Example:
--readers.stac.properties
'{"pc:type": ["lidar", "sonar"], "pc:encoding": "ept"}' In this example, a
Feature must have a pc:type key with values of either lidar or sonar, and a pc:encoding
key with a value of ept.

reader_args
A list of JSON objects with keys of reader options and the values to pass through. These
will be in the exact same form as a Pipeline Stage object minus the filename.

Example:

```
--readers.stac.reader_args
'[{"type": "readers.ept", "resolution": 100}, {"type": "readers.las",
   "nosrs": true}]'
```

catalog_schema_url
URL of JSON schema you’d like to use for JSON schema validation of STAC Catalogs.

collection_schema_url
URL of JSON schema you’d like to use for JSON schema validation of STAC
Collections.

feature_schema_url
URL of JSON schema you’d like to use for JSON schema validation of STAC
Items/Features.

7.3. Readers 127
Metadata

Metadata outputs will include \textit{ids} and \textit{item_ids} for representing STAC Feature Ids, as well as \textit{catalog_ids} and \textit{collection_ids} representing STAC Catalogs and Collections, respectively.

```bash
pdal info --summary --driver readers.stac \
--readers.stac.asset_names 'ept.json' \
--readers.stac.asset_names 'data' \
${PDAL_DIR}/test/data/stac/local_catalog/catalog.json
```

```json
{
  "file_size": 1177,
  "filename": "/PDAL_DIR/test/data/stac/local_catalog/catalog.json",
  "now": "2023-08-07T15:48:59-0500",
  "pdal_version": "2.6.0 (git-version: 54be24)",
  "reader": "readers.stac",
  "summary": {
    "bounds": {
      "maxx": 637179.22,
      "maxy": 5740737,
      "maxz": 1069,
      "minx": -10543360,
      "miny": 848935.2,
      "minz": -22
    },
    "dimensions": "ClassFlags, Classification, EdgeOfFlightLine,\
                    GpsTime, Intensity, NumberOfReturns, PointSourceId, ReturnNumber,\
                    ScanAngleRank, ScanChannel, ScanDirectionFlag, UserData, X, Y, Z,\
                    OriginId, Red, Green, Blue",
    "metadata": {
      "catalog_ids": [
        "3dep"
      ],
      "collection_ids": [
        "usgs-test"
      ],
      "ids": [
        "IA_SouthCentral_1_2020"
      ]
    }
  }
}
```

(continues on next page)


7.3.34 readers.terrasolid

The Terrasolid Reader loads points from Terrasolid (https://www.terrasolid.com/home.php) files (.bin). It supports both Terrasolid format 1 and format 2.

Example

```json
[
  {
    "type": "readers.terrasolid",
    "filename": "autzen.bin"
  },
  {
    "type": "writers.las",
    "filename": "output.las"
  }
]
```
Options

filename
   Input file name [Required]

count
   Maximum number of points to read. [Default: unlimited]

override_srs
   Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

default_srs
   Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

7.3.35 readers.text

The text reader reads data from ASCII text files. Each point is represented in the file as a single line. Each line is expected to be divided into a number of fields by a separator. Each field represents a value for a point’s dimension. Each value needs to be formatted properly for C++ language double-precision values.

The text reader expects a header line to indicate the dimensions are in each subsequent line. There are two types of header lines.

Quoted dimension names

When the first character of the header is a double quote, each dimension name is assumed to be surrounded by double quotes. A single separator character is expected between the dimension names (spaces are stripped). If no separator character is found, a space is assumed. You can set the separator (page 133) character if it differs from that in the header. Note that PDAL requires dimension names that consist only of alphabetic characters and underscores. Edit the header line or use the header (page 133) option to set the dimension names to ones that PDAL understands.
Unquoted dimension names

The first non alpha-numeric character encountered is treated as a separator between dimension names. The separator in the header line can be overridden by the separator (page 133) option.

Each line in the file must contain the same number of fields as indicated by dimension names in the header. Spaces are generally ignored in the input unless used as a separator. When a space character is used as a separator, any number of consecutive spaces are treated as single space and leading/trailing spaces are ignored.

Blank lines are ignored after the header line is read.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example Input File

This input file contains X, Y and Z value for 10 points.

```
X, Y, Z
289814.15, 4320978.61, 170.76
289814.64, 4320978.84, 170.76
289815.12, 4320979.06, 170.75
289815.60, 4320979.28, 170.74
289816.08, 4320979.50, 170.68
289816.56, 4320979.71, 170.66
289817.03, 4320979.92, 170.63
289817.53, 4320980.16, 170.62
289818.01, 4320980.38, 170.61
289818.50, 4320980.59, 170.58
```
Example #1

```
[
  {
    "type": "readers.text",
    "filename": "inputfile.txt"
  },
  {
    "type": "writers.text",
    "filename": "outputfile.txt"
  }
]
```

Example #2

This reads the data in the input file as Red, Green and Blue instead of as X, Y and Z.

```
[
  {
    "type": "readers.text",
    "filename": "inputfile.txt",
    "header": "Red, Green, Blue",
    "skip": 1
  },
  {
    "type": "writers.text",
    "filename": "outputfile.txt"
  }
]
```

Options

**filename**

- text file to read, or “STDIN” to read from standard in [Required]

**count**

- Maximum number of points to read. [Default: unlimited]

**override_srs**

- Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

**default_srs**

- Spatial reference to apply to the data if the input does not specify one. Can be specified
as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

`header`
String to use as the file header. All lines in the file are assumed to be records containing point data unless skipped with the `skip` (page 133) option. [Default: None]

`separator`
Separator character to override that found in header line. [Default: None]

`skip`
Number of lines to ignore at the beginning of the file. [Default: 0]

### 7.3.36 readers.tiledb

Implements [TileDB](https://tiledb.io) 2.3.0+ storage.

**Dynamic Plugin**
This stage requires a dynamic plugin to operate

**Streamable Stage**
This stage supports streaming operations

**Example**

```
[  
  {  
    "type": "readers.tiledb",  
    "array_name": "my_array"  
  },  
  {  
    "type": "writers.las",  
    "filename": "outputfile.las"  
  }  
]
```

7.3. Readers 133
Options

array_name
TileDB (https://tiledb.io) array to read from. Synonymous with filename. [Required]

config_file
TileDB (https://tiledb.io) configuration file [Optional]

chunk_size
Size of chunks to read from TileDB array [Optional]

stats
Dump query stats to stdout [Optional]

bbox3d
TileDB subarray to read in format ([minx, maxx], [miny, maxy], [minz, maxz]) [Optional]

start_timestamp
Opens the array between a timestamp range of start_timestamp and end_timestamp. Default is 0. [Optional]

end_timestamp
Opens the array between a timestamp range of start_timestamp and end_timestamp. Default is UINT64_MAX. [Optional]

timestamp
Synonymous with start_timestamp. [Optional]

strict
Raise an error if the array contains a TileDB attribute not supported by PDAL, the default is set to true to raise an error for unsupported attribute types [Optional]

count
Maximum number of points to read. [Default: unlimited]

override_srs
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

default_srs
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]
7.3.37 readers.tindex

A GDAL tile index (http://www.gdal.org/gdaltindex.html) is an OGR (http://gdal.org/ogr/)-readable data source of boundary information. PDAL provides a similar concept for PDAL-readable point cloud data. You can use the tindex (page 48) application to generate tile index files in any format that OGR (http://gdal.org/ogr/) supports writing. Once you have the tile index, you can then use the tindex reader to automatically merge and query the data described by the tiles.

**Default Embedded Stage**

This stage is enabled by default

**Basic Example**

Given a tile index that was generated with the following scenario:

```sh
pdal tindex index.sqlite \
  "~/Users/hobu/dev/git/pdal/test/data/las/interesting.las" \
  -f "SQLite" \ 
  --lyr_name "pdal" \ 
  --t_srs "EPSG:4326"
```

Use the following pipeline (page 55) example to read and automatically merge the data.

```json
[
  {
    "type":"readers.tindex",
    "filter_srs":"+proj=lcc +lat_1=43 +lat_2=45.5 +lat_0=41.75 +lon_0=-120.5 +x_0=399999.9999999999 +y_0=0 +ellps=GRS80 +units=ft +no_defs",
    "filename":"index.sqlite",
    "where":"location LIKE '%nteresting.las'",
    "wkt":"POLYGON ((635629.85000000 848999.70000000, 635629.85000000 853535.43000000, 638982.55000000 853535.43000000, 638982.55000000 848999.70000000, 635629.85000000 848999.70000000))"
  },
  {
    "type":"writers.las",
    "filename":"outputfile.las"
  }
]
```
Options

filename
OGROpen’able raster file to read [Required]

count
Maximum number of points to read. [Default: unlimited]

override_srs
Spatial reference to apply to the data. Overrides any SRS in the input itself. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘default_srs’. [Default: none]

default_srs
Spatial reference to apply to the data if the input does not specify one. Can be specified as a WKT, proj.4 or EPSG string. Can’t use with ‘override_srs’. [Default: none]

lyr_name
The OGR layer name for the data source to use to fetch the tile index information.

reader_args
A list of JSON objects with keys of reader options and the values to pass through. These will be in the exact same form as a Pipeline Stage object minus the filename.

Example:

```
--readers.stac.reader_args
'[["type": "readers.ept", "resolution": 100}, {"type": "readers.las",
  "nosrs": true}]
```

srs_column
The column in the layer that provides the SRS information for the file. Use this if you wish to override or set coordinate system information for files.

tindex_name
The column name that defines the file location for the tile index file. [Default: location]

sql
OGR SQL (http://www.gdal.org/ogr_sql.html) to use to define the tile index layer.

bounds
A 2D box to pre-filter the tile index. If it is set, it will override any wkt (page 136) option.

wkt
A geometry to pre-filter the tile index using OGR.

t_srs
Reproject the layer SRS, otherwise default to the tile index layer’s SRS. [Default: “EPSG:4326”]

filter_srs
Transforms any wkt (page 136) or bounds (page 136) option to this coordinate system
before filtering or reading data. [Default: “EPSG:4326”]

where

**OGR SQL** (http://www.gdal.org/ogr_sql.html) filter clause to use on the layer. It only
works in combination with tile index layers that are defined with **lyr_name** (page 136)

**dialect**

**OGR SQL** (http://www.gdal.org/ogr_sql.html) dialect to use when querying tile index
layer [Default: OGRSQL]

**readers.bpf** (page 66)
Read BPF files encoded as version 1, 2, or 3. BPF is an NGA specification for point
cloud data.

**readers.copc** (page 68)
COPC, or Cloud Optimized Point Cloud is an LAZ 1.4 file stored as a clustered octree.

**readers.buffer** (page 68)
Special stage that allows you to read data from your own PointView rather than fetching
data from a specific reader.

**readers.draco** (page 71)
Read a buffer in Google Draco format

**readers.ept** (page 72)
Used for reading Entwine Point Tile (https://entwine.io) format.

**readers.e57** (page 76)
Read point clouds in the E57 format.

**readers.faux** (page 77)
Used for testing pipelines. It does not read from a file or database, but generates synthetic
data to feed into the pipeline.

**readers.fbi** (page 79)
Read TerraSolid FBI format

**readers.gdal** (page 80)
Read GDAL readable raster data sources as point clouds.

**readers.hdf** (page 82)
Read data from files in the HDF5 format.

**readers.i3s** (page 85)
Read data stored in the Esri I3S format. The data is read from an appropriate server.

**readers.ilvis2** (page 87)
Read from files in the ILVIS2 format.

**readers.las** (page 89)
Read ASPRS LAS versions 1.0 - 1.4. Does not support point formats containing
waveform data. LASzip support is also enabled through this driver if LASzip or LAZperf are found during compilation.

**readers.matlab** (page 92)
Read point cloud data from MATLAB .mat files where dimensions are stored as arrays in a MATLAB struct.

**readers.mbio** (page 94)
Read sonar bathymetry data from formats supported by the MB-System library.

**readers.memoryview** (page 93)
Read data from memory where dimension data is arranged in rows. For use only with the PDAL API.

**readers.nitf** (page 96)
Read point cloud data (LAS or LAZ) wrapped in NITF 2.1 files.

**readers.numpy** (page 98)
Read point cloud data from Numpy .npy files.

**readers.obj** (page 103)
Read points and a mesh from Wavefront OBJ files.

**readers.optech** (page 104)
Read Optech Corrected Sensor Data (.csd) files.

**readers.pcd** (page 105)
Read files in the PCD format.

**readers.pgpointcloud** (page 106)
Read point cloud data from a PostgreSQL database with the PostgreSQL Pointcloud extension enabled.

**readers.ply** (page 107)
Read points and vertices from either ASCII or binary PLY files.

**readers.pts** (page 108)
Read data from Leica Cyclone PTS files.

**readers.ptx** (page 109)
Read data from Leica Cyclone PTX files.

**readers.qfit** (page 110)
Read data in the QFIT format originated for NASA’s Airborne Topographic Mapper project.

**readers.rxp** (page 119)
Read data in the RXP format, the in-house streaming format used by RIEGL. The reader requires a copy of RiVLib during compilation.

**readers.rdb** (page 112)
Read data in the RDB format, the in-house database format used by RIEGL. The reader
requires a copy of rdblib during compilation and usage.

readers.sbet (page 121)
Read the SBET format.

readers.slpk (page 123)
Read data stored in an Esri SLPK file.

readers.stac (page 125)
Read STAC JSON Catalogs and Items with the Pointcloud extension.

readers.terrasolid (page 129)
TerraSolid Reader

readers.text (page 130)
Read point clouds from ASCII text files.

readers.tiledb (page 133)
Read point cloud data from a TileDB instance.

readers.tindex (page 135)
The tindex (tile index) reader allows you to automatically merge and query data
described in tile index files that have been generated using the PDAL tindex command.

7.4 Writers

Writers consume data provided by Readers (page 65). Some writers can consume any
dimension type, while others only understand fixed dimension names.

Note: PDAL predefined dimension names can be found in the dimension registry: Dimensions
(page 359)

7.4.1 writers.arrow

The Arrow Writer supports writing to Apache Arrow (https://arrow.apache.org/) Feather
(https://arrow.apache.org/docs/python/feather.html) and Parquet

Dynamic Plugin
This stage requires a dynamic plugin to operate

Streamable Stage
This stage supports streaming operations

Example

```
[  
  {  
    "type": "readers.las",  
    "filename": "inputfile.las"  
  },  
  {  
    "type": "writers.arrow",  
    "format": "feather",  
    "filename": "outputfile.feather"  
  }
]

```

```
[  
  {  
    "type": "readers.las",  
    "filename": "inputfile.las"  
  },  
  {  
    "type": "writers.arrow",  
    "format": "parquet",  
    "geoparquet": "true",  
    "filename": "outputfile.parquet"  
  }
]
```

Options

batch_size
Number of rows to write as a batch [Default: 65536*64]

filename
Output file to write [Required]

format
File type to write (feather, parquet) [Default: "feather"]

geoarrow_dimension_name
Dimension name to write GeoArrow struct [Default: xyz]
geoparquet
Write WKB column and GeoParquet metadata when writing parquet output

write_pipeline_metadata
Write PDAL pipeline metadata into PDAL:pipeline:metadata of geoarrow_dimension_name

where
An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: auto]

7.4.2 writers.bpf

BPF is an NGA specification (https://nsgreg.nga.mil/doc/view?i=4202) for point cloud data. The PDAL BPF Writer only supports writing of version 3 BPF format files.

Default Embedded Stage
This stage is enabled by default

Streamable Stage
This stage supports streaming operations

Example

```
[  
   {  
        "type":"readers.bpf",
        "filename":"inputfile.las"
   },
   {  
        "type":"writers.bpf",
        "filename":"outputfile.bpf"
   }
]
```
(continues on next page)
Options

filename
BPF file to write. The writer will accept a filename containing a single placeholder character (‘#’). If input to the writer consists of multiple PointViews, each will be written to a separate file, where the placeholder will be replaced with an incrementing integer. If no placeholder is found, all PointViews provided to the writer are aggregated into a single file for output. Multiple PointViews are usually the result of using filters.splitter (page 322), filters.chipper (page 318) or filters.divider (page 320). [Required]

compression
This option can be set to true to cause the file to be written with Zlib compression as described in the BPF specification. [Default: false]

format
Specifies the format for storing points in the file. [Default: dim]
- dim: Dimension-major (non-interleaved). All data for a single dimension are stored contiguously.
- point: Point-major (interleaved). All data for a single point are stored contiguously.
- byte: Byte-major (byte-segregated). All data for a single dimension are stored contiguously, but bytes are arranged such that the first bytes for all points are stored contiguously, followed by the second bytes of all points, etc. See the BPF specification for further information.

bundledfile
Path of file to be written as a bundled file (see specification). The path part of the filespec is removed and the filename is stored as part of the data. This option can be specified as many times as desired.

header data
Base64-encoded data that will be decoded and written following the standard BPF header.

coord_id
The coordinate ID (UTM zone) of the data. Southern zones take negative values. A value of 0 indicates cartesian instead of UTM coordinates. A value of ‘auto’ will attempt to set the UTM zone from a suitable spatial reference, or set to 0 if no such SRS is set. [Default: 0]

scale_x, scale_y, scale_z
Scale to be divided from the X, Y and Z nominal values, respectively, after the offset has
been applied. The special value “auto” can be specified, which causes the writer to select a scale to set the stored values of the dimensions to range from [0, 2147483647]. [Default: .01]

Note: written value = (nominal value - offset) / scale.

**offset_x, offset_y, offset_z**

Offset to be subtracted from the X, Y and Z nominal values, respectively, before the value is scaled. The special value “auto” can be specified, which causes the writer to set the offset to the minimum value of the dimension. [Default: auto]

Note: written value = (nominal value - offset) / scale.

**Note:** Because BPF data is always stored in UTM, the XYZ offsets are set to “auto” by default. This is to avoid truncation of the decimal digits (which may occur with offsets left at 0).

---

**output_dims**

If specified, limits the dimensions written for each point. Dimensions are listed by name and separated by commas. X, Y and Z are required and must be explicitly listed.

**where**

An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: **auto**]

---

### 7.4.3 writers.copc

The **COPC Writer** supports writing to COPC format (https://copc.io/) files. COPC is *Cloud Optimized Point Clouds*, and it is a LAZ 1.4 file that is organized stored as a clustered octree.

**Default Embedded Stage**

This stage is enabled by default

---

**Note:** Visit https://viewer.copc.io to view COPC files in your browser. Simply drag-n-drop the
VLRs

VLRs can be created by providing a JSON node called `vlrs` with objects as shown:

```json
[
  {
    "type": "readers.las",
    "filename": "inputfile.las"
  },
  {
    "type": "writers.las",
    "vlrs": [
      {
        "description": "A description under 32 bytes",
        "record_id": 42,
        "user_id": "hobu",
        "data": "dGhpcyBpcyBzb21lIHRleHQ=
      },
      {
        "description": "A description under 32 bytes",
        "record_id": 43,
        "user_id": "hobu",
        "filename": "path-to-my-file.input"
      },
      {
        "description": "A description under 32 bytes",
        "record_id": 44,
        "user_id": "hobu",
        "metadata": "metadata_keyname"
      }
    ],
    "filename": "outputfile.las"
  }
]
```

**Note:** One of `data`, `filename` or `metadata` must be specified. Data must be specified as base64 encoded strings. The content of a file is inserted as binary. The metadata key specified must refer to a string or base64 encoded data.
Example

```
[  
    "inputfile1.las",
    "inputfile2.laz",
    
    
    "type": "writers.copc",
    "filename": "outputfile.copc.laz"
  
]
```

Options

date
   Output filename. [Required]

forward
   List of header fields whose values should be preserved from a source LAS file. The option can be specified multiple times, which has the same effect as listing values separated by a comma. The following values are valid: filesource_id, global_encoding, project_id, system_id, software_id, creation_doy, creation_year, scale_x, scale_y, scale_z, offset_x, offset_y, offset_z. In addition, the special value header can be specified, which is equivalent to specifying all the values except the scale and offset values. Scale and offset values can be forwarded as a group by using the special values scale and offset respectively. The special value all is equivalent to specifying header, scale, offset and vlr (see below). If a header option is specified explicitly, it will override any forwarded header value. If a LAS file is the result of multiple LAS input files, the header values to be forwarded must match or they will be ignored and a default will be used instead.

VLRs can be forwarded by using the special value vlr. VLRs containing the following User IDs are NOT forwarded: LASF_Projection, liblas, laszip_encoded. VLRs with the User ID LASF_Spec and a record ID other than 0 or 3 are also not forwarded. These VLRs are known to contain information regarding the formatting of the data and will be rebuilt properly in the output file as necessary. Unlike header values, VLRs from multiple input files are accumulated and each is written to the output file. Forwarded VLRs may contain duplicate User ID/Record ID pairs.

software_id
   String identifying the software that created this LAS file. [Default: PDAL version num (build num)]

creation_doy
   Number of the day of the year (January 1 == 1) this file is being created.
creation_year
Year (Gregorian) this file is being created.

system_id
String identifying the system that created this LAS file. [Default: “PDAL”]

global_encoding
Various indicators to describe the data. See the LAS documentation. Note that PDAL will always set bit four when creating LAS version 1.4 output. [Default: 0]

project_id
UID reserved for the user [Default: Nil UID]

scale_x, scale_y, scale_z
Scale to be divided from the X, Y and Z nominal values, respectively, after the offset has been applied. The special value auto can be specified, which causes the writer to select a scale to set the stored values of the dimensions to range from [0, 2147483647]. [Default: 0.01]

Note: written value = (nominal value - offset) / scale.

offset_x, offset_y, offset_z
Offset to be subtracted from the X, Y and Z nominal values, respectively, before the value is scaled. The special value auto can be specified, which causes the writer to set the offset to the minimum value of the dimension. [Default: 0]

Note: written value = (nominal value - offset) / scale.

filesoure_id
The file source id number to use for this file (a value between 0 and 65535 - 0 implies “unassigned”) [Default: 0]

pipeline
Write a JSON representation of the running pipeline as a VLR.

vlrs
Add VLRS specified as json. See VLRs (page 144) above for details.

threads
Number of threads to use when writing [Default: 10]

enhanced_srs_vlrs
Write WKT2 and PROJJSON as VLR [Default: false]

where
An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto,
skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: auto]

7.4.4 writers.draco

Draco (https://github.com/google/draco) is a library for compressing and decompressing 3D geometric meshes and point clouds and was designed and built for compression efficiency and speed. The code supports compressing points, connectivity information, texture coordinates, color information, normals, and any other generic attributes associated with geometry.

This writer aims to use the encoding feature of the Draco library to compress and output Draco files.

Example

This example will read in a las file and output a Draco encoded file, with options to include PDAL dimensions X, Y, and Z as double, and explicitly setting quantization levels of some of the Draco attributes.

```json
[
  {
    "type": "readers.las",
    "filename": "color.las"
  },
  {
    "type": "writers.draco",
    "filename": "draco.drc",
    "dimensions": {
      "X": "float",
      "Y": "float",
      "Z": "float"
    },
    "quantization": {
      "NORMAL": 8,
      "TEX_COORD": 7,
      "GENERIC": 6
    }
  }
]
```
Options

**filename**
Output file name. [Required]

**dimensions**
A json map of PDAL dimensions to desired data types. Data types must be string and must be available in PDAL’s Type specification (https://github.com/PDAL/PDAL/blob/master/pdal/DimUtil.hpp). Any dimension that combine to make one Draco dimension must all have the same type (eg. POSITION is made up of X, Y, and Z. X cannot by float while Y and Z are specified as double)

This argument will filter the dimensions being written to only the dimensions that have been specified. If that dimension is part of a multi-dimensional draco attribute (POSITION=[X,Y,Z]), then any dimension not specified will be filled in with zeros.

**quantization**
A json map of Draco attributes to desired quantization levels. These levels must be integers. Default quantization levels are below, and will be overridden by any values placed in the options.

```json
{
    "POSITION": 11,
    "NORMAL": 7,
    "TEXCOORD": 10,
    "COLOR": 8,
    "GENERIC": 8
}
```

**where**
An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: auto]
7.4.5 writers.ept_addon

The **EPT Addon Writer** supports writing additional dimensions to Entwine Point Tile (https://entwine.io/entwine-point-tile.html) datasets. The EPT addon writer may only be used in a pipeline with an **EPT reader** (page 72), and it creates additional attributes for an existing dataset rather than creating a brand new one.

The addon dimensions created by this writer are stored independently from the corresponding EPT dataset, therefore write-access to the EPT resource itself is not required to create and use addon dimensions.

**Default Embedded Stage**

This stage is enabled by default

**Example**

This example downloads the Autzen dataset (10M points) and runs the **SMRF filter** (page 197), which populates the Classification dimension with ground values, and writes the resulting attribute to an EPT addon dataset on the local filesystem.

```
[  
  {  
    "type": "readers.ept",
    "filename": "http://na.entwine.io/autzen/ept.json"
  },  
  {  
    "type": "filters.assign",
    "assignment": "Classification[:]=0"
  },  
  {  
    "type": "filters.smrf"
  },  
  {  
    "type": "writers.ept_addon",
    "addons": {  "~/entwine/addons/autzen/smrf": "Classification" }
  }
]
```

And here is a follow-up example of reading this dataset with the **EPT reader** (page 72) with the created addon overwriting the Classification value. The output is then written to a single file with the **LAS writer** (page 161).
This is an example of using multiple mappings in the addons option to apply a new color scheme with \texttt{filters.colorinterp} (page 219) mapping the Red, Green, and Blue dimensions to new values.

The following pipeline will read the data with the new colors:
Options

addons
A JSON object whose keys represent output paths for each addon dimension, and whose corresponding values represent the attributes to be written to these addon dimensions. [Required]

Note: The addons option is reversed between the EPT reader and addon-writer: in each case, the right-hand side represents an assignment to the left-hand side. In the writer, the dimension value is assigned to an addon path. In the reader, the addon path is assigned to a dimension.

threads
Number of worker threads used to write EPT addon data. A minimum of 4 will be used no matter what value is specified.

where
An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: auto]
7.4.6 writers.e57

The **E57 Writer** supports writing to E57 files.

The writer supports E57 files with Cartesian point clouds.

---

**Note:** E57 files can contain multiple point clouds stored in a single file. The writer will only write a single cloud per file.

---

**Note:** Spherical format points are not supported.

---

**Note:** The E57 `cartesianInvalidState` dimension is mapped to the Omit PDAL dimension. A range filter can be used to filter out the invalid points.

---

**Dynamic Plugin**

This stage requires a dynamic plugin to operate

---

**Streamable Stage**

This stage supports streaming operations

---

**Example**

```
[  
  {  
    "type":"readers.las",  
    "filename":"inputfile.las"  
  },  
  {  
    "type":"writers.e57",  
    "filename":"outputfile.e57",  
    "double_precision":false  
  }  
]
```
Options

filename
   E57 file to write [Required]

double_precision
   Use double precision for storage (false by default).

where
   An expression that limits points passed to a writer. Points that don’t pass the expression
   skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
   A strategy for merging points skipped by a ‘where’ option when running in standard
   mode. If true, the skipped points are added to the first point view returned by the
   skipped filter. If false, skipped points are placed in their own point view. If auto,
   skipped points are merged into the returned point view provided that only one point view
   is returned and it has the same point count as it did when the writer was run. [Default:
   auto]

7.4.7 writers.fbi

The fbi writer writes the FastBinary file format. FastBinary is the internal format for
TerraScan (https://terrasolid.com/products/terrascan/). This driver allows to write FBI files in
version 1 of the FBI specification.

Note:  Support for all point attributes in LAS 1.2 format so data can be converted between
LAS 1.2 and Fast Binary formats without any loss of point attribute information.

Point attributes are stored as attribute streams instead of point records. This makes it possible
for reading software to read only those attributes it is interested in.

Default Embedded Stage

This stage is enabled by default
Example

```json
[
    {
        "type": "readers.las",
        "filename": "inputfile.las"
    },
    {
        "type": "writers.fbi",
        "filename": "outputfile.fbi"
    }
]
```

Options

filename

FBI file to write [Required]

7.4.8 writers.fbx

Output to the Autodesk FBX format. You must use a filter that creates a mesh, such as `filters.poisson` (page 341) or `filters.greedyprojection`, in order to use this writer.

Dynamic Plugin

This stage requires a dynamic plugin to operate

Compilation

You must download and install the Autodesk SDK and then compile the PDAL FBX plugin against it. Visit https://www.autodesk.com/developer-network/platform-technologies/fbx-sdk-2019-0 to obtain a current copy of the SDK.

Example Windows CMake configuration

```bash
-DFBX_ROOT_DIR:FILEPATH="C:\fbx2019.0" ^-DBUILD_PLUGIN_FBX=ON ^
```
Example

```
[
    {
        "type": "readers.las",
        "filename": "inputfile.las"
    },
    {
        "type": "filters.poisson"
    },
    {
        "type": "writers.fbox",
        "filename": "outputfile.fbx"
    }
]
```

.. code-block:: shell

    pdal translate autzen.las autzen.fbx -f poisson

Options

**filename**

FBX filename to write. [Required]

**ascii**

Write ASCII FBX format. [Default: false]

**where**

An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: auto]
7.4.9 writers.gdal

The **GDAL** writer creates a raster from a point cloud using an interpolation algorithm. Output is produced using **GDAL** (http://gdal.org) and can use any driver that supports creation of rasters (http://www.gdal.org/formats_list.html). A data type (page 158) can be specified for the raster (double, float, int32, etc.). If no data type is specified, the data type with the largest range supported by the driver is used.

The technique used to create the raster is a simple interpolation where each point that falls within a given **radius** (page 157) of a raster cell center potentially contributes to the raster’s value. If no radius is provided, it is set to the product of the **resolution** (page 157) and the square root of two. If a circle with the provided radius doesn’t encompass the entire cell, it is possible that some points will not be considered at all, including those that may be within the bounds of the raster cell.

The GDAL writer creates rasters using the data specified in the **dimension** (page 158) option (defaults to Z). The writer creates up to six rasters based on different statistics in the output dataset. The order of the layers in the dataset is as follows:

- **min**
  
  Give the cell the minimum value of all points within the given radius.

- **max**
  
  Give the cell the maximum value of all points within the given radius.

- **mean**
  
  Give the cell the mean value of all points within the given radius.

- **idw**
  
  Cells are assigned a value based on Shepard’s inverse distance weighting (https://en.wikipedia.org/wiki/Inverse_distance_weighting) algorithm, considering all points within the given radius.

- **count**
  
  Give the cell the number of points that lie within the given radius.

- **stdev**
  
  Give the cell the population standard deviation of the points that lie within the given radius.

If no points fall within the circle about a raster cell, a secondary algorithm can be used to attempt to provide a value after the standard interpolation is complete. If the **window_size** (page 158) option is non-zero, the values of a square of rasters surrounding an empty cell is applied using inverse distance weighting of any non-empty cells. The value provided for window_size is the maximum horizontal or vertical distance that a donor cell may be in order to contribute to the subject cell (A window_size of 1 essentially creates a 3x3 array around the subject cell. A window_size of 2 creates a 5x5 array, and so on.)

Cells that have no value after interpolation are given a value specified by the **nodata** (page 158)
Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Basic Example

This pipeline reads the file autzen_trim.las and creates a Geotiff dataset called outputfile.tif. Since output_type isn't specified, it creates six raster bands ("min", "max", "mean", "idx", "count" and "stdev") in the output dataset. The raster cells are 10x10 and the radius used to locate points whose values contribute to the cell value is 14.14.

```
[ "pdal/test/data/las/autzen_trim.las",
  {
     "resolution": 10,
     "radius": 14.14,
     "filename":"outputfile.tif"
  }
]
```

Options

filename

Name of output file. The writer will accept a filename containing a single placeholder character (#). If input to the writer consists of multiple PointViews, each will be written to a separate file, where the placeholder will be replaced with an incrementing integer. If no placeholder is found, all PointViews provided to the writer are aggregated into a single file for output. Multiple PointViews are usually the result of using filters.splitter (page 322), filters.chipper (page 318) or filters.divider (page 320).[Required]

binmode:

If ‘true’, only points inside the raster pixel will be considered for statistics, and no distance-based summary or interpolation will be applied [Default: false]

resolution

Length of raster cell edges in X/Y units. [Required]
radius
   Radius about cell center bounding points to use to calculate a cell value. [Default: 
   \textit{resolution} (page 157) * sqrt(2)]

power
   Exponent of the distance when computing IDW. Close points have higher significance 
   than far points. [Default: 1.0]

gdaldriver
   GDAL code of the \textit{GDAL driver} (http://www.gdal.org/formats_list.html) to use to write 
   the output. [Default: “GTiff”]

gdalopts
   A list of key/value options to pass directly to the GDAL driver. The format is 
   \textit{name=value,name=value,…}. The option may be specified any number of times.

\underline{Note:} The INTERLEAVE GDAL driver option is not supported. writers.gdal always 
uses BAND interleaving.

data_type
   The \textit{data type} (page 367) to use for the output raster. Many GDAL drivers only support a 
limited set of output data types. [Default: depends on the driver]

nodata
   The value to use for a raster cell if no data exists in the input data with which to compute 
an output cell value. [Default: depends on the \textit{data type} (page 158). -9999 for double, 
float, int and short, 9999 for unsigned int and unsigned short, 255 for unsigned char and 
-128 for char]

output_type
   A comma separated list of statistics for which to produce raster layers. The supported 
values are “min”, “max”, “mean”, “idw”, “count”, “stdev” and “all”. The option may be 
specified more than once. [Default: “all”]

window_size
   The maximum distance from a donor cell to a target cell when applying the fallback 
interpolation method. See the stage description for more information. [Default: 0]

dimension
   A dimension name to use for the interpolation. [Default: “Z”]

bounds
   The bounds of the data to be written. Points not in bounds are discarded. The format is 
([minx, maxx],[miny,maxy]). [Optional]

origin_x
   X origin (lower left corner) of the grid. [Default: None]
origin_y
Y origin (lower left corner) of the grid. [Default: None]

width
Number of cells in the X direction. [Default: None]

height
Number of cells in the Y direction. [Default: None]

override_srs
Write the raster with the provided SRS. [Default: None]

default_srs
Write the raster with the provided SRS if none exists. [Default: None]

metadata:
Add or set GDAL metadata to set on the raster, in the form
NAME=VALUE, NAME2=VALUE2, NAME3=VALUE3 [Default: None]

pdal_metadata:
Write PDAL’s pipeline and metadata as base64 to the GDAL PAM metadata [Default: False]

where
An expression that limits points passed to a writer. Points that don’t pass the expression
skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard
mode. If true, the skipped points are added to the first point view returned by the
skipped filter. If false, skipped points are placed in their own point view. If auto,
skipped points are merged into the returned point view provided that only one point view
is returned and it has the same point count as it did when the writer was run. [Default: auto]

---

**Note:** You may use the ‘bounds’ option, or ‘origin_x’, ‘origin_y’, ‘width’ and ‘height’, but not both.

---

**Note:** Unless the raster being written is empty, the spatial reference will automatically come
from the data and does not need to be set with ‘override_srs’ or ‘default_srs’.
7.4.10 writers.gltf

GLTF is a file format specification (https://www.khronos.org/gltf/) for 3D graphics data. If a mesh has been generated for a PDAL point view, the GLTF Writer will produce simple output in the GLTF format. PDAL does not currently support many of the attributes that can be found in a GLTF file. This writer creates a binary GLTF (extension `.glb`).

Default Embedded Stage

This stage is enabled by default

Example

```
[
  "infile.las",
  {
    "type": "filters.poisson",
    "depth": 12
  },
  {
    "type": "writers.gltf",
    "filename": "output.glb",
    "red": 0.8,
    "metallic": 0.5
  }
]
```

Options

**filename**

Name of the GLTF (.glb) file to be written. [Required]

**metallic**

The metallic factor of the faces. [Default: 0]

**roughness**

The roughness factor of the faces. [Default: 0]

**red**

The base red component of the color applied to the faces. [Default: 0]

**green**

The base green component of the color applied to the faces. [Default: 0]
blue
   The base blue component of the color applied to the faces. [Default: 0]

alpha
   The alpha component to be applied to the faces. [Default: 1.0]

double_sided
   Whether the faces are colored on both sides, or just the side visible from the initial
   observation point (positive normal vector). [Default: false]

colors
   Write color data for each vertex. Red, Green and Blue dimensions must exist. Note that
   most renderers will “interpolate the color of each vertex across a face, so this may look
   odd.” [Default: false]

normals
   Write vertex normals. NormalX, NormalY and NormalZ dimensions must exist.
   [Default: false]

where
   An expression that limits points passed to a writer. Points that don’t pass the expression
   skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
   A strategy for merging points skipped by a ‘where’ option when running in standard
   mode. If true, the skipped points are added to the first point view returned by the
   skipped filter. If false, skipped points are placed in their own point view. If auto,
   skipped points are merged into the returned point view provided that only one point view
   is returned and it has the same point count as it did when the writer was run. [Default: auto]

7.4.11 writers.las

The LAS Writer supports writing to LAS format
(http://asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) files,
the standard interchange file format for LIDAR data.

Warning: Scale/offset are not preserved from an input LAS file. See below for
information on the scale/offset options and the forward (page 163) option.

Default Embedded Stage

This stage is enabled by default
Streamable Stage

This stage supports streaming operations

VLRS

VLRS can be created by providing a JSON node called vlrs with objects as shown:

```json
[
  {
    "type": "readers.las",
    "filename": "inputfile.las"
  },
  {
    "type": "writers.las",
    "vlrs": [
      {
        "description": "A description under 32 bytes",
        "record_id": 42,
        "user_id": "hobu",
        "data": "dGhpcyBpcyBzb21lIHRleHQ=
      },
      {
        "description": "A description under 32 bytes",
        "record_id": 43,
        "user_id": "hobu",
        "filename": "path-to-my-file.input"
      },
      {
        "description": "A description under 32 bytes",
        "record_id": 44,
        "user_id": "hobu",
        "metadata": "metadata_keyname"
      }]
  },
  "filename": "outputfile.las"
]
```

Note: One of data, filename or metadata must be specified. Data must be specified as base64 encoded strings. The content of a file is inserted as binary. The metadata key specified must refer to a string or base64 encoded data.
Example

```json
[
    {
        "type": "readers.las",
        "filename": "inputfile.las"
    },
    {
        "type": "writers.las",
        "filename": "outputfile.las"
    }
]
```

Options

filename
Output filename. The writer will accept a filename containing a single placeholder character (#). If input to the writer consists of multiple PointViews, each will be written to a separate file, where the placeholder will be replaced with an incrementing integer. If no placeholder is found, all PointViews provided to the writer are aggregated into a single file for output. Multiple PointViews are usually the result of using filters.splitter (page 322), filters.chipper (page 318) or filters.divider (page 320). [Required]

forward
List of header fields whose values should be preserved from a source LAS file. The option can be specified multiple times, which has the same effect as listing values separated by a comma. The following values are valid: major_version, minor_version, dataformat_id, filesource_id, global_encoding, project_id, system_id, software_id, creation_doy, creation_year, scale_x, scale_y, scale_z, offset_x, offset_y, offset_z. In addition, the special value header can be specified, which is equivalent to specifying all the values EXCEPT the scale and offset values. Scale and offset values can be forwarded as a group by using the special values scale and offset respectively. The special value all is equivalent to specifying header, scale, offset and vlr (see below). If a header option is specified explicitly, it will override any forwarded header value. If a LAS file is the result of multiple LAS input files, the header values to be forwarded must match or they will be ignored and a default will be used instead.

VLRs can be forwarded by using the special value vlr. VLRs containing the following User IDs are NOT forwarded: LASF_Projection, liblas, laszip encoded. VLRs with the User ID LASF_Spec and a record ID other than 0 or 3 are also not forwarded. These VLRs are known to contain information regarding the formatting of the data and will be rebuilt properly in the output file as necessary. Unlike header values, VLRs from multiple input files are accumulated and each is written to the output file. Forwarded
VLRs may contain duplicate User ID/Record ID pairs.

**minor_version**
All LAS files are version 1, but the minor version (0 - 4) can be specified with this option. [Default: 2]

**software_id**
String identifying the software that created this LAS file. [Default: PDAL version num (build num)]’

**creation_doy**
Number of the day of the year (January 1 == 1) this file is being created.

**creation_year**
Year (Gregorian) this file is being created.

**dataformat_id**
Controls whether information about color and time are stored with the point information in the LAS file. [Default: 3]

- 0 == no color or time stored
- 1 == time is stored
- 2 == color is stored
- 3 == color and time are stored
- 4 [Not Currently Supported]
- 5 [Not Currently Supported]
- 6 == time is stored (version 1.4+ only)
- 7 == time and color are stored (version 1.4+ only)
- 8 == time, color and near infrared are stored (version 1.4+ only)
- 9 [Not Currently Supported]
- 10 [Not Currently Supported]

**system_id**
String identifying the system that created this LAS file. [Default: “PDAL”]

**a_srs**
The spatial reference system of the file to be written. Can be an EPSG string (e.g. “EPSG:26910”) or a WKT string. [Default: Not set]

**global_encoding**
Various indicators to describe the data. See the LAS documentation. Note that PDAL will always set bit four when creating LAS version 1.4 output. [Default: 0]

**project_id**
UID reserved for the user [Default: Nil UID]
compression
Set to “lazperf” or “laszip” to apply compression to the output, creating a LAZ file instead of an LAS file. “lazperf” selects the LazPerf compressor and “laszip” (or “true”) selects the LasZip compressor. PDAL must have been built with support for the requested compressor. [Default: “none”]

scale_x, scale_y, scale_z
Scale to be divided from the X, Y and Z nominal values, respectively, after the offset has been applied. The special value auto can be specified, which causes the writer to select a scale to set the stored values of the dimensions to range from [0, 2147483647]. [Default: .01]

Note: written value = (nominal value - offset) / scale.

offset_x, offset_y, offset_z
Offset to be subtracted from the X, Y and Z nominal values, respectively, before the value is scaled. The special value auto can be specified, which causes the writer to set the offset to the minimum value of the dimension. [Default: 0]

Note: written value = (nominal value - offset) / scale.

filesource_id
The file source id number to use for this file (a value between 0 and 65535 - 0 implies “unassigned”) [Default: 0]

discard_high_return_numbers
If true, discard all points with a return number greater than the maximum supported by the point format (5 for formats 0-5, 15 for formats 6-10). [Default: false]

extraDims
Extra dimensions to be written as part of each point beyond those specified by the LAS point format. The format of the option is <dimension_name>=<type> [, ...]. Any valid PDAL type (page 367) can be specified.

The special value all can be used in place of a dimension/type list to request that all dimensions that can’t be stored in the predefined LAS point record get added as extra data at the end of each point record.

PDAL writes an extra bytes VLR (User ID: LASF_Spec, Record ID: 4) when extra dims are written. The VLR describes the extra dimensions specified by this option. Note that reading of this VLR is only specified for LAS version 1.4, though some systems will honor it for earlier file formats. The LAS reader (page 89) requires the option use_eb_vlr in order to read the extra bytes VLR for files written with 1.1 - 1.3 LAS format.

Setting –verbose=Info will provide output on the names, types and order of dimensions being written as part of the LAS extra bytes.

pdal_metadata
Write two VLRs containing JSON (http://www.json.org/) output with both the Metadata (page 545) and Pipeline (page 55) serialization. [Default: false]
vhrs
Add VLRS specified as json. See VLRs (page 162) above for details.

where
An expression that limits points passed to a writer. Points that don’t pass the expression
skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard
mode. If true, the skipped points are added to the first point view returned by the
skipped filter. If false, skipped points are placed in their own point view. If auto,
skipped points are merged into the returned point view provided that only one point view
is returned and it has the same point count as it did when the writer was run. [Default: auto]

7.4.12 writers.matlab

The Matlab Writer supports writing Matlab .mat files.
The produced files has a single variable, PDAL, an array struct.

Note: The Matlab writer requires the Mat-File API from MathWorks, and it must be explicitly
enabled at compile time with the BUILD_PLUGIN_MATLAB=ON variable
Dynamic Plugin

This stage requires a dynamic plugin to operate

Example

```json
[
    {
        "type": "readers.las",
        "filename": "inputfile.las"
    },
    {
        "type": "writers.matlab",
        "output_dims": "X,Y,Z,Intensity",
        "filename": "outputfile.mat"
    }
]
```

Options

**filename**

Output file name [Required]

**output_dims**

A comma-separated list of dimensions to include in the output file. May also be specified as an array of strings. [Default: all available dimensions]

**struct**

Array structure name to read [Default: “PDAL”]

**where**

An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: auto]
7.4.13 writers.nitf

The NITF (http://en.wikipedia.org/wiki/National_Imagery_Transmission_Format) format is a US Department of Defense format for the transmission of imagery. It supports various formats inside a generic wrapper.

Note: LAS inside of NITF is widely supported by software that uses NITF for point cloud storage, and LAZ is supported by some softwares. No other content type beyond those two is widely supported as of January of 2016.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example

Example One

```
[ 
  { 
    "type":"readers.las",
    "filename":"inputfile.las"
  },
  { 
    "type":"writers.nitf",
    "compression":"laszip",
    "idatim":"20160102220000",
    "forward":"all",
    "acftb":"SENSOR_ID:LIDAR,SENSOR_ID_TYPE:LILN",
    "filename":"outputfile.ntf"
  }
]
```

Example Two
Options

**filename**
NITF file to write. The writer will accept a filename containing a single placeholder character ('#'). If input to the writer consists of multiple PointViews, each will be written to a separate file, where the placeholder will be replaced with an incrementing integer. If no placeholder is found, all PointViews provided to the writer are aggregated into a single file for output. Multiple PointViews are usually the result of using `filters.splitter` (page 322), `filters.chipper` (page 318) or `filters.divider` (page 320).

**clevel**
File complexity level (2 characters) [Default: 03]

**sstyle**
Standard type (4 characters) [Default: BF01]

**ostaid**
Originating station ID (10 characters) [Default: PDAL]

**ftitle**
File title (80 characters) [Default: <spaces>]

**fsclas**

**oname**
Originator name (24 characters) [Default: <spaces>]

**ophone**
Originator phone (18 characters) [Default: <spaces>]
fsctlh
   File control and handling (2 characters) [Default: <spaces>]

fsclsy
   File classification system (2 characters) [Default: <spaces>]

idatim
   Image date and time (format: ‘CCYYMMDDhhmmss’). Required. [Default:
   AIMIDB.ACQUISITION_DATE if set or <spaces>]

iid2
   Image identifier 2 (80 characters) [Default: <spaces>]

fscltx
   File classification text (43 characters) [Default: <spaces>]

aimidb
   Comma separated list of name/value pairs to complete the AIMIDB (Additional Image
   ID) TRE record (format name:value). Required: ACQUISITION_DATE, will default to
   IDATIM value. [Default: NITF defaults]

acftb
   Comma separated list of name/value pairs to complete the ACFTB (Aircraft Information)
   TRE record (format name:value). Required: SENSOR_ID, SENSOR_ID_TYPE
   [Default: NITF defaults]

where
   An expression that limits points passed to a writer. Points that don’t pass the expression
   skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
   A strategy for merging points skipped by a ‘where’ option when running in standard
   mode. If true, the skipped points are added to the first point view returned by the
   skipped filter. If false, skipped points are placed in their own point view. If auto,
   skipped points are merged into the returned point view provided that only one point view
   is returned and it has the same point count as it did when the writer was run. [Default: auto]

7.4.14 writers.null

The null writer discards its input. No point output is produced when using a null writer.

Default Embedded Stage

This stage is enabled by default
Streamable Stage

This stage supports streaming operations

Example

```json
[
  {
    "type" : "readers.las",
    "filename" : "inputfile.las"
  },
  {
    "type" : "filters.hexbin"
  },
  {
    "type" : "writers.null"
  }
]
```

When used with an option that forces metadata output, like --pipeline-serialization, this pipeline will create a hex boundary for the input file, but no output point data file will be produced.

Options

The null writer discards all passed options.

7.4.15 writers.ogr

The OGR Writer will create files of various vector formats (https://gdal.org/drivers/vector/index.html) as supported by the OGR library. PDAL points are generally stored as point geometries in the output format, though PDAL will create multipoint geometries instead if the `multicount` (page 172) option is set to a value greater than 1. Points can be written with an additional measure value (POINTZM) if `measure_dim` (page 172) specifies a valid PDAL dimension, and dimensions can be set as feature attributes using the `attr_dims` (page 172) option.

By default, the OGR writer will create ESRI shapefiles. The particular OGR driver can be specified with the `ogrdriver` option.
Example

```
[
    "inputfile.las",
    {
        "type": "writers.ogr",
        "filename": "outfile.geojson",
        "measure_dim": "Intensity",
        "attr_dims": "Classification"
    }
]
```

Options

**filename**

Output file to write. The writer will accept a filename containing a single placeholder character (#). If input to the writer consists of multiple PointViews, each will be written to a separate file, where the placeholder will be replaced with an incrementing integer. If no placeholder is found, all PointViews provided to the writer are aggregated into a single file for output. Multiple PointViews are usually the result of multiple input files, or using `filters.splitter` (page 322), `filters.chipper` (page 318) or `filters.divider` (page 320).

The driver will use the OGR GeoJSON driver if the output filename extension is `.geojson`, and the ESRI Shapefile driver if the output filename extension is `.shp`. If neither extension is recognized, the filename is taken to represent a directory in which ESRI Shapefiles are written. The driver can be explicitly specified by using the `ogrdriver` (page 172) option.

**multicount**

If 1, point features will be written. If greater than 1, specifies the number of points to group into a feature with a multipoint geometry. Not all OGR drivers support multipoint geometries. [Default: 1]

**measure_dim**

If specified, points will be written with an extra data field, the dimension of which is specified by this option. Not all output formats support measure data. [Default: None]

**attr_dims**

List of dimensions to write as feature attributes. Separate multiple values with , or repeat the option. Use a11 to write all dimensions. X, Y, Z, and any `measure_dim` (page 172) are never written as attributes. This option is incompatible with the `multicount` (page 172) option. [Default: None]

**ogrdriver**

The OGR driver to use for output. This option overrides any inference made about output drivers from `filename` (page 172).
ogr_options
List of OGR driver-specific layer creation options, formatted as an OPTION=VALUE string. Separate multiple values with , or repeat the option. [Default: None]

where
An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: auto]

7.4.16 writers.pcd

The PCD Writer supports writing to Point Cloud Data (PCD) (https://pcl-tutorials.readthedocs.io/en/latest/pcd_file_format.html) formatted files, which are used by the Point Cloud Library (PCL) (http://pointclouds.org).

By default, compression is not enabled, and the PCD writer will output ASCII formatted data.

Default Embedded Stage
This stage is enabled by default

Streamable Stage
This stage supports streaming operations

Note: X, Y, and Z dimensions will be written as single-precision floats by default to be compatible with most of the existing PCL point types. These dimensions can be forced to double-precision using the order option, but the PCL code reading this data must be capable of reading double-precision fields (i.e., it is not the responsibility of PDAL to ensure this compatibility).

Note: When working with large coordinate values it is recommended that users first translate the coordinate values using filters.transformation (page 278) to avoid loss of precision when...
writing single-precision XYZ data.

Example

```
[
    {
        "type": "readers.pcd",
        "filename": "inputfile.pcd"
    },
    {
        "type": "writers.pcd",
        "filename": "outputfile.pcd"
    }
]
```

Options

filename

PCD file to write [Required]

compression

Level of PCD compression to use (ascii, binary, compressed) [Default: “ascii”]

precision

Decimal Precision for output of values. This can be overridden for individual dimensions using the order option. [Default: 2]

order

Comma-separated list of dimension names in the desired output order. For example “X,Y,Z,Red,Green,Blue”. Dimension names can optionally be followed by a PDAL type (e.g., Unsigned32) and dimension-specific precision (used only with “ascii” compression). Ex: “X=Float:2, Y=Float:2, Z=Float:3, Intensity=Unsigned32” If no precision is specified the value provided with the precision (page 174) option is used. The default dimension type is double precision float. [Default: none]

keep_unspecified

If true, writes all dimensions. Dimensions specified with the order (page 174) option precede those not specified. [Default: true]

where

An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge

A strategy for merging points skipped by a ‘where’ option when running in standard
mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: auto]

7.4.17 writers.pgpointcloud

The PostgreSQL Pointcloud Writer allows you to write to PostgreSQL database that have the PostgreSQL Pointcloud (http://github.com/pramsey/pointcloud) extension enabled. The Pointcloud extension stores point cloud data in tables that contain rows of patches. Each patch in turn contains a large number of spatially nearby points.

While you can theoretically store the contents of a whole file of points in a single patch, it is more practical to store a table full of smaller patches, where the patches are under the PostgreSQL page size (8kb). For most LIDAR data, this practically means a patch size of between 400 and 600 points.

In order to create patches of the right size, the Pointcloud writer should be preceded in the pipeline file by filters.chipper (page 318).

The pgpointcloud format does not support WKT spatial reference specifications. A subset of spatial references can be stored by using the `srid` option, which allows storage of an EPSG code (http://www.epsg.org) that covers many common spatial references. PDAL makes no attempt to reproject data to your specified srid. Use filters.reprojection (page 275) for this purpose.

Dynamic Plugin

This stage requires a dynamic plugin to operate

Example

```
[
  {
    "type":"readers.las",
    "filename":"inputfile.las",
    "spatialreference":"EPSG:26916"
  },
  {
    "type":"filters.chipper",
    "capacity":400
  }
]
```

(continues on next page)
Options

connection
PostgreSQL connection string. In the form "host=hostname dbname=database user=username password=pw port=5432" [Required]

table
Database table to write to. [Required]

schema
Database schema to write to. [Default: "public"]

column
Table column to put patches into. [Default: "pa"]

compression
Patch compression type to use. [Default: "dimensional"]

• none applies no compression
• dimensional applies dynamic compression to each dimension separately
• lazperf applies a “laz” compression (using the laz-perf (https://github.com/hobu/laz-perf) library in PostgreSQL Pointcloud)

overwrite
To drop the table before writing set to ‘true’. To append to the table set to ‘false’. [Default: false]

srid
Spatial reference ID (relative to the spatial_ref_sys table in PostGIS) to store with the point cloud schema. [Default: 4326]

pcid
An optional existing PCID to use for the point cloud schema. If specified, the schema must be present. If not specified, a match will still be looked for, or a new schema will be inserted. [Default: 0]
pre_sql
SQL to execute *before* running the translation. If the value references a file, the file is read and any SQL inside is executed. Otherwise the value is executed as SQL itself.
[Optional]

post_sql
SQL to execute *after* running the translation. If the value references a file, the file is read and any SQL inside is executed. Otherwise the value is executed as SQL itself.
[Optional]

scale_x, scale_y, scale_z / offset_x, offset_y, offset_z
If ANY of these options are specified the X, Y and Z dimensions are adjusted by subtracting the offset and then dividing the values by the specified scaling factor before being written as 32-bit integers (as opposed to double precision values). If any of these options is specified, unspecified scale_<x,y,z> options are given the value of 1.0 and unspecified offset_<x,y,z> are given the value of 0.0.

output_dims
If specified, limits the dimensions written for each point. Dimensions are listed by name and separated by commas.

where
An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: auto]

7.4.18 writers.ply

The ply writer writes the polygon file format (http://paulbourke.net/dataformats/ply/), a common file format for storing three dimensional models. The writer emits points as PLY vertices. The writer can also emit a mesh as a set of faces. filters.greedyprojection (page 339) and filters.poisson (page 341) create a mesh suitable for output as faces.

Default Embedded Stage

This stage is enabled by default
Example

```
[
  {
    "type": "readers.pcd",
    "filename": "inputfile.pcd"
  },
  {
    "type": "writers.ply",
    "storage_mode": "little endian",
    "filename": "outputfile.ply"
  }
]
```

Options

**filename**

Ply file to write [Required]

**storage_mode**

Type of ply file to write. Valid values are ‘ascii’, ‘little endian’, ‘big endian’. [Default: “ascii”]

**dims**

List of dimensions (and Types (page 367)) in the format <dimension_name>[=<type>] [,...] to write as output. (e.g., “Y=int32_t, X,Red=char”) [Default: All dimensions with stored types]

**faces**

Write a mesh as faces in addition to writing points as vertices. [Default: false]

**sized_types**

PLY has variously been written with explicitly sized type strings (‘int8’, ‘float32’, ‘uint32’, etc.) and implied sized type strings (‘char’, ‘float’, ‘int’, etc.). If true, explicitly sized type strings are used. If false, implicitly sized type strings are used. [Default: true]

**precision**

If specified, the number of digits to the right of the decimal place using f-style formatting. Only permitted when ‘storage_mode’ is ‘ascii’. See the printf (https://en.cppreference.com/w/cpp/io/c/printf) reference for more information. [Default: g-style formatting (variable precision)]

**where**

An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]
where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: auto]

7.4.19 writers.raster

The Raster Writer writes an existing raster to a file. Output is produced using GDAL (http://gdal.org) and can use any driver that supports creation of rasters (http://www.gdal.org/formats_list.html). A data_type can be specified for the raster (double, float, int32, etc.). If no data type is specified, the data type with the largest range supported by the driver is used.

Cells that have no value are given a value specified by the nodata option.

Default Embedded Stage
This stage is enabled by default

Streamable Stage
This stage supports streaming operations

Basic Example
This pipeline reads the file autzen_trim.las, triangulates the data, creates a raster based on the Z dimension as determined by interpolation of the location and values of ‘Z’ of the vertices of a containing triangle, if any exists. The resulting raster is written to “outputfile.tif”.

```
[  
  "pdal/test/data/las/autzen_trim.las",
  {  
    "type": "filters.delaunay"
  }
  {  
    "type": "filters.faceraster",
    "resolution": 1
  }
]
```

(continues on next page)
Options

filename
   Name of output file. [Required]

gdaldriver
   GDAL code of the GDAL driver (http://www.gdal.org/formats_list.html) to use to write the output. [Default: “GTiff”]

gdalopts
   A list of key/value options to pass directly to the GDAL driver. The format is name=value,name=value,… The option may be specified any number of times.

Note: The INTERLEAVE GDAL driver option is not supported. writers.gdal always uses BAND interleaving.

rasters
   A comma-separated list of raster names to be written as bands of the raster. All rasters must have the same limits (origin/width/height). Rasters following the first that don’t have the same limits will be dropped. If no raster names are provided, only the first raster found will be placed into a single band for output.

data_type
   The data type (page 367) to use for the output raster. Many GDAL drivers only support a limited set of output data types. [Default: depends on the driver]

nodata
   The value to use for a raster cell if the raster contains no data in a cell. Note that the nodata written to the output may be different from that of the raster being written. [Default: depends on the data_type. -9999 for double, float, int and short, 9999 for unsigned int and unsigned short, 255 for unsigned char and -128 for char]

where
   An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
   A strategy for merging points skipped by a ‘where’ option when running in standard
mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: auto]

7.4.20 writers.sbet

The SBET writer writes files in the SBET format, used for exchange data from inertial measurement units (IMUs).

Default Embedded Stage

This stage is enabled by default

Example

```
[  
    "input.sbet",
    "output.sbet"
]
```

Options

filename

File to write. [Required]

angles_are_degrees

Convert all angular values from degrees to radians before write. [Default: true]

where

An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: auto]
7.4.21 writers.text

The text writer writes out to a text file. This is useful for debugging or getting smaller files into an easily parseable format. The text writer supports both GeoJSON (http://geojson.org) and CSV (http://en.wikipedia.org/wiki/Comma-separated_values) output.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example

```
[  
  {  
    "type":"readers.las",
    "filename":"inputfile.las"
  },
  {  
    "type":"writers.text",
    "format":"geojson",
    "order":"X,Y,Z",
    "keep_unspecified":"false",
    "filename":"outputfile.txt"
  }
]
```

Options

**filename**

File to write to, or “STDOUT” to write to standard out [Required]

**format**

Output format to use. One of geojson or csv. [Default: “csv”]

**precision**

Decimal Precision for output of values. This can be overridden for individual dimensions using the order option. [Default: 3]
order
Comma-separated list of dimension names in the desired output order. For example
“X,Y,Z,Red,Green,Blue”. Dimension names can optionally be followed with a colon (‘:’) and an integer to indicate the precision to use for output. Ex: “X:3, Y:5,Z:0” If no precision is specified the value provided with the precision (page 182) option is used. [Default: none]

keep_unspecified
If true, writes all dimensions. Dimensions specified with the order (page 183) option precede those not specified. [Default: true]

jscallback
When producing GeoJSON, the callback allows you to wrap the data in a function, so the output can be evaluated in a <script> tag.

quote_header
When producing CSV, should the column header named by quoted? [Default: true]

write_header
Whether a header should be written. [Default: true]

delimiter
When producing CSV, what character to use as a delimiter? [Default: “,”]

where
An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: auto]
7.4.22 writers.tiledb

Implements TileDB (https://tiledb.io) 2.3.0+ reads from an array.

Dynamic Plugin
This stage requires a dynamic plugin to operate

Streamable Stage
This stage supports streaming operations

Example

```
[  
  
  {  
      "type": "readers.las",  
      "array_name": "input.las"  
  },  
  
  {  
      "type": "filters.stats"  
  },  
  
  {  
      "type": "writers.tiledb",  
      "array_name": "output_array"  
  }  
]
```

Options

array_name
TileDB (https://tiledb.io) array to write to. Synonymous with filename. [Required]

config_file
TileDB (https://tiledb.io) configuration file. [Optional]

data_tile_capacity
Number of points per tile. Not used when append=true. [Default: 100,000]

cell_order
The layout to use for TileDB cells. May be auto, row-major, col-major, or hilbert. Not used when append=true. [Default: auto]
tile_order
The layout to use for TileDB tiles. May be row-major or col-major. Not used when append=true. [Default: row-major]

x_tile_size
Tile size (x). Floating point value used for determining on-disk data order. Not used when append=true. [Optional]

y_tile_size
Tile size (y). Floating point value used for determining on-disk data order. Not used when append=true. [Optional]

z_tile_size
Tile size (z). Floating point value used for determining on-disk data order. Not used when append=true. [Optional]

time_tile_size
Tile size (time). Not used when append=true. [Optional]

x_domain_st
Domain minimum for x. Not used when append=true. [Optional]

x_domain_end
Domain maximum for x. Not used when append=true. [Optional]

y_domain_st
Domain minimum for y. Not used when append=true. [Optional]

y_domain_end
Domain maximum for y. Not used when append=true. [Optional]

z_domain_st
Domain minimum for z. Not used when append=true. [Optional]

z_domain_end
Domain maximum for z. Not used when append=true. [Optional]

time_domain_st
Domain minimum for GpsTime. Not used when append=true. [Optional]

time_domain_end
Domain maximum for GpsTime. Not used when append=true. [Optional]

use_time_dim
Use GpsTime coordinate data as an array dimension instead of an array attribute. Not used when append=true. [Default: false]

time_first
Put the GpsTime dimension first instead of last. Only used when use_time_dim=true. Not used when append=true. [Default: false]
**combine_bit_fields**
Store all sub-byte fields together in an attribute named `BitFields`. Not used when `append=true`. [Default: true]

**chunk_size**
Point cache size for chunked writes. [Default: 1,000,000]

**append**
Instead of creating a new array, append to an existing array that has the dimensions stored as a TileDB dimension or TileDB attribute. [Default: false]

**stats**
Dump query stats to stdout. [Default: false]

**filters**
JSON array or object of compression filters for either dimensions or attributes of the form `{dimension/attribute name : {“compression”: name, compression_options: value, ...}}`. Not used when `append=true`. [Optional]

**filter_profile**
Profile of compression filters to use for dimensions and attributes not provided in `filters`. Options include `balanced`, `aggressive`, and `none`. Not used when `append=true`. [Default: balanced]

**scale_x, scale_y, scale_z**
Scale factor used for the float-scale filter for the X, Y, and Z dimensions, respectively, when using the `balanced` or `aggressive` filter profile. Not used when `append=true`. [Default: 0.01]

Note: written value = (nominal value - offset) / scale.

**offset_x, offset_y, offset_z**
Offset used for the float-scale filter for the X, Y and Z dimensions, respectively, when using the `balanced` or `aggressive` filter profile. Not used when `append=true`. [Default: 0.0]

Note: written value = (nominal value - offset) / scale.

**compression**
The default TileDB compression filter to use. Only used if the dimension or attribute name is not included in `filters`. Not used when `append=true`. [Default: none]

**compression_level**
The TileDB compression level to use for the default compression. Option is ignored if set to `-l`. Not used when `append=true`. [Default: -1]

**timestamp**
Sets the TileDB timestamp for this write. [Optional]

**where**
An expression that limits points passed to a writer. Points that don’t pass the expression
skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: auto]

TileDB provides default filter profiles. The filters can be over-written by the `filters` option. If a TileDB attribute is not set by the filter profile or the `filter` option, the compression filter set by the compression option is used.

Filters set by the `balanced` (default) filter profile (the delta filter is skipped if using TileDB version less than 2.16.0):

- **X**
  1. Float-scale filter (factor='scale_x', offset='offset_x', scale_float_bytewidth=4)
  2. Delta filter (reinterpret_datatype='INT32')
  3. Bit shuffle filter
  4. Zstd filter (level=7)

- **Y**
  1. Float-scale filter (factor='scale_y', offset='offset_y', scale_float_bytewidth=4)
  2. Delta filter (reinterpret_datatype='INT32')
  3. Bit shuffle filter
  4. Zstd filter (level=7)

- **Z**
  1. Float-scale filter (factor='scale_z', offset='offset_z', scale_float_bytewidth=4)
  2. Delta filter (reinterpret_datatype='INT32')
  3. Bit shuffle filter
  4. Zstd filter (level=7)

- **GPSTime**
  1. Delta filter (reinterpret_datatype='"INT64")
  2. Bit width reduction filter
  3. Zstd filter (level=7)

- **Intensity**
1. Delta filter
2. Zstd filter (level=5)

- BitFields
  1. Zstd filter (level=5)

- ReturnNumber
  1. Zstd filter (level=5)

- NumberOfReturns
  1. Zstd filter (level=5)

- ScanDirectionFlag
  1. Zstd filter (level=5)

- EdgeOfFlightLine
  1. Zstd filter (level=5)

- Classification
  1. Zstd filter (level=5)

- UserData
  1. Zstd filter (level=5)

- PointSourceId
  1. Zstd filter (level=5)

- Red
  1. Delta filter
  2. Bit width reduction filter
  3. Zstd filter (level=7)

- Green
  1. Delta filter
  2. Bit width reduction filter
  3. Zstd filter (level=7)

- Blue
  1. Delta filter
  2. Bit width reduction filter
  3. Zstd filter (level=7)
Filters set by the *aggressive* filter profile (the delta filter is skipped if using TileDB version less than 2.16.0):

- **X**
  1. Float-scale filter (factor=\`scale_x\`, offset=\`offset_x\`, scale_float_bytewidth=4)
  2. Delta filter (reinterpret_datatype=`INT32`)
  3. Bit width reduction filter
  4. BZIP2 filter (level=9)

- **Y**
  1. Float-scale filter (factor=\`scale_y\`, offset=\`offset_y\`, scale_float_bytewidth=4)
  2. Delta filter (reinterpret_datatype=`INT32`)
  3. Bit width reduction filter
  4. BZIP2 filter (level=9)

- **Z**
  1. Float-scale filter (factor=\`scale_z\`, offset=\`offset_z\`, scale_float_bytewidth=4)
  2. Delta filter (reinterpret_datatype=`INT32`)
  3. Bit width reduction filter
  4. BZIP2 filter (level=9)

- **GPSTime**
  1. Delta filter (reinterpret_datatype=``INT64``)
  2. Bit width reduction filter
  3. BZIP2 filter (level=9)

- **Intensity**
  1. Delta filter
  2. Bit width reduction
  3. BZIP2 filter (level=5)

- **BitFields**
  1. BZIP2 filter (level=9)

- **ReturnNumber**

- **NumberOfReturns**
1. BZIP2 filter (level=9)

• ScanDirectionFlag
  1. BZIP2 filter (level=9)

• EdgeOfFlightLine
  1. BZIP2 filter (level=9)

• Classification
  1. BZIP2 filter (level=9)

• UserData
  1. BZIP2 filter (level=9)

• PointSourceId
  1. BZIP2 filter (level=9)

• Red
  1. Delta filter
  2. Bit width reduction filter
  3. BZIP2 filter (level=9)

• Green
  1. Delta filter
  2. Bit width reduction filter
  3. BZIP2 filter (level=9)

• Blue
  1. Delta filter
  2. Bit width reduction filter
  3. BZIP2 filter (level=9)

The filter profile *none* does not set any default filters.

*writers.arrow*  (**page 139**)  
write Apache Arrow Feather- or Parquet-formatted files

*writers.bpf*  (**page 141**)  
write BPF version 3 files. BPF is an NGA specification for point cloud data.

*writers.copc*  (**page 143**)  
COPC, or Cloud Optimized Point Cloud, is an LAZ 1.4 file stored as a clustered octree.
7.4. Writers

**writers.draco** (page 147)
Write a buffer in Google Draco format

**writers.ept_addon** (page 149)
Append additional dimensions to Entwine resources.

**writers.e57** (page 152)
Write data in the E57 format.

**writers.fbi** (page 153)
Write TerraSolid FBI format

**writers.fbx** (page 154)
Write mesh output in the Adobe FBX format.

**writers.gdal** (page 156)
Create a raster from a point cloud using an interpolation algorithm.

**writers.gltf** (page 160)
Write mesh data in GLTF format. Point clouds without meshes cannot be written.

**writers.las** (page 161)
Write ASPRS LAS versions 1.0 - 1.4 formatted data. LAZ support is also available if enabled at compile-time.

**writers.matlab** (page 166)
Write MATLAB .mat files. The output has a single array struct.

**writers.nitf** (page 168)
Write LAS and LAZ point cloud data, wrapped in a NITF 2.1 file.

**writers.null** (page 170)
Provides a sink for points in a pipeline. It's the same as sending pipeline output to /dev/null.

**writers.ogr** (page 171)
Write a point cloud as a set of OGR points/multipoints

**writers.pcd** (page 173)
Write PCD-formatted files in the ASCII, binary, or compressed format.

**writers.pgpointcloud** (page 175)
Write to a PostgreSQL database that has the PostgreSQL Pointcloud extension enabled.

**writers.ply** (page 177)
Write points as PLY vertices. Can also emit a mesh as a set of faces.

**writers.raster** (page 179)
Writes rasters using GDAL. Rasters must be created using a PDAL filter.

**writers.sbet** (page 181)
Write data in the SBET format.
PDAL: Point cloud Data Abstraction Library, Release 2.6.2

*writers.text* (page 182)
Write points in a text file. GeoJSON and CSV formats are supported.

*writers.tiledb* (page 184)
Write points into a TileDB database.

### 7.5 Filters

Filters operate on data as inline operations. They can remove, modify, reorganize, and add points to the data stream as it goes by. Some filters can only operate on dimensions they understand (consider *filters.reprojection* (page 275) doing geographic reprojection on XYZ coordinates), while others do not interrogate the point data at all and simply reorganize or split data.

#### 7.5.1 Create

PDAL filters commonly create new dimensions (e.g., `HeightAboveGround`) or alter existing ones (e.g., `Classification`). These filters will not invalidate an existing KD-tree.

**Note:** We treat those filters that alter XYZ coordinates separately.

**Note:** When creating new dimensions, be mindful of the writer you are using and whether or not the custom dimension can be written to disk if that is the desired behavior.

### Classification

#### Ground/Unclassified

*filters.csf*

The **Cloth Simulation Filter (CSF)** classifies ground points based on the approach outlined in [Zhang2016].

### Default Embedded Stage

This stage is enabled by default
Example

The sample pipeline below uses CSF to segment ground and non-ground returns, using default options, and writing only the ground returns to the output file.

```json
[
  "input.las",
  {
    "type":"filters.csf"
  },
  {
    "type":"filters.range",
    "limits":"Classification[2:2]"
  },
  "output.laz"
]
```

Options

resolution
- Cloth resolution. [Default: 1.0]

ignore
- A range (page 315) of values of a dimension to ignore.

returns
- Return types to include in output. Valid values are “first”, “last”, “intermediate” and “only”. [Default: “last, only”]

threshold
- Classification threshold. [Default: 0.5]

smooth
- Perform slope post-processing? [Default: true]

step
- Time step. [Default: 0.65]

rigidness
- Rigidness. [Default: 3]

iterations
- Maximum number of iterations. [Default: 500]

where
- An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]
where_merge

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.pmf

The Progressive Morphological Filter (PMF) is a method of segmenting ground and non-ground returns. This filter is an implementation of the method described in [Zhang2003].

Default Embedded Stage

This stage is enabled by default

Example

```
[
  "input.las",
  {
    "type": "filters.pmf"
  },
  "output.las"
]
```

Notes

- **slope** (page 196) controls the height threshold at each iteration. A slope of 1.0 represents a 1:1 or 45°.

- **initial_distance** (page 195) is intended to be set to account for z noise, so for a flat surface if you have an uncertainty of around 15 cm, you set `initial_distance` (page 195) large enough to not exclude these points from the ground.

- For a given iteration, the height threshold is determined by multiplying slope by `cell_size` (page 195) by the difference in window size between the current and last iteration, plus the `initial_distance` (page 195). This height threshold is constant across all cells and is maxed out at the `max_distance` (page 196) value. If the difference in elevation between a point and its “opened” value (from the morphological operator) exceeds the height
threshold, it is treated as non-ground. So, bigger slope leads to bigger height thresholds, and these grow with each iteration (not to exceed the max). With flat terrain, keep this low, the thresholds are small, and stuff is more aggressively dumped into non-ground class. In rugged terrain, open things up a little, but then you can start missing buildings, veg, etc.

- Very large `max_window_size` (page 196) values will result in a lot of potentially extra iteration. This parameter can have a strongly negative impact on computation performance.

- `exponential` (page 195) is used to control the rate of growth of morphological window sizes toward `max_window_size` (page 196). Linear growth preserves gradually changing topographic features well, but demands considerable compute time. The default behavior is to grow the window sizes exponentially, thus reducing the number of iterations.

- This filter will mark all returns deemed to be ground returns with a classification value of 2 (per the LAS specification). To extract only these returns, users can add a `range filter` (page 313) to the pipeline.

```json
{
  "type": "filters.range",
  "limits": "Classification[2:2]"
}
```

**Note:** [Zhang2003] describes the consequences and relationships of the parameters in more detail and is the canonical resource on the topic.

### Options

**cell_size**
- Cell Size. [Default: 1]

**exponential**
- Use exponential growth for window sizes? [Default: true]

**ignore**
- Range of values to ignore. [Optional]

**initial_distance**
- Initial distance. [Default: 0.15]

**returns**
- Comma-separated list of return types into which data should be segmented. Valid groups are “last”, “first”, “intermediate” and “only”. [Default: “last, only”]
**max_distance**
Maximum distance. [Default: 2.5]

**max_window_size**
Maximum window size. [Default: 33]

**slope**
Slope. [Default: 1.0]

**where**
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.skewnessbalancing**

**Skewness Balancing** classifies ground points based on the approach outlined in [Bartels2010].

**Default Embedded Stage**
This stage is enabled by default

**Note:** For Skewness Balancing to work well, the scene being processed needs to be quite flat, otherwise many above ground features will begin to be included in the ground surface.

**Example**

The sample pipeline below uses the Skewness Balancing filter to segment ground and non-ground returns, using default options, and writing only the ground returns to the output file.

```json
[
    "input.las",
    {
        "type":"filters.skewnessbalancing"
    }
]
```

(continues on next page)
Options

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

Note: The Skewness Balancing method is touted as being threshold-free. We may still in the future add convenience parameters that are common to other ground segmentation filters, such as returns or ignore to limit the points under consideration for filtering.

filters.smrf

The Simple Morphological Filter (SMRF) classifies ground points based on the approach outlined in [Pingel2013].

Default Embedded Stage

This stage is enabled by default
Example #1

The sample pipeline below uses the SMRF filter to segment ground and non-ground returns, using default options, and writing only the ground returns to the output file.

```json
[  
   "input.las",
   {
      "type":"filters.smrf"
   },
   {
      "type":"filters.range",
      "limits":"Classification[2:2]"
   },
   "output.laz"
]
```

Example #2

A more complete example, specifying some options. These match the optimized parameters for Sample 1 given in Table 3 of [Pingel2013].

```json
[  
   "input.las",
   {
      "type":"filters.smrf",
      "scalar":1.2,
      "slope":0.2,
      "threshold":0.45,
      "window":16.0
   },
   {
      "type":"filters.range",
      "limits":"Classification[2:2]"
   },
   "output.laz"
]
```
Options

**cell**
Cell size. [Default: 1.0]

**classbits**
Selectively ignore points marked as “synthetic”, “keypoint”, or “withheld”. [Default: empty string, use all points]

**cut**
Cut net size (cut=0 skips the net cutting step). [Default: 0.0]

**dir**
Optional output directory for debugging intermediate rasters.

**ignore**
A *range* (page 315) of values of a dimension to ignore.

**returns**
Return types to include in output. Valid values are “first”, “last”, “intermediate” and “only”. [Default: “last, only”]

**scalar**
Elevation scalar. [Default: 1.25]

**slope**
Slope (rise over run). [Default: 0.15]

**threshold**
Elevation threshold. [Default: 0.5]

**window**
Max window size. [Default: 18.0]

**where**
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]
filters.trajectory

The trajectory filter computes an estimate of the sensor location based on the position of multiple returns and the sensor scan angle. It is primarily useful for LAS input as it requires scan angle and return counts in order to work.

The method is described in detail here. It extends the method of [GM19].

Note: This filter creates a new dataset describing the trajectory of the sensor, replacing the input dataset.

Examples

```json
[
    "input.las",
    {
        "type": "filters.trajectory"
    },
    "trajectory.las"
]
```

Options

dtr
Multi-return sampling interval in seconds. [Default: .001]

dst
Single-return sampling interval in seconds. [Default: .001]

minsep
Minimum separation of returns considered in meters. [Default: .01]

tblock
Block size for cubic spline in seconds. [Default: 1.0]

tout
Output data interval in seconds. [Default: .01]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard
mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

`filters.csf` *(page 192)*
Label ground/non-ground returns using [Zhang2016].

`filters.pmf` *(page 194)*
Label ground/non-ground returns using [Zhang2003].

`filters.skewnessbalancing` *(page 196)*
Label ground/non-ground returns using [Bartels2010].

`filters.smrf` *(page 197)*
Label ground/non-ground returns using [Pingel2013].

`filters.trajectory` *(page 200)*
Label ground/non-ground returns using estimate flight trajectory given multi-return point cloud data with timing information.

### Noise

**`filters.elm`**

The Extended Local Minimum (ELM) filter marks low points as noise. This filter is an implementation of the method described in [Chen2012].

ELM begins by rasterizing the input point cloud data at the given `cell` (page 203) size. Within each cell, the lowest point is considered noise if the next lowest point is a given threshold above the current point. If it is marked as noise, the difference between the next two points is also considered, marking points as noise if needed, and continuing until another neighbor is found to be within the threshold. At this point, iteration for the current cell stops, and the next cell is considered.

---

**Default Embedded Stage**

This stage is enabled by default

---

7.5. Filters
Example #1

The following PDAL pipeline applies the ELM filter, using a cell (page 203) size of 20 and applying the classification (page 203) code of 18 to those points determined to be noise.

```json
{
    "pipeline": [
        "input.las",
        {
            "type": "filters.elm",
            "cell": 20.0,
            "class": 18
        },
        "output.las"
    ]
}
```

Example #2

This variation of the pipeline begins by assigning a value of 0 to all classifications, thus resetting any existing classifications. It then proceeds to compute ELM with a threshold (page 203) value of 2.0, and finishes by extracting all returns that are not marked as noise.

```json
[  
    "input.las",
    {
        "type": "filters.assign",
        "assignment": "Classification[:]=0"
    },
    {
        "type": "filters.elm",
        "threshold": 2.0
    },
    {
        "type": "filters.range",
        "limits": "Classification![:7:][7:7]"
    },
    "output.las"
]
```
Options

**cell**
Cell size. [Default: 10.0]

**class**
Classification value to apply to noise points. [Default: 7]

**threshold**
Threshold value to identify low noise points. [Default: 1.0]

**where**
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.outlier**

The **outlier filter** provides two outlier filtering methods: radius and statistical. These two approaches are discussed in further detail below.

It is worth noting that both filtering methods simply apply a classification value of 7 to the noise points (per the LAS specification (http://www.asprs.org/a/society/committees/standards/LAS_1_4_r13.pdf)). To remove the noise points altogether, users can add a `range filter` (page 313) to their pipeline, downstream from the outlier filter.

**Default Embedded Stage**

This stage is enabled by default

```json
{
    "type":"filters.range",
    "limits":"Classification![7:7]"
}
```
Statistical Method

The default method for identifying outlier points is the statistical outlier method. This method requires two passes through the input PointView, first to compute a threshold value based on global statistics, and second to identify outliers using the computed threshold.

In the first pass, for each point $p_i$ in the input PointView, compute the mean distance $\mu_i$ to each of the $k$ nearest neighbors (where $k$ is configurable and specified by mean_k (page 207)). Then,

$$
\bar{\mu} = \frac{1}{N} \sum_{i=1}^{N} \mu_i
$$

$$
\sigma = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (\mu_i - \bar{\mu})^2}
$$

A global mean $\bar{\mu}$ of these mean distances is then computed along with the standard deviation $\sigma$. From this, the threshold is computed as

$$
t = \mu + m\sigma
$$

where $m$ is a user-defined multiplier specified by multiplier (page 207).

We now iterate over the pre-computed mean distances $\mu_i$ and compare to computed threshold value. If $\mu_i$ is greater than the threshold, it is marked as an outlier.

$$
outlier_i = \begin{cases} 
true, & \text{if } \mu_i \geq t \\
false, & \text{otherwise}
\end{cases}
$$

Before outlier removal, noise points can be found both above and below the scene.

After outlier removal, the noise points are removed.

See [Rusu2008] for more information.

Example

In this example, points are marked as outliers if the average distance to each of the 12 nearest neighbors is below the computed threshold.

```json
[
  "input.las",
  {
    "type":"filters.outlier",
    "method":"statistical",
    "mean_k":20
  }
]
```
Radius Method

For each point $p_i$ in the input PointView, this method counts the number of neighboring points $k_i$ within radius $r$ (specified by radius (page 207)). If $k_i < k_{\text{min}}$, where $k_{\text{min}}$ is the minimum number of neighbors specified by $\text{min}_k$ (page 206), it is marked as an outlier.

\[
\text{outlier}_i = \begin{cases} 
\text{true}, & \text{if } k_i < k_{\text{min}} \\
\text{false}, & \text{otherwise}
\end{cases}
\]

Example

The following example will mark points as outliers when there are fewer than four neighbors within a radius of 1.0.

```json
[
    "input.las",
    {
        "type": "filters.outlier",
        "method": "radius",
        "radius": 1.0,
        "min_k": 4
    },
    "output.las"
]
```

Options

**class**

The classification value to apply to outliers. [Default: 7]

**method**

The outlier removal method (either “statistical” or “radius”). [Default: “statistical”]

**min_k**

Minimum number of neighbors in radius (radius method only). [Default: 2]
radius
   Radius (radius method only). [Default: 1.0]

mean_k
   Mean number of neighbors (statistical method only). [Default: 8]

multiplier
   Standard deviation threshold (statistical method only). [Default: 2.0]

where
   An expression that limits points passed to a filter. Points that don’t pass the expression
   skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
   A strategy for merging points skipped by a ‘where’ option when running in standard
   mode. If true, the skipped points are added to the first point view returned by the
   skipped filter. If false, skipped points are placed in their own point view. If auto,
   skipped points are merged into the returned point view provided that only one point view
   is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.elm (page 201)
   Marks low points as noise.

filters.outlier (page 203)
   Label noise points using either a statistical or radius outlier detection.

Consensus

filters.neighborclassifier

The neighborclassifier filter allows you update the value of the classification for specific
points to a value determined by a K-nearest neighbors vote. For each point, the k (page 208)
nearest neighbors are queried and if more than half of them have the same value, the filter
updates the selected point accordingly

For example, if an automated classification procedure put/left erroneous vegetation points near
the edges of buildings which were largely classified correctly, you could try using this filter to
fix that problem.

Similarly, some automated classification processes result in prediction for only a subset of the
original point cloud. This filter could be used to extrapolate those predictions to the original.

Default Embedded Stage

This stage is enabled by default

---

7.5. Filters 207
Example 1

This pipeline updates the Classification of all points with classification 1 (unclassified) based on the consensus (majority) of its nearest 10 neighbors.

```json
[  
  "autzen_class.las",
  {
    "type" : "filters.neighborclassifier",
    "domain" : "Classification[1:1]",
    "k" : 10
  },
  "autzen_class_refined.las"
]
```

Example 2

This pipeline moves all the classifications from “pred.txt” to src.las. Any points in src.las that are not in pred.txt will be assigned based on the closest point in pred.txt.

```json
[  
  "src.las",
  {
    "type" : "filters.neighborclassifier",
    "k" : 1,
    "candidate" : "pred.txt"
  },
  "dest.las"
]
```

Options

candidate
A filename which points to the point cloud containing the points which will do the voting. If not specified, defaults to the input of the filter.

domain
A range (page 315) which selects points to be processed by the filter. Can be specified multiple times. Points satisfying any range will be processed.

k
An integer which specifies the number of neighbors which vote on each selected point.
where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

`filters.neighborclassifier` (page 207)
Update pointwise classification using k-nearest neighbor consensus voting.

**Height Above Ground**

`filters.hag_delaunay`

The **Height Above Ground Delaunay filter** takes as input a point cloud with Classification set to 2 for ground points. It creates a new dimension, HeightAboveGround, that contains the normalized height values.

**Note:** We expect ground returns to have the classification value of 2 in keeping with the ASPRS Standard LIDAR Point Classes (http://www.asprs.org/a/society/committees/standards/LAS_1_4_r13.pdf).

Ground points may be generated by `filters.pmf` (page 194) or `filters.smrf` (page 197), but you can use any method you choose, as long as the ground returns are marked.

Normalized heights are a commonly used attribute of point cloud data. This can also be referred to as height above ground (HAG) or above ground level (AGL) heights. In the end, it is simply a measure of a point’s relative height as opposed to its raw elevation value.

The filter creates a delaunay triangulation of the `count` (page 211) ground points closest to the non-ground point in question. If the non-ground point is within the triangulated area, the assigned HeightAboveGround is the difference between its Z value and a ground height interpolated from the three vertices of the containing triangle. If the non-ground point is outside of the triangulated area, its HeightAboveGround is calculated as the difference between its Z value and the Z value of the nearest ground point.

Choosing a value for `count` (page 211) is difficult, as placing the non-ground point in the triangulated area depends on the layout of the nearby points. If, for example, all the ground points near a non-ground point lay on one side of that non-ground point, finding a containing triangle will fail.
Default Embedded Stage

This stage is enabled by default

Example #1

Using the autzen dataset (here shown colored by elevation), which already has points classified as ground

we execute the following pipeline

```
[  
  "autzen.laz",
  {
    "type": "filters.hag_delaunay"
  },
  {
    "type": "writers.laz",
    "filename": "autzen_hag_delaunay.laz",
    "extra_dims": "HeightAboveGround=float32"
  }
]
```

(continues on next page)
which is equivalent to the pdal translate command

```
$ pdal translate autzen.laz autzen_hag_delaunay.laz hag_delaunay \
   --writers.las.extra_dims="HeightAboveGround=float32"
```

In either case, the result, when colored by the normalized height instead of elevation is

![Image](image.jpg)

### Options

**count**

The number of ground neighbors to consider when determining the height above ground for a non-ground point. [Default: 10]

**allow_extrapolation**

If false and a non-ground point lies outside of the bounding box of all ground points, its HeightAboveGround is set to 0. If true and delaunay is set, the HeightAboveGround is set to the difference between the heights of the non-ground point and nearest ground point. [Default: false]
where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.hag_dem
The Height Above Ground (HAG) Digital Elevation Model (DEM) filter loads a GDAL-readable raster image specifying the DEM. The Z value of each point in the input is compared against the value at the corresponding X,Y location in the DEM raster. It creates a new dimension, HeightAboveGround, that contains the normalized height values.

Normalized heights are a commonly used attribute of point cloud data. This can also be referred to as height above ground (HAG) or above ground level (AGL) heights. In the end, it is simply a measure of a point’s relative height as opposed to its raw elevation value.

Default Embedded Stage
This stage is enabled by default

Streamable Stage
This stage supports streaming operations

Example #1
Using the autzen dataset (here shown colored by elevation)
we generate a DEM based on the points already classified as ground

```
$ pdal translate autzen.laz autzen_dem.tif range
   --filters.range.limits="Classification[2:2]"
   --writers.gdal.output_type="idw"
   --writers.gdal.resolution=6
   --writers.gdal.window_size=24
```

and execute the following pipeline

```
[
    "autzen.laz",
    {
        "type": "filters.hag_dem",
        "raster": "autzen_dem.tif"
    },
    {
        "type": "writers.las",
        "filename": "autzen_hag_dem.laz",
        "extra_dims": "HeightAboveGround=float32"
    }
]
```

which is equivalent to the `pdal translate` command

### 7.5. Filters
In either case, the result, when colored by the normalized height instead of elevation is

![Image of colored data]

**Options**

- **raster**
  GDAL-readable raster to use for DEM.

- **band**
  GDAL Band number to read (count from 1). [Default: 1]

- **zero_ground**
  If true, set HAG of ground-classified points to 0 rather than comparing Z value to raster DEM. [Default: true]

- **where**
  An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

- **where_merge**
  A strategy for merging points skipped by a ‘where’ option when running in standard
mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.hag_nn**

The **Height Above Ground Nearest Neighbor filter** takes as input a point cloud with Classification set to 2 for ground points. It creates a new dimension, HeightAboveGround, that contains the normalized height values.

---

**Note:** We expect ground returns to have the classification value of 2 in keeping with the ASPRS Standard LIDAR Point Classes (http://www.asprs.org/a/society/committees/standards/LAS_1_4_r13.pdf).

Ground points may be generated by filters.pmf (page 194) or filters.smrf (page 197), but you can use any method you choose, as long as the ground returns are marked.

Normalized heights are a commonly used attribute of point cloud data. This can also be referred to as **height above ground** (HAG) or **above ground level** (AGL) heights. In the end, it is simply a measure of a point’s relative height as opposed to its raw elevation value.

The filter finds the count (page 218) ground points nearest the non-ground point under consideration. It calculates an average ground height weighted by the distance of each ground point from the non-ground point. The HeightAboveGround is the difference between the Z value of the non-ground point and the interpolated ground height.

---

**Default Embedded Stage**

This stage is enabled by default

---

**Example #1**

Using the autzen dataset (here shown colored by elevation), which already has points classified as ground
we execute the following pipeline

```
[  
    "autzen.laz",
    {  
      "type":"filters.hag_nn"
    },
    {  
      "type":"writers.laz",
      "filename":"autzen_hag_nn.laz",
      "extra_dims":"HeightAboveGround=fp32"
    }
]
```

which is equivalent to the pdal translate command

```
$ pdal translate autzen.laz autzen_hag_nn.laz hag_nn \
   --writers.las.extra_dims="HeightAboveGround=float32"
```

In either case, the result, when colored by the normalized height instead of elevation is
Example #2

In the previous example, we chose to write HeightAboveGround using the extra_dims option of `writers.las` (page 161). If you'd instead like to overwrite your Z values, then follow the height filter with `filters.ferry` (page 258) as shown

```json
[  
  "autzen.laz",
  {  
    "type":"filters.hag_nn"
  },
  {  
    "type":"filters.ferry",
    "dimensions":"HeightAboveGround=>Z"
  },
  "autzen-height-as-Z.laz"
]
```
Example #3

If you don’t yet have points classified as ground, start with filters.pmf (page 194) or filters.smrf (page 197) to label ground returns, as shown

```
[  
  "autzen.laz",  
  {   
    "type": "filters.smrf"  
  },  
  {   
    "type": "filters.hag_nn"  
  },  
  {   
    "type": "filters.ferry",   
    "dimensions": "HeightAboveGround=>Z"  
  },  
  "autzen-height-as-Z-smrf.laz"  
]
```

**Options**

- **count**
  The number of ground neighbors to consider when determining the height above ground for a non-ground point. [Default: 1]

- **max_distance**
  Use only ground points within max_distance of non-ground point when performing neighbor interpolation. [Default: None]

- **allow_extrapolation**
  If false and a non-ground point lies outside of the bounding box of all ground points, its HeightAboveGround is set to 0. If true, extrapolation is used to assign the HeightAboveGround value. [Default: false]

- **where**
  An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

- **where_merge**
  A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view
is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.hag_delaunay (page 209)**
Compute pointwise height above ground using triangulation. Requires points to classified as ground/non-ground prior to estimating.

**filters.hag_dem (page 212)**
Compute pointwise height above GDAL-readable DEM raster.

**filters.hag_nn (page 215)**
Compute pointwise height above ground estimate. Requires points to be classified as ground/non-ground prior to estimating.

**Colorization**

**filters.colorinterp**

The color interpolation filter assigns scaled RGB values from an image based on a given dimension. It provides three possible approaches:

1. You provide a **minimum** (page 222) and **maximum** (page 222), and the data are scaled for the given **dimension** (page 222) accordingly.

2. You provide a **k** (page 222) and a **mad** (page 222) setting, and the scaling is set based on Median Absolute Deviation.

3. You provide a **k** (page 222) setting and the scaling is set based on the **k** (page 222)-number of standard deviations from the median.

You can provide your own GDAL (http://www.gdal.org)-readable image for the scale color factors, but a number of pre-defined ramps are embedded in PDAL. The default ramps provided by PDAL are 256x1 RGB images, and might be a good starting point for creating your own scale factors. See **Default Ramps** (page 220) for more information.

**Note:** **filters.colorinterp** (page 219) will use the entire band to scale the colors.

**Default Embedded Stage**

This stage is enabled by default
Example

```
[  
    "uncolored.las",
    {  
        "type": "filters.colorinterp",
        "ramp": "pestel_shades",
        "mad": true,
        "k": 1.8,
        "dimension": "Z"
    },
    "colorized.las"
]
```

Fig. 4: Image data with interpolated colors based on Z dimension and pestel_shades ramp.

**Default Ramps**

PDAL provides a number of default color ramps you can use in addition to providing your own. Give the ramp name as the `ramp` (page 222) option to the filter and it will be used. Otherwise, provide a GDAL (http://www.gdal.org)-readable raster filename.
awesome_green

black_orange

blue_orange

blue_hue

blue_orange

blue_red

heat_map

pestel_shades

7.5. Filters
Options

ramp
The raster file to use for the color ramp. Any format supported by GDAL (http://www.gdal.org) may be read. Alternatively, one of the default color ramp names can be used. [Default: “pestel_shades”]

dimension
A dimension name to use for the values to interpolate colors. [Default: “Z”]

minimum
The minimum value to use to scale the data. If none is specified, one is computed from the data. If one is specified but a $k$ value is also provided, the $k$ value will be used.

maximum
The maximum value to use to scale the data. If none is specified, one is computed from the data. If one is specified but a $k$ value is also provided, the $k$ value will be used.

invert
Invert the direction of the ramp? [Default: false]

k
Color based on the given number of standard deviations from the median. If set, $minimum$ and $maximum$ will be computed from the median and setting them will have no effect.

mad
If true, $minimum$ and $maximum$ will be computed by the median absolute deviation. See filters.mad (page 300) for discussion. [Default: false]

mad_multiplier
MAD threshold multiplier. Used in conjunction with $k$ to threshold the differencing. [Default: 1.4862]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]
The colorization filter populates dimensions in the point buffer using input values read from a raster file. Commonly this is used to add Red/Green/Blue values to points from an aerial photograph of an area. However, any band can be read from the raster and applied to any dimension name desired.

Fig. 5: After colorization, points take on the colors provided by the input image

**Note:** GDAL (http://www.gdal.org) is used to read the color information and any GDAL-readable supported format (https://www.gdal.org/formats_list.html) can be read.

The bands of the raster to apply to each are selected using the “band” option, and the values of the band may be scaled before being written to the dimension. If the band range is 0-1, for example, it might make sense to scale by 256 to fit into a traditional 1-byte color value range.

### Default Embedded Stage
This stage is enabled by default

### Streamable Stage
This stage supports streaming operations
Example

```
[  
    "uncolored.las",
    {  
        "type": "filters.colorization",
        "dimensions": "Red:1:1.0, Blue, Green::256.0",
        "raster": "aerial.tif"
    },
    "colorized.las"
]
```

Considerations

Certain data configurations can cause degenerate filter behavior. One significant knob to adjust is the GDAL\_CACHEMAX environment variable. One driver which can have issues is when a TIFF (http://www.gdal.org/frmt_gtiff.html) file is striped vs. tiled. GDAL’s data access in that situation is likely to cause lots of re-reading if the cache isn’t large enough.

Consider a striped TIFF file of 286mb:

```
-rw-r-----@ 1 hobu staff 286M Oct 29 16:58 orth-striped.tif
```

```
[  
    "colourless.laz",
    {  
        "type": "filters.colorization",
        "raster": "orth-striped.tif"
    },
    "coloured-striped.las"
]
```

Simple application of the filters.colorization (page 223) using the striped TIFF (http://www.gdal.org/frmt_gtiff.html) with a 268mb readers.las (page 89) file will take nearly 1:54.

```
[hobu@pyro knudsen (master)]$ time ~/dev/git/pdal/bin/pdal pipeline -i striped.json
real 1m53.477s
user 1m20.018s
sys 0m33.397s
```
Setting the `GDAL_CACHEMAX` variable to a size larger than the TIFF file dramatically speeds up the color fetching:

```
[hobu@pyro knudsen (master)]$ export GDAL_CACHEMAX=500
[hobu@pyro knudsen (master)]$ time ~/dev/git/pdal/bin/pdal pipeline →striped.json
real   0m19.034s
user   0m15.557s
sys    0m1.102s
```

### Options

**raster**

The raster file to read the band from. Any format (https://www.gdal.org/formats_list.html) supported by GDAL (http://www.gdal.org) may be read.

**dimensions**

A comma separated list of dimensions to populate with values from the raster file. Dimensions will be created if they don't already exist. The format of each dimension is `<name>:<band_number>:<scale_factor>`. Either or both of band number and scale factor may be omitted as may ‘:’ separators if the data is not ambiguous. If not supplied, band numbers begin at 1 and increment from the band number of the previous dimension. If not supplied, the scaling factor is 1.0. [Default: “Red:1:1.0, Green:2:1.0, Blue:3:1.0”]

**where**

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.colorinterp** *(page 219)*

Assign RGB colors based on a dimension and a ramp

**filters.colorization** *(page 223)*

Fetch and assign RGB color information from a GDAL-readable datasource.
Clustering

**filters.cluster**

The Cluster filter first performs Euclidean Cluster Extraction on the input PointView and then labels each point with its associated cluster ID. It creates a new dimension ClusterID that contains the cluster ID value. Cluster IDs start with the value 1. Points that don’t belong to any cluster will are given a cluster ID of 0.

**Default Embedded Stage**

This stage is enabled by default.

**Example**

```json
[
    "input.las",
    {
        "type": "filters.cluster"
    },
    {
        "type": "writers.bpf",
        "filename": "output.bpf",
        "output_dims": "X,Y,Z,ClusterID"
    }
]
```

**Options**

- **min_points**
  Minimum number of points to be considered a cluster. [Default: 1]

- **max_points**
  Maximum number of points to be considered a cluster. [Default: $2^{64} - 1$]

- **tolerance**
  Cluster tolerance - maximum Euclidean distance for a point to be added to the cluster. [Default: 1.0]

- **is3d**
  By default, clusters are formed by considering neighbors in a 3D sphere, but if is3d is
set to false, it will instead consider neighbors in a 2D cylinder (XY plane only). [Default: true]

**where**
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.dbscan**
The DBSCAN filter performs Density-Based Spatial Clustering of Applications with Noise (DBSCAN) [Ester1996] and labels each point with its associated cluster ID. Points that do not belong to a cluster are given a Cluster ID of -1. The remaining clusters are labeled as integers starting from 0.

**Default Embedded Stage**
This stage is enabled by default

New in version 2.1.

**Example**

```
[
    "input.las",
    {
        "type": "filters.dbscan",
        "min_points": 10,
        "eps": 2.0,
        "dimensions": "X,Y,Z"
    },
    {
        "type": "writers.bpf",
        "filename": "output.bpf",
        "output_dims": "X,Y,Z,ClusterID"
    }
]
```

(continues on next page)
Options

min_points
The minimum cluster size \texttt{min\_points} should be greater than or equal to the number of dimensions (e.g., X, Y, and Z) plus one. As a rule of thumb, two times the number of dimensions is often used. [Default: 6]

eps
The epsilon parameter can be estimated from a k-distance graph (for \( k = \texttt{min\_points} \) minus one). \texttt{eps} defines the Euclidean distance that will be used when searching for neighbors. [Default: 1.0]

dimensions
Comma-separated string indicating dimensions to use for clustering. [Default: X,Y,Z]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘\texttt{where}’ option when running in standard mode. If \texttt{true}, the skipped points are added to the first point view returned by the skipped filter. If \texttt{false}, skipped points are placed in their own point view. If \texttt{auto}, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: \texttt{auto}]

filters.litree

The purpose of the Li tree filter is to segment individual trees from an input \texttt{PointView}. In the output \texttt{PointView} points that are deemed to be part of a tree are labeled with a \texttt{ClusterID}. Tree IDs start at 1, with non-tree points given a \texttt{ClusterID} of 0.

\textbf{Note:} The filter differs only slightly from the paper in the addition of a few conditions on size of tree, minimum height above ground for tree seeding, and flexible radius for non-tree seed insertion.

\textbf{Note:} In earlier PDAL releases (up to v2.2.0), \texttt{ClusterID} was stored in the \texttt{TreeID}
Dimension.

Default Embedded Stage

This stage is enabled by default

Example

The Li tree algorithm expects to visit points in descending order of HeightAboveGround, which is also used in determining the minimum tree height to consider. As such, the following pipeline precomputes HeightAboveGround using filters.hag_delaunay (page 209) and subsequently sorts the PointView using this dimension.

```
[  
  "input.las",
  {
    "type":"filters.hag_delaunay"
  },
  {
    "type":"filters.sort",
    "dimension":"HeightAboveGround",
    "order":"DESC"
  },
  {
    "type":"filters.litree",
    "min_points":50,
    "min_height":10.0,
    "radius":200.0
  },
  {
    "type":"writers.las",
    "filename":"output.laz",
    "minor_version":1.4,
    "extra_dims":"all"
  }
]
```
Options

min_points
Minimum number of points in a tree cluster. [Default: 10]

min_height
Minimum height above ground to start a tree cluster. [Default: 3.0]

radius
The seed point for the non-tree cluster is the farthest point in a 2D Euclidean sense from the seed point for the current tree. [Default: 100.0]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.lloydkmeans

K-means clustering using Lloyd’s algorithm labels each point with its associated cluster ID (starting at 0).

Default Embedded Stage

This stage is enabled by default

New in version 2.1.

Example

```json
[
    "input.las",
    {
        "type":"filters.lloydkmeans",
        "k":10,
        "maxiters":20,
    }
]```

(continues on next page)
Options

\[ \text{k} \]
The desired number of clusters. [Default: 10]

\[ \text{maxiters} \]
The maximum number of iterations. [Default: 10]

\[ \text{dimensions} \]
Comma-separated string indicating dimensions to use for clustering. [Default: X,Y,Z]

\[ \text{where} \]
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

\[ \text{where_merge} \]
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

\[ \text{filters.cluster} \ (\text{page} \ 226) \]
Extract and label clusters using Euclidean distance metric. Returns a new dimension ClusterID that indicates the cluster that a point belongs to. Points not belonging to a cluster are given a cluster ID of 0.

\[ \text{filters.dbscan} \ (\text{page} \ 227) \]
Perform Density-Based Spatial Clustering of Applications with Noise (DBSCAN) [Ester1996].

\[ \text{filters.litree} \ (\text{page} \ 228) \]
Segment and label individual trees. Returns a new dimension TreeID that indicates the
tree that a point belongs to. TreeID starts at 1, which non-tree points given a TreeID of 0. [Li2012].

**filters.lloydkmeans** *(page 230)*
Perform K-means clustering using Lloyd’s algorithm. Returns a new dimension ClusterID with each point being assigned to a cluster. ClusterID starts at 0. [Lloyd1982].

**Pointwise Features**

**filters.approximatecoplanar**

The approximate coplanar filter implements a portion of the algorithm presented in [Limberger2015]. Prior to clustering points, the authors first apply an approximate coplanarity test, where points that meet the following criteria are labeled as approximately coplanar.

\[
\lambda_2 > (s_\alpha \lambda_1) \&\& (s_\beta \lambda_2) > \lambda_3
\]

\(\lambda_1, \lambda_2, \lambda_3\) are the eigenvalues of a neighborhood of points (defined by knn nearest neighbors) in ascending order. The threshold values \(s_\alpha\) and \(s_\beta\) are user-defined and default to 25 and 6 respectively.

The filter returns a point cloud with a new dimension Coplanar that indicates those points that are part of a neighborhood that is approximately coplanar (1) or not (0).

**Default Embedded Stage**

This stage is enabled by default

**Example**

The sample pipeline presented below estimates the planarity of a point based on its eight nearest neighbors using the approximate coplanar filter. A filters.range *(page 313)* stage then filters out any points that were not deemed to be coplanar before writing the result in compressed LAZ.

```json
{
    "input.las",
    "type": "filters.approximatecoplanar",
    "knn": 8,
    "thresh1": 25,
    "thresh2": 6
}
```

(continues on next page)
Options

**knn**

The number of k-nearest neighbors. [Default: 8]

**thresh1**

The threshold to be applied to the smallest eigenvalue. [Default: 25]

**thresh2**

The threshold to be applied to the second smallest eigenvalue. [Default: 6]

**where**

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.covariancefeatures**

This filter implements various local feature descriptors that are based on the covariance matrix of a point’s neighborhood.

The user can pick a set of feature descriptors by setting the feature_set option. The **dimensionality** (page 236) set of feature descriptors introduced below is the default. The user can also provide a comma-separated list of features to explicitly itemize those covariance features they wish to be computed. This can be combined with any supported presets like “Dimensionality”. Specifying “all” will compute all available features.

Supported features include:
• Anisotropy
• DemantkeVerticality
• Density
• Eigenentropy
• Linearity
• Omnipassivity
• Planarity
• Scattering
• EigenvalueSum
• SurfaceVariation
• Verticality

Note: Density requires both OptimalKNN and OptimalRadius which can be computed by running filters.optimalneighborhood (page 246) prior to filters.covariancefeatures.

Example #1

```
[  
  "input.las",
  
  
    
  "type": "filters.covariancefeatures",
  "knn": 8,
  "threads": 2,
  "feature_set": "Dimensionality"

  
  
  },
  
  
    
  "type": "writers.bpf",
  "filename": "output.bpf",
  "output_dims": "X,Y,Z,Linearity,Planarity,Scattering,Verticality"

  ]
```
Example #2

```
[  
  "input.las",
  {
    "type": "filters.optimalneighborhood"
  },
  {
    "type": "filters.covariancefeatures",
    "knn": 8,
    "threads": 2,
    "optimized": true,
    "feature_set": "Linearity,Omnivariance,Density"
  },
  {
    "type": "writers.las",
    "minor_version": 4,
    "extra_dims": "all",
    "forward": "all",
    "filename": "output.las"
  }
]
```

**Options**

**knn**
The number of k nearest neighbors used for calculating the covariance matrix. [Default: 10]

**threads**
The number of threads used for computing the feature descriptors. [Default: 1]

**feature_set**
A comma-separated list of individual features or feature presets (e.g., “Dimensionality”) to be computed. To compute all available features, specify “all”. [Default: “Dimensionality”]

**stride**
When finding k nearest neighbors, stride determines the sampling rate. A stride of 1 retains each neighbor in order. A stride of two selects every other neighbor and so on. [Default: 1]

**min_k**
Minimum number of neighbors in radius (radius search only). [Default: 3]
radius
If radius is specified, neighbors will be obtained by radius search rather than k nearest
neighbors, subject to meeting the minimum number of neighbors (min_k).

mode
By default, features are computed using the standard deviation along each eigenvector,
i.e., using the square root of the computed eigenvalues (mode="SQRT"). mode also
accepts “Normalized” which normalizes eigenvalue such that they sum to one, or “Raw”
such that the eigenvalues are used directly. [Default: “SQRT”]

optimized
optimized can be set to true to enable computation of features using precomputed
optimal neighborhoods (found in the OptimalKNN dimension). Requires
filters.optimalneighborhood (page 246) be run prior to this stage. [Default: false]

where
An expression that limits points passed to a filter. Points that don’t pass the expression
skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard
mode. If true, the skipped points are added to the first point view returned by the
skipped filter. If false, skipped points are placed in their own point view. If auto,
skipped points are merged into the returned point view provided that only one point view
is returned and it has the same point count as it did when the filter was run. [Default: auto]

Dimensionality feature set
The features introduced in [Demantke2011] describe the shape of the neighborhood, indicating
whether the local geometry is more linear (1D), planar (2D) or volumetric (3D) while the one
introduced in [Guinard2017] adds the idea of a structure being vertical.

The dimensionality filter introduces the following four descriptors that are computed from the
covariance matrix of a point’s neighbors (as defined by knn or radius):

- linearity - higher for long thin strips
- planarity - higher for planar surfaces
- scattering - higher for complex 3d neighbourhoods
- verticality - higher for vertical structures, highest for thin vertical strips

It introduces four new dimensions that hold each one of these values: Linearity, Planarity,
Scattering and Verticality.
The `eigenvalues` filter returns the eigenvalues for a given point, based on its k-nearest neighbors. The filter produces three new dimensions (Eigenvalue0, Eigenvalue1, and Eigenvalue2), which can be analyzed directly, or consumed by downstream stages for more advanced filtering. The eigenvalues are sorted in ascending order.

The eigenvalue decomposition is performed using Eigen's `SelfAdjointEigenSolver` (https://eigen.tuxfamily.org/dox/classEigen_1_1SelfAdjointEigenSolver.html).

### Default Embedded Stage

This stage is enabled by default

### Example

This pipeline demonstrates the calculation of the eigenvalues. The newly created dimensions are written out to BPF for further inspection.

```json
[
    "input.las",
    {
        "type": "filters.eigenvalues",
        "knn": 8
    },
    {
        "type": "writers.bpf",
        "filename": "output.bpf",
        "output_dims": "X,Y,Z,Eigenvalue0,Eigenvalue1,Eigenvalue2"
    }
]
```

### Options

**knn**

The number of k-nearest neighbors. [Default: 8]

**normalize**

Normalize eigenvalues such that the sum is 1. [Default: false]

**where**

An expression that limits points passed to a filter. Points that don’t pass the expression
skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.estimaterank**

The **rank estimation filter** uses singular value decomposition (SVD) to estimate the rank of a set of points. Point sets with rank 1 correspond to linear features, while sets with rank 2 correspond to planar features. Rank 3 corresponds to a full 3D feature. In practice this can be used alone, or possibly in conjunction with other filters to extract features (e.g., buildings, vegetation).

Two parameters are required to estimate rank (though the default values will be suitable in many cases). First, the `knn` (page 239) parameter defines the number of points to consider when computing the SVD and estimated rank. Second, the `thresh` (page 239) parameter is used to determine when a singular value shall be considered non-zero (when the absolute value of the singular value is greater than the threshold).

The rank estimation is performed on a pointwise basis, meaning for each point in the input point cloud, we find its `knn` (page 239) neighbors, compute the SVD, and estimate rank. The filter creates a new dimension called Rank that can be used downstream of this filter stage in the pipeline. The type of writer used will determine whether or not the Rank dimension itself can be saved to disk.

**Default Embedded Stage**

This stage is enabled by default

**Example**

This sample pipeline estimates the rank of each point using this filter and then filters out those points where the rank is three using **filters.range** (page 313).

```json
[
    "input.las",
    {
        "type":"filters.estimaterank",
```
Options

**knn**
The number of k-nearest neighbors. [Default: 8]

**thresh**
The threshold used to identify nonzero singular values. [Default: 0.01]

**where**
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.lof**

The Local Outlier Factor (LOF) filter was introduced as a method of determining the degree to which an object is an outlier. This filter is an implementation of the method described in [Breunig2000].

The filter creates three new dimensions, **NNDistance**, **LocalReachabilityDistance** and **LocalOutlierFactor**, all of which are double-precision floating values. The **NNDistance** dimension records the Euclidean distance between a point and its k-th nearest neighbor (the number of k neighbors is set with the **minpts** (page 241) option). The **LocalReachabilityDistance** is the inverse of the mean of all reachability distances for a neighborhood of points. This reachability distance is defined as the max of the Euclidean distance to a neighboring point and that neighbor’s own previously computed **NNDistance**.

7.5. Filters 239
Finally, each point has a LocalOutlierFactor which is the mean of all LocalReachabilityDistance values for the neighborhood. In each case, the neighborhood is the set of \( k \) nearest neighbors.

In practice, setting the \textit{minpts} (page 241) parameter appropriately and subsequently filtering outliers based on the computed LocalOutlierFactor can be difficult. The authors present some work on establishing upper and lower bounds on LOF values, and provide some guidelines on selecting \textit{minpts} (page 241) values, which users of this filter should find instructive.

\textbf{Note: } To inspect the newly created, non-standard dimensions, be sure to write to an output format that can support arbitrary dimensions, such as BPF.

\textbf{Note: } In earlier PDAL releases (up to v2.2.0), NNDistance was stored in the KDistance Dimension.

\textbf{Default Embedded Stage}

This stage is enabled by default

\textbf{Example}

The sample pipeline below computes the LOF with a neighborhood of 20 neighbors, followed by a range filter to crop out points whose LocalOutlierFactor exceeds 1.2 before writing the output.

```
[  
  "input.las",
  {  
    "type": "filters.lof",
    "minpts": 20
  },
  {  
    "type": "filters.range",
    "limits": "LocalOutlierFactor[:1.2]"
  },
  "output.laz"
]
```
Options

**minpts**
The number of k nearest neighbors. [Default: 10]

**where**
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.miniball**

The Miniball Criterion was introduced in [Weyrich2004] and is based on the assumption that points that are distant to the cluster built by their k-neighborhood are likely to be outliers. First, the smallest enclosing ball is computed for the k-neighborhood, giving a center point and radius [Fischer2010]. The miniball criterion is then computed by comparing the distance (from the current point to the miniball center) to the radius of the miniball.

The author suggests that the Miniball Criterion is more robust than the Plane Fit Criterion (page 247) around high-frequency details, but demonstrates poor outlier detection for points close to a smooth surface.

The filter creates a single new dimension, Miniball, that records the Miniball criterion for the current point.

**Note:** To inspect the newly created, non-standard dimensions, be sure to write to an output format that can support arbitrary dimensions, such as BPF.

**Default Embedded Stage**

This stage is enabled by default
Example

The sample pipeline below computes the Miniball criterion with a neighborhood of 8 neighbors. We do not apply a fixed threshold to single out outliers based on the Miniball criterion as the range of values can vary from one dataset to another. In general, higher values indicate the likelihood of a point being an outlier.

```
[
    "input.las",
    {
        "type": "filters.miniball",
        "knn": 8
    },
    "output.laz"
]
```

Options

**knn**
The number of k nearest neighbors. [Default: 8]

**where**
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

**filters.nndistance**

The NNDistance filter runs a 3-D nearest neighbor algorithm on the input cloud and creates a new dimension, `NNDistance`, that contains a distance metric described by the `mode` (page 243) of the filter.

Default Embedded Stage

This stage is enabled by default
Example

```
[  
   "input.las",
   
   
   "type":"filters.nndistance",
   "k":8
   
   
   
   
   
   
   "type":"writers.bpf",
   "filename":"output.las",
   "output_dims":"X,Y,Z,NNDistance"

]
```

Options

**mode**

The mode of operation. Either “kth”, in which the distance is the euclidian distance of the subject point from the kth remote point or “avg” in which the distance is the average euclidian distance from the $k$ (page 243) nearest points. [Default: ‘kth’]

**k**

The number of k nearest neighbors to consider. [Default: 10]

**where**

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]
**filters.normal**

The **normal filter** returns the estimated normal and curvature for a collection of points. The algorithm first computes the eigenvalues and eigenvectors of the collection of points, which is comprised of the k-nearest neighbors. The normal is taken as the eigenvector corresponding to the smallest eigenvalue. The curvature is computed as

\[
\text{curvature} = \frac{\lambda_0}{\lambda_0 + \lambda_1 + \lambda_2}
\]

where \(\lambda_i\) are the eigenvalues sorted in ascending order.

The filter produces four new dimensions (NormalX, NormalY, NormalZ, and Curvature), which can be analyzed directly, or consumed by downstream stages for more advanced filtering.

The eigenvalue decomposition is performed using Eigen’s [SelfAdjointEigenSolver](https://eigen.tuxfamily.org/dox/classEigen_1_1SelfAdjointEigenSolver.html).

Normals will be automatically flipped towards positive Z, unless the **always_up** (page 245) flag is set to false. Users can optionally set any of the XYZ coordinates to specify a custom **viewpoint** (page 245) or set them all to zero to effectively disable the normal flipping.

**Note:** By default, the Normal filter will invert normals such that they are always pointed “up” (positive Z). If the user provides a **viewpoint** (page 245), normals will instead be inverted such that they are oriented towards the viewpoint, regardless of the **always_up** (page 245) flag. To disable all normal flipping, do not provide a **viewpoint** (page 245) and set **always_up** (page 245) to false.

In addition to **always_up** (page 245) and **viewpoint** (page 245), users can run a refinement step (off by default) that propagates normals using a minimum spanning tree. The propagated normals can lead to much more consistent results across the dataset.

**Note:** To enable normal propagation, users can set **refine** (page 245) to true.

**Default Embedded Stage**

This stage is enabled by default.
Example

This pipeline demonstrates the calculation of the normal values (along with curvature). The newly created dimensions are written out to BPF for further inspection.

```json
[
  "input.las",
  {
    "type": "filters.normal",
    "knn": 8
  },
  {
    "type": "writers.bpf",
    "filename": "output.bpf",
    "output_dims": "X,Y,Z,NormalX,NormalY,NormalZ,Curvature"
  }
]
```

Options

**knn**

The number of k-nearest neighbors. [Default: 8]

**viewpoint**

A single WKT or GeoJSON 3D point. Normals will be inverted such that they are all oriented towards the viewpoint.

**always_up**

A flag indicating whether or not normals should be inverted only when the Z component is negative. [Default: true]

**refine**

A flag indicating whether or not to reorient normals using minimum spanning tree propagation. [Default: false]

**where**

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]
filters.optimalneighborhood

The **Optimal Neighborhood filter** computes the eigenentropy (defined as the Shannon entropy of the normalized eigenvalues) for a neighborhood of points in the range \( \text{min}_k \) to \( \text{max}_k \). The neighborhood size that minimizes the eigenentropy is saved to a new dimension \( \text{OptimalKNN} \). The corresponding radius of the neighborhood is saved to \( \text{OptimalRadius} \). These dimensions can be written to an output file or utilized directly by \textit{filters.covariancefeatures} (page 233).

**Default Embedded Stage**

This stage is enabled by default

**Example**

```json
[
    "input.las",
    {
        "type":"filters.optimalneighborhood",
        "min_k":8,
        "max_k":50
    },
    {
        "type":"writers.las",
        "minor_version":4,
        "extra_dims":"all",
        "forward":"all",
        "filename":"output.las"
    }
]
```

**Options**

\textbf{min\_k}  
The minimum number of k nearest neighbors to consider for optimal neighborhood selection. [Default: 10]

\textbf{max\_k}  
The maximum number of k nearest neighbors to consider for optimal neighborhood selection. [Default: 14]
filters.planefit

The **Plane Fit Criterion** was introduced in [Weyrich2004] and computes the deviation of a point from a manifold approximating its neighbors. First, a plane is fit to each point's k-neighborhood by performing an eigenvalue decomposition. Next, the mean point to plane distance is computed by considering all points within the neighborhood. This is compared to the point to plane distance of the current point giving rise to the k-neighborhood. As the mean distance of the k-neighborhood approaches 0, the Plane Fit criterion will tend toward 1. As point to plane distance of the current point approaches 0, the Plane Fit criterion will tend toward 0.

The author suggests that the Plane Fit Criterion is well suited to outlier detection when considering noisy reconstructions of smooth surfaces, but produces poor results around small features and creases.

The filter creates a single new dimension, **PlaneFit**, that records the Plane Fit criterion for the current point.

---

**Note:** To inspect the newly created, non-standard dimensions, be sure to write to an output format that can support arbitrary dimensions, such as BPF.

---

**Default Embedded Stage**

This stage is enabled by default

---

**Example**

The sample pipeline below computes the Plane Fit criterion with a neighborhood of 8 neighbors. We do not apply a fixed threshold to single out outliers based on the Plane Fit criterion as the range of values can vary from one dataset to another. In general, higher values indicate the likelihood of a point being an outlier.

```
[  
    "input.las",
    {
      "type":"filters.planefit",
      "knn":8
    },
    "output.laz"
]
```
Options

knn
The number of k nearest neighbors. [Default: 8]

threads
The number of threads used for computing the plane fit criterion. [Default: 1]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.radialdensity

The Radial Density filter creates a new attribute RadialDensity that contains the density of points in a sphere of given radius.

The density at each point is computed by counting the number of points falling within a sphere of given radius (default is 1.0) and centered at the current point. The number of neighbors (including the query point) is then normalized by the volume of the sphere, defined as

\[ V = \frac{4}{3} \pi r^3 \]

The radius \( r \) can be adjusted by changing the radius (page 249) option.

Default Embedded Stage

This stage is enabled by default
Example

```
[  
  "input.las",
  {  
    "type": "filters.radialdensity",
    "radius": 2.0
  },
  {  
    "type": "writers.bpf",
    "filename": "output.bpf",
    "output_dims": "X,Y,Z,RadialDensity"
  }
]
```

Options

**radius**

Radius. [Default: 1.0]

**where**

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.reciprocity**

The Nearest-Neighbor Reciprocity Criterion was introduced in [Weyrich2004] and is based on a simple assumption, that valid points may be in the k-neighborhood of an outlier, but the outlier will most likely not be part of the valid point’s k-neighborhood.

The author suggests that the Nearest-Neighbor Reciprocity Criterion is more robust than both the Plane Fit (page 247) and Miniball (page 241) Criterion, being equally sensitive around smooth and detailed regions. The criterion does however produce invalid results near manifold borders.
The filter creates a single new dimension, `Reciprocity`, that records the percentage of points (in the range 0 to 100) that are considered uni-directional neighbors of the current point.

**Note:** To inspect the newly created, non-standard dimensions, be sure to write to an output format that can support arbitrary dimensions, such as BPF.

### Default Embedded Stage

This stage is enabled by default

### Example

The sample pipeline below computes reciprocity with a neighborhood of 8 neighbors, followed by a range filter to crop out points whose `Reciprocity` percentage is less than 98% before writing the output.

```json
[  
  "input.las",
  {
    "type": "filters.reciprocity",
    "knn": 8
  },
  {
    "type": "filters.range",
    "limits": "Reciprocity[:98.0]"
  },
  "output.laz"
]
```

### Options

#### knn

The number of k nearest neighbors. [Default: 8]

#### where

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

#### where_merge

A strategy for merging points skipped by a `where` option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the
skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.zsmooth**

The **Zsmooth Filter** computes a new Z value as another dimension that is based on the Z values of neighboring points.

All points within some distance in the X-Y plane from a reference point are ordered by Z value. The reference point’s new smoothed Z value is chosen to be that of the Nth median value of the neighboring points, where N is specified as the medianpercent option.

Use **filters.assign** (page 253) to assign the smoothed Z value to the actual Z dimension if desired.

**Example**

Compute the smoothed Z value as the median Z value of the neighbors within 2 units and assign the value back to the Z dimension.

**Options**

**radius**

All points within radius units from the reference point in the X-Y plane are considered to determine the smoothed Z value. [Default: 1]

**medianpercent**

A value between 0 and 100 that specifies the relative position of ordered Z values of neighbors to use as the new smoothed Z value. 0 specifies the minimum value. 100 specifies the maximum value. 50 specifies the mathematical median of the values. [Default: 50]

**dim**

The name of a dimension to use for the adjusted Z value. Cannot be ‘Z’. [Required]

**where**

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto,
skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.approximatecoplanar** (page 232)
Estimate pointwise planarity, based on k-nearest neighbors. Returns a new dimension `Coplanar` where a value of 1 indicates that a point is part of a coplanar neighborhood (0 otherwise).

**filters.covariancefeatures** (page 233)
Filter that calculates local features based on the covariance matrix of a point’s neighborhood.

**filters.eigenvalues** (page 237)
Compute pointwise eigenvalues, based on k-nearest neighbors.

**filters.estimaterank** (page 238)
Compute pointwise rank, based on k-nearest neighbors.

**filters.lof** (page 239)
Compute pointwise Local Outlier Factor (along with K-Distance and Local Reachability Distance).

**filters.miniball** (page 241)
Compute a criterion for point neighbors based on the miniball algorithm.

**filters.nndistance** (page 242)
Compute a distance metric based on nearest neighbors.

**filters.normal** (page 244)
Compute pointwise normal and curvature, based on k-nearest neighbors.

**filters.optimalneighborhood** (page 246)
Compute optimal k nearest neighbors and corresponding radius by minimizing pointwise eigenentropy. Creates two new dimensions `OptimalKNN` and `OptimalRadius`.

**filters.plane(n)fit** (page 247)
Compute a deviation of a point from a manifold approximating its neighbors.

**filters.radialdensity** (page 248)
Compute pointwise density of points within a given radius.

**filters.reciprocity** (page 249)
Compute the percentage of points that are considered uni-directional neighbors of a point.

**filters.zsmooth** (page 251)
Compute a smoothed ‘Z’ value based on the ‘Z’ value of neighboring points.
Assignment

filters.assign

The assign filter allows you set the value of a dimension for all points to a provided value that pass a range filter.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Note: The assignment and condition options are deprecated and may be removed in a future release.

Options

assignment

A range (page 315) followed by an assignment of a value (see example). Can be specified multiple times. The assignments are applied sequentially to the dimension value as set when the filter began processing. [Required]

condition

A single ranges (page 315) that a point's values must pass in order for the assignment to be performed. [Default: none] [Deprecated - use 'value']

value

A list of assignment expressions (page 254) to be applied to points. The list of values is evaluated in order. [Default: none]

where

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view
is returned and it has the same point count as it did when the filter was run. [Default: auto]

**Assignment Expressions**

The assignment expression syntax is an expansion on the PDAL expression syntax that provides for assignment of values to points. The generic expression is:

```json
"value" : "Dimension = ValueExpression [WHERE ConditionalExpression]"
```

*Dimension* is the name of a PDAL dimension.

A *ValueExpression* consists of constants, dimension names and mathematical operators that evaluates to a numeric value. The supported mathematical operations are addition(+) subtraction(-), multiplication(*) and division(/).

A *ConditionalExpression* is an optional boolean value that must evaluate to *true* for the *ValueExpression* to be applied.

**Example 1**

```
[  
  "input.las",
  {   
    "type" : "filters.assign",
    "value" : "Red = Red / 256"
  },
  "output.laz"
]
```

This scales the Red value by 1/256. If the input values are in the range 0 - 65535, the output value will be in the range 0 - 255.

**Example 2**

```
[  
  "input.las",
  {   
    "type" : "filters.assign",
    "value" : [ "Red = Red * 256",
                "Green = Green * 256"
               ]
  },
  "output.laz"
]
```

(continues on next page)
"Blue = Blue * 256"
],
"output.laz"
]

This scales the values of Red, Green and Blue by 256. If the input values are in the range 0 - 255, the output value will be in the range 0 - 65535. This can be handy when creating a COPC (page 143) file which (as defined in LAS 1.4) needs color values scaled in that range.

**Example 3**

```json
[  
  "input.las",
  {
    "type": "filters.assign",
    "value": [
      "Classification = 2 WHERE HeightAboveGround < 5",
      "Classification = 1 WHERE HeightAboveGround >= 5"
    ]
  },
  "output.laz"
]
```

This sets the classification of points to either Ground or Unassigned depending on the value of the HeightAboveGround dimension.

**Example 4**

```json
[  
  "input.las",
  {
    "type": "filters.assign",
    "value": [
      "X = 1",
      "X = 2 WHERE X > 10"
    ]
  },
  "output.laz"
]
```
This sets the value of X for all points to 1. The second statement is essentially ignored since the first statement sets the X value of all points to 1 and therefore no points the ConditionalExpression of the second statement.

**filters.overlay**

The overlay filter allows you to set the values of a selected dimension based on an OGR-readable polygon or multi-polygon.

---

**Default Embedded Stage**

This stage is enabled by default

---

**Streamable Stage**

This stage supports streaming operations

---

**OGR SQL support**

You can limit your queries based on OGR’s SQL support. If the filter has both a datasource (page 257) and a query (page 258) option, those will be used instead of the entire OGR data source. At this time it is not possible to further filter the OGR query based on a geometry but that may be added in the future.

**Note:** The OGR SQL support follows the rules specified in ExecuteSQL (http://www.gdal.org/ogr_api_8h.html#a9892ecb0bf61add295bd9decdb13797a) documentation, and it will pass SQL down to the underlying datasource if it can do so.

---

**Example 1**

In this scenario, we are altering the attributes of the dimension Classification. Points from autzen-dd.las that lie within a feature will have their classification to match the CLS field associated with that feature.

```json
[
    "autzen-dd.las",
    {
        "type":"filters.overlay",
    }
]  
```

(continues on next page)
Example 2

This example sets the Intensity attribute to CLS values read from the OGR SQL (http://www.gdal.org/ogr_sql_sqlite.html) query.

```
[  
  "autzen-dd.las",
  {
    "type": "filters.overlay",
    "dimension": "Intensity",
    "datasource": "attributes.shp",
    "query": "SELECT CLS FROM attributes where cls!=6",
    "column": "CLS"
  },
  "attributed.las"
]
```

Options

bounds
A bounds to pre-filter the OGR datasource that is passed to OGR_L_SetSpatialFilter (https://gdal.org/doxygend/ogr__api_8h.html#a678d1735bc82533614ac005691d1138c) in the form \([(xmin, xmax), (ymin, ymax)]\).

dimension
Name of the dimension whose value should be altered. [Required]

datasource
OGR-readable datasource for Polygon or MultiPolygon data. [Required]
column
   The OGR datasource column from which to read the attribute. [Default: first column]

query
   OGR SQL query to execute on the datasource to fetch geometry and attributes. The entire layer is fetched if no query is provided. [Default: none]

layer
   The data source’s layer to use. [Default: first layer]

where
   An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
   A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.assign (page 253)
   Assign values for a dimension range to a specified value.

filters.overlay (page 256)
   Assign values to a dimension based on the extent of an OGR-readable data source or an OGR SQL query.

Dimension Create/Copy

filters.ferry

The ferry filter copies data from one dimension to another, creates new dimensions or both.

The filter is guided by a list of ‘from’ and ‘to’ dimensions in the format <from>=<to>. Data from the ‘from’ dimension is copied to the ‘to’ dimension. The ‘from’ dimension must exist. The ‘to’ dimension can be pre-existing or will be created by the ferry filter.

Alternatively, the format =><to> can be used to create a new dimension without copying data from any source. The values of the ‘to’ dimension are default initialized (set to 0).

Default Embedded Stage

This stage is enabled by default
Streamable Stage

This stage supports streaming operations

Example 1

In this scenario, we are making copies of the X and Y dimensions into the dimensions StatePlaneX and StatePlaneY. Since the reprojection filter will modify the dimensions X and Y, this allows us to maintain both the pre-reprojection values and the post-reprojection values.

```json
[  
  "uncompressed.las",
  {  
    "type":"readers.las",
    "spatialreference":"EPSG:2993",
    "filename":"../las/1.2-with-color.las"
  },
  {  
    "type":"filters.ferry",
    "dimensions":"X => StatePlaneX, Y=>StatePlaneY"
  },
  {  
    "type":"filters.reprojection",
    "out_srs":"EPSG:4326+4326"
  },
  {  
    "type":"writers.las",
    "scale_x":"0.0000001",
    "scale_y":"0.0000001",
    "filename":"colorized.las"
  }
]
```
Example 2

The ferry filter is being used to add a dimension Classification to points so that the value can be set to ‘2’ and written as a LAS file.

```
[
    {
        "type": "readers.gdal",
        "filename": "somefile.tif"
    },
    {
        "type": "filters.ferry",
        "dimensions": "=>Classification"
    },
    {
        "type": "filters.assign",
        "assignment": "Classification[:]=2"
    },
    "out.las"
]
```

Options

dimensions
A list of dimensions whose values should be copied. The format of the option is `<from>=><to>, <from>=><to>,...` Spaces are ignored. ‘from’ can be left empty, in which case the ‘to’ dimension is created and default-initialized. ‘to’ dimensions will be created if necessary.

Note: the old syntax that used ‘=’ instead of ‘=>’ between dimension names is still supported.

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]
7.5.2 Order

There are currently three PDAL filters that can be used to reorder points. These filters will invalidate an existing KD-tree.

filters.mortonorder


It’s also possible to compute a reverse Morton code by reading the binary representation from the end to the beginning. This way, points are sorted with a good dispersement. For example, by successively selecting N representative points within tiles:

See also:

See LOPoCS (https://github.com/Oslandia/lopocs) and pgmorton (https://github.com/Oslandia/pgmorton) for some use case examples of the Reverse Morton algorithm.

Default Embedded Stage

This stage is enabled by default
Example

```json
[
  "uncompressed.las",
  {
    "type": "filters.mortonorder",
    "reverse": "false"
  },
  {
    "type": "writers.las",
    "filename": "compressed.laz",
    "compression": "true"
  }
]
```

Options

**where**

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.randomize**

The randomize filter reorders the points in a point view randomly.

Default Embedded Stage

This stage is enabled by default
Example

```
[  
    "input.las",
    {
      "type": "filters.randomize"
    },
    {
      "type": "writers.las",
      "filename": "output.las"
    }
]
```

Options

**where**

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.sort**

The sort filter orders a point view based on the values of a dimension (page 264). The sorting can be done in increasing (ascending) or decreasing (descending) order (page 264).

---

**Default Embedded Stage**

This stage is enabled by default

---

7.5. Filters 263
Example

```
[  
    "unsorted.las",  
    {  
        "type":"filters.sort",  
        "dimension":"X",  
        "order":"ASC"  
    },  
    "sorted.las"  
]
```

Options

dimension
The dimension on which to sort the points. [Required]

order
The order in which to sort, ASC or DESC [Default: “ASC”]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

(filters.mortonorder (page 261)
Sort XY data using Morton ordering (aka Z-order/Z-curve).

(filters.randomize (page 262)
Randomize points in a view.

(filters.sort (page 263)
Sort data based on a given dimension.)
7.5.3 Move

PDAL filters that move XYZ coordinates will invalidate an existing KD-tree.

Registration

filters.cpd

The Coherent Point Drift (CPD) filter uses the algorithm of [MS10] algorithm to compute a rigid, nonrigid, or affine transformation between datasets. The rigid and affine are what you’d expect; the nonrigid transformation uses Motion Coherence Theory [YG88] to “bend” the points to find a best alignment.

Note: CPD is computationally intensive and can be slow when working with many points (i.e. > 10,000). Nonrigid is significantly slower than rigid and affine.

The first input to the change filter are considered the “fixed” points, and all subsequent inputs are “moving” points. The output from the change filter are the “moving” points after the calculated transformation has been applied, one point view per input. Any additional information about the cpd registration, e.g. the rigid transformation matrix, will be placed in the stage’s metadata.

When to use CPD vs ICP

Summarized from the Non-rigid point set registration: Coherent Point Drift (http://graphics.stanford.edu/courses/cs468-07-winter/Papers/nips2006_0613.pdf) paper.

• CPD outperforms the ICP in the presence of noise and outliers by the use of a probabilistic assignment of correspondences between pointsets, which is innately more robust than the binary assignment used in ICP.

• CPD does not work well for large in-plane rotation, such transformation can be first compensated by other well known global registration techniques before CPD algorithm is carried out

• CPD is most effective when estimating smooth non-rigid transformations.

Dynamic Plugin

This stage requires a dynamic plugin to operate
Examples

```json
[
  "fixed.las",
  "moving.las",
  {
    "type": "filters.cpdp",
    "method": "rigid"
  },
  "output.las"
]
```

If `method` (page 267) is not provided, the cpd filter will default to using the rigid registration method. To get the transform matrix, you’ll need to use the “metadata” option of the pipeline command:

```
$ pdal pipeline cpd-pipeline.json --metadata cpd-metadata.json
```

The metadata output might start something like:

```json
{
  "stages":
  {
    "filters.cpdp":
    {
      "iterations": 10,
      "method": "rigid",
      "runtime": 0.003839,
      "sigma2": 5.684342128e-16,
      "transform": "1 -6.21722e-17 1.30104e-18 5.29303e-11-8.99346e-17 1 2.60209e-18 -3.49247e-10 -2.1684e-19 1.73472e-18 1 -1.53477e-12 0 0 0 1"
    }
  }
}
```

See also:

* `filters.transformation` (page 278) to apply a transform to other points. *filters.icp* (page 267) for deterministic binary point pair assignments.
Options

method
Change detection method to use. Valid values are “rigid”, “affine”, and “nonrigid”. [Default: “rigid”]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.icp

The ICP filter uses the Iterative Closest Point (ICP) algorithm to calculate a rigid (rotation and translation) transformation that best aligns two datasets. The first input to the ICP filter is considered the “fixed” points, and all subsequent points are “moving” points. The output from the filter are the “moving” points after the calculated transformation has been applied, one point view per input. The transformation matrix is inserted into the stage’s metadata.

Note: ICP requires the initial pose of the two point sets to be adequately close, which is not always possible, especially when the transformation is non-rigid. ICP can handle limited non-rigid transformations but be aware ICP may be unable to escape a local minimum. Consider using CPD instead.

From [LLW+19]:

ICP starts with an initial guess of the transformation between the two point sets and then iterates between finding the correspondence under the current transformation and updating the transformation with the newly found correspondence. ICP is widely used because it is rather straightforward and easy to implement in practice; however, its biggest problem is that it does not guarantee finding the globally optimal transformation. In fact, ICP converges within a very small basin in the parameter space, and it easily becomes trapped in local minima. Therefore, the results of ICP are very sensitive to the initialization, especially when high levels of noise and large proportions of outliers exist.
Examples

```
[  
  "fixed.las",
  "moving.las",
  {  
    "type": "filters.icp"
  },
  "output.las"
]
```

To get the transform matrix, you’ll need to use the --metadata option from the pipeline command:

```
$ pdal pipeline icp-pipeline.json --metadata icp-metadata.json
```

The metadata output might start something like:

```
{  
  "stages":{
    "filters.icp":{
      "centroid": "583394 5.2831e+06 498.152",
      "composed": "1 2.60209e-18 -1.97906e-09 -0.374999 8.9407e-08 -0.614662 6.98492e-10 -5.58794e-09 1 0.033234 0 
      "transform": "1 2.60209e-18 -1.97906e-09 -0.375 8.9407e-08 -0.5625 6.98492e-10 -5.58794e-09 1 0.00411987 0 0 "
    }
  },
  "converged": true,
  "fitness": 0.01953125097,
  "transform": "1 2.60209e-18 -1.97906e-09 -0.375 8.9407e-08 -0.5625 6.98492e-10 -5.58794e-09 1 0.00411987 0 0 
  "
}
```

To apply this transformation to other points, the centroid and transform metadata items can by used with filters.transformation in another pipeline. First, move the centroid of the points to (0,0,0), then apply the transform, then move the points back to the original location.

For the above metadata, the pipeline would be similar to:

```
[  
  {  
    "type": "readers.las",
    "transform": "1 2.60209e-18 -1.97906e-09 -0.375 8.9407e-08 -0.5625 6.98492e-10 -5.58794e-09 1 0.00411987 0 0 
    "
  },
  "output.las"
]  
```
"filename": "in.las"
},
{
  "type": "filters.transformation",
  "matrix": "1 0 0 -583394 0 1 0 -5.2831e+06 0 0 1 -498.152 0 0 0 1"
},
{
  "type": "filters.transformation",
  "matrix": "1 2.60209e-18 -1.97906e-09 -0.375 8.9407e-08 1 5.58794e-09 -0.5625 6.98492e-10 -5.58794e-09 1 0.00411987 0 0 0 1"
},
{
  "type": "filters.transformation",
  "matrix": "1 0 0 583394 0 1 0 5.2831e+06 0 0 1 498.152 0 0 0 1"
},
{
  "type": "writers.las",
  "filename": "out.las"
}]

**Note:** The composed metadata matrix is a composition of the three transformation steps outlined above, and can be used in a single call to `filters.transformation` as opposed to the three separate calls.

---

**See also:**

`filters.transformation` (page 278) to apply a transform to other points. `filters.cpd` (page 265) for the use of a probabilistic assignment of correspondences between pointsets.
Options

**max_iter**
Maximum number of iterations. [Default: 100]

**max_similar**
Max number of similar transforms to consider converged. [Default: 0]

**mse_abs**
Absolute threshold for MSE. [Default: 1e-12]

**rt**
Rotation threshold. [Default: 0.99999]

**tt**
Translation threshold. [Default: 9e-8]

**where**
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.teaser**

The **TEASER filter** uses the Truncated least squares Estimation And SEmidefinite Relaxation (TEASER) algorithm [Yang2020] to calculate a rigid transformation that best aligns two datasets. The first input to the ICP filter is considered the “fixed” points, and all subsequent points are “moving” points. The output from the filter are the “moving” points after the calculated transformation has been applied, one point view per input. The transformation matrix is inserted into the stage’s metadata.

**See also:**

The plugin wraps the TEASER++ library, which can be found at https://github.com/MIT-SPARK/TEASER-plusplus.

**Dynamic Plugin**

This stage requires a dynamic plugin to operate
Examples

```
[  
  "fixed.las",
  "moving.las",
  {  
    "type": "filters.teaser"
  },
  "output.las"
]
```

To get the transform matrix, you’ll need to use the \--metadata option from the pipeline command:

```
$ pdal pipeline teaser-pipeline.json \--metadata teaser-metadata.json
```

The metadata output might start something like:

```
{
  "stages":{
    "filters.teaser":{
      "centroid": "583394 5.2831e+06 498.152",
      "composed": "1 2.60209e-18 -1.97906e-09 -0.374999 8.9407e-08 -5.58794e-09 0.375 8.9407e-08 1 0.033234 0 0 0 1",
      "converged": true,
      "fitness": 0.01953125097,
      "transform": "1 2.60209e-18 -1.97906e-09 -5.58794e-09 0.00411987 0 0 1"
    }
  }
```

To apply this transformation to other points, the centroid and transform metadata items can by used with filters.transformation in another pipeline. First, move the centroid of the points to (0,0,0), then apply the transform, then move the points back to the original location.

For the above metadata, the pipeline would be similar to:

```
[
  {
    "type": "readers.las",
    "..."  
  }
```

(continues on next page)
PDAL: Point cloud Data Abstraction Library, Release 2.6.2

Note: The composed metadata matrix is a composition of the three transformation steps outlined above, and can be used in a single call to `filters.transformation` as opposed to the three separate calls.

See also:

`filters.transformation` (page 278) to apply a transform to other points.

Options

nr

Radius to use for normal estimation. [Default: 0.02]

fr

Radius to use when computing features. [Default: 0.04]

fpfh
Use FPFH to find correspondences? [Default: true]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.cpd (page 265)
Compute and apply transformation between two point clouds using the Coherent Point Drift algorithm.

filters.icp (page 267)
Compute and apply transformation between two point clouds using the Iterative Closest Point algorithm.

filters.teaser (page 270)
Compute a rigid transformation between two point clouds using the teaser algorithm.

Predefined

filters.projpipeline

The projpipeline filter applies a coordinates transformation pipeline. The pipeline could be specified as PROJ string (single step operation or multiple step string starting with +proj=pipeline), a WKT2 string describing a CoordinateOperation, or a “urn:ogc:def:coordinateOperation:EPSG::XXXX” URN.

Note: The projpipeline filter does not consider any spatial reference information. However user could specify an output srs, but no check is done to ensure the compliance with the provided transformation pipeline.

Note: The projpipeline filter is enabled if the version of GDAL is superior or equal to 3.0

Streamable Stage

7.5. Filters
This stage supports streaming operations

**Example**

This example shift point on the z-axis.

```json
[
    "untransformed.las",
    {
        "type":"filters.projpipeline",
        "coord_op": "+proj=affine +zoff=100"
    },
    {
        "type":"writers.las",
        "filename": "transformed.las"
    }
]
```

This example apply a shift on the z-axis then reproject from utm 10 to WGS84, using the `reverse_transfo` flag. It also set the output srs.

```json
[
    "utm10.las",
    {
        "type":"filters.projpipeline",
        "coord_op": "+proj=pipeline +step +proj=unitconvert +xy_in=deg +xy_out=rad +step +proj=utm +zone=10 +step +proj=affine +zoff=100",
        "reverse_transfo": "true",
        "out_srs": "EPSG:4326"
    },
    {
        "type": "writers.las",
        "filename": "wgs84.las"
    }
]
```

**Note:** PDAL use the GDAL *OGRCoordinateTransformation* class to transform coordinates. By default output angular unit are in radians. To change to degrees we need to apply a unit conversion step.
Options

**coord_op**

The coordinate operation string. Could be specified as PROJ string (single step operation or multiple step string starting with +proj=pipeline), a WKT2 string describing a CoordinateOperation, or a “urn:ogc:def:coordinateOperation:EPSG::XXXX” URN.

**reverse_transfo**

Boolean, Whether the coordinate operation should be evaluated in the reverse path [Default: false]

**out_srs**

The spatial reference system of the file to be written. Can be an EPSG string (e.g. “EPSG:26910”) or a WKT string. No check is done to ensure the compliance with the specified coordinate operation [Default: Not set]

**where**

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.reprojection**

The reprojection filter converts the X, Y and/or Z dimensions to a new spatial reference system. The old coordinates are replaced by the new ones. If you want to preserve the old coordinates for future processing, use a filters.ferry (page 258) to create copies of the original dimensions before reprojecting.

**Note:** When coordinates are reprojected, it may significantly change the precision necessary to represent the values in some output formats. Make sure that you’re familiar with any scaling necessary for your output format based on the projection you’ve used.

**Default Embedded Stage**

This stage is enabled by default
Streamable Stage

This stage supports streaming operations

Example 1

This pipeline reprojects terrain points with Z-values between 0 and 100 by first applying a range filter and then specifying both the input and output spatial reference as EPSG-codes. The X and Y dimensions are scaled to allow enough precision in the output coordinates.

```json
[
  {
    "filename": "input.las",
    "type": "readers.las",
    "spatialreference": "EPSG:26916"
  },
  {
    "type": "filters.range",
    "limits": "Z[0:100],Classification[2:2]"
  },
  {
    "type": "filters.reprojection",
    "in_srs": "EPSG:26916",
    "out_srs": "EPSG:4326"
  },
  {
    "type": "writers.las",
    "scale_x": "0.0000001",
    "scale_y": "0.0000001",
    "scale_z": "0.01",
    "offset_x": "auto",
    "offset_y": "auto",
    "offset_z": "auto",
    "filename": "example-geog.las"
  }
]
```
Example 2

In some cases it is not possible to use a EPSG-code as a spatial reference. Instead Proj.4 (http://proj4.org) parameters can be used to define a spatial reference. In this example the vertical component of points in a laz file is converted from geometric (ellipsoidal) heights to orthometric heights by using the geoidgrids parameter from Proj.4. Here we change the vertical datum from the GRS80 ellipsoid to DVR90, the vertical datum in Denmark. In the writing stage of the pipeline the spatial reference of the file is set to EPSG:7416. The last step is needed since PDAL will otherwise reference the vertical datum as “Unnamed Vertical Datum” in the spatial reference VLR.

```json
[ 
  "/1km_6135_632.laz",
  {
    "type": "filters.reprojection",
    "in_srs": "EPSG:25832",
    "out_srs": "+init=epsg:25832 +geoidgrids=C:/data/geoids/dvr90.gtx",
  },
  {
    "type": "writers.las",
    "a_srs": "EPSG:7416",
    "filename": "1km_6135_632_DVR90.laz"
  }
]
```

Options

**in_srs**
Spatial reference system of the input data. Express as an EPSG string (eg “EPSG:4326” for WGS84 geographic), Proj.4 string or a well-known text string. [Required if not part of the input data set]

**out_srs**
Spatial reference system of the output data. Express as an EPSG string (eg “EPSG:4326” for WGS84 geographic), Proj.4 string or a well-known text string. [Required]

**in_axis_ordering**
An array of numbers that override the axis order for the in_srs (or if not specified, the inferred SRS from the previous Stage). “2, 1” for example would swap X and Y, which may be commonly needed for something like “EPSG:4326”.

**in_coord_epoch**
Coordinate epoch for the input coordinate system as a double. [Default: 0]
out_axis_ordering
An array of numbers that override the axis order for the out_srs. “2, 1” for example
would swap X and Y, which may be commonly needed for something like “EPSG:4326”.

out_coord_epoch
Coordinate epoch for the output coordinate system as a double. [Default: 0]

error_on_failure
If true and reprojection of any point fails, throw an exception that terminates PDAL .
[Default: false]

filters.transformation
The transformation filter applies an arbitrary homography transformation, represented as a 4x4
matrix (page 279), to each xyz triplet.

Note: The transformation filter does not apply or consider any spatial reference information.

Default Embedded Stage
This stage is enabled by default

Streamable Stage
This stage supports streaming operations

Example
This example rotates the points around the z-axis while translating them.

```json
[
  "untransformed.las",
  {
    "type": "filters.transformation",
    "matrix": "0 -1 0 1 1 0 0 2 0 0 1 3 0 0 0 1"
  },
  {
    "type": "writers.las",
    "filename": "transformed.las"
  }
]
```

(continues on next page)
Options

invert
If set to true, applies the inverse of the provided transformation matrix. [Default: false]

matrix
A whitespace-delimited transformation matrix. The matrix is assumed to be presented in row-major order. Only matrices with sixteen elements are allowed.

where
An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

Further details

A full tutorial about transformation matrices is beyond the scope of this documentation. Instead, we will provide a few pointers to introduce core concepts, especially as pertains to PDAL's handling of the matrix argument.

Transformations in a 3-dimensional coordinate system can be represented as a homography transformation using homogeneous coordinates. This 4x4 matrix can represent affine transformations describing operations like translation, rotation, and scaling of coordinates. In addition it can represent perspective transformations modeling a pinhole camera.

The transformation filter’s matrix argument is a space delimited, 16 element string. This string is simply a row-major representation of the 4x4 matrix (i.e., first four elements correspond to the top row of the transformation matrix and so on).

In the event that readers are accustomed to an alternate representation of the transformation matrix, we provide some simple examples in the form of pure translations, rotations, and scaling, and show the corresponding matrix string.
Translation

A pure translation by \( t_x \), \( t_y \), and \( t_z \) in the X, Y, and Z dimensions is represented by the following matrix.

\[
\begin{bmatrix}
1 & 0 & 0 & t_x \\
0 & 1 & 0 & t_y \\
0 & 0 & 1 & t_z \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

The JSON syntax required for such a translation is written as follows for \( t_x = 7 \), \( t_y = 8 \), and \( t_z = 9 \).

```
[
  {
    "type": "filters.transforma\tion",
    "matrix": "1 0 0 7 0 1 0 8 0 0 1 9 0 0 0 1"
  }
]
```

Scaling

Scaling of coordinates is also possible using a transformation matrix. The matrix shown below will scale the X coordinates by \( s_x \), the Y coordinates by \( s_y \), and Z by \( s_z \).

\[
\begin{bmatrix}
s_x & 0 & 0 & 0 \\
0 & s_y & 0 & 0 \\
0 & 0 & s_z & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

We again provide an example JSON snippet to demonstrate the scaling transformation. In the example, X and Y are not scaled at all (i.e., \( s_x = s_y = 1 \)) and Z is magnified by a factor of 2 (\( s_z = 2 \)).

```
[
  {
    "type": "filters.transforma\tion",
    "matrix": "1 0 0 0 0 1 0 0 0 0 2 0 0 0 0 1"
  }
]
```
Rotation

A rotation of coordinates by $\theta$ radians counter-clockwise about the z-axis is accomplished with the following matrix.

$$
\begin{bmatrix}
\cos \theta & -\sin \theta & 0 & 0 \\
\sin \theta & \cos \theta & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
$$

In JSON, a rotation of 90 degrees ($\theta = 1.57$ radians) takes the form shown below.

```
[
  {
    "type": "filters.transformation",
    "matrix": "0 0 -1 0 1 0 0 0 0 0 1 0 0 0 0 1"
  }
]
```

Similarly, a rotation about the x-axis by $\theta$ radians is represented as

$$
\begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & \cos \theta & -\sin \theta & 0 \\
0 & \sin \theta & \cos \theta & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
$$

which takes the following form in JSON for a rotation of 45 degrees ($\theta = 0.785$ radians)

```
[
  {
    "type": "filters.transformation",
    "matrix": "1 0 0 0 0 0.707 -0.707 0 0 0.707 0.707 0 \rightarrow 0 0 0 1"
  }
]
```

Finally, a rotation by $\theta$ radians about the y-axis is accomplished with the matrix

$$
\begin{bmatrix}
\cos \theta & 0 & \sin \theta & 0 \\
0 & 1 & 0 & 0 \\
-\sin \theta & 0 & \cos \theta & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
$$

and the JSON string for a rotation of 10 degrees ($\theta = 0.175$ radians) becomes
filters.straighten

The `straighten` filter transforms the point cloud in a new parametric coordinate system, each point in world coordinate (X,Y,Z) is being projected along closest polyline segment, and rotated along the segment accordingly to the average m/roll value.

Streamable Stage

This stage supports streaming operations

---

**Note:** The new coordinate system (X', Y', Z') could be understood as:

* X' : curvilinear abcissa (or meter point)
* Y' : orthogonal distance to segment (or orthogonal distance to line)
* Z' : orthogonal distance from (rolling) plane

---

Examples

```json
[
  "input.las",
  {
    "type": "filters.straighten",
    "polyline": "LINSTRING ZM (...)"
  },
  "straighten.las"
]
```

```json
[
  "input.las",
  {
    "type": "filters.straighten",
    "polyline": "LINSTRING ZM (...)"
  }
]
```

(continues on next page)
Options

polyline
    wkt `or json` definition of a 3D linestring with measurment (LINESTRING ZM in wkt) along which the cloud will be straighten. M is supposed to be roll expressed in radians. This is mandatory.

offset
    if you want to add an X` during straightening operation (or take an offset into account while unstraightening). This can be understood as a starting meter point. [Default: 0]

reverse
    whether to straighten or unstraighten the point cloud [Default: false]

where
    An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
    A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.georeference

The georeference filter georeferences point cloud expressed in scanner coordinates, using GpsTime Dimension as a synchronisation reference with a given trajectory.

Streamable Stage

This stage supports streaming operations

Note: This filter expects trajectory to :

- contains X, Y, Z, Roll, Pitch, Yaw, WanderAngle and GpsTime ;
• have coordinates expressed in WGS84 system (EPSG:4979);
• have all its angle values expressed in radians.

Examples

```
[    
  "input.rxp",
  
  {
    "type": "filters.georeference",
    "trajectory_file": "sbet.out",
    "trajectory_options": {
      "type": "readers.sbet",
      "angles_as_degrees": false
    },
    "scan2imu": 
      -0.555809 0.545880 0.626970 0.053833
      0.280774 0.833144 -0.476484 -0.830238
      -0.782459 -0.088797 -0.616338 -0.099672
      0.000000 0.000000 0.000000 1.000000"
  },
  
  {
    "type": "filters.reprojection",
    "in_srs": "EPSG:4979",
    "out_srs": "EPSG:2154+5720"
  },
  
  "georeference.las"
]
```

Options

**trajectory_file**
path to a sbet trajectory file. [Mandatory]

**trajectory_options**
JSON object with keys of reader options and the values to pass through. [Default: {}]

**scan2imu**
4x4 transformation matrix from scanner frame to body imu. By default expressed in NED coordinates. [Mandatory]

**reverse**
revert georeferencing (go back to scanner frame). [Default: false]
time_offset
timestamp offset between trajectory and scanner GpsTime. [Default: 0]

coordinate_system
Two right-handed variants exist for Local tangent plane coordinates: east, north, up (ENU) coordinates and north, east, down (NED). [Default : NED]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.projpipeline (page 273)
Apply coordinates operation on point triplets, based on PROJ pipeline string, WKT2 coordinates operations or URN definitions.

filters.reprojection (page 275)
Reproject data using GDAL from one coordinate system to another.

filters.transformation (page 278)
Transform each point using a 4x4 transformation matrix.

filters.straighten (page 282)
Transforms each in a new parametric coordinate system along a given polyline.

filters.georeference (page 283)
Georeference point cloud.
7.5.4 Cull

Some PDAL filters will cull points, returning a point cloud that is smaller than the input. These filters will invalidate an existing KD-tree.

Spatial

filters.crop

The crop filter removes points that fall outside or inside a cropping bounding box (2D or 3D), polygon, or point+distance. If more than one bounding region is specified, the filter will pass all input points through each bounding region, creating an output point set for each input crop region.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

The provided bounding regions are assumed to have the same spatial reference as the points unless the option a_srs (page 288) provides an explicit spatial reference for bounding regions. If the point input consists of multiple point views with differing spatial references, one is chosen at random and assumed to be the spatial reference of the input bounding region. In this case a warning will be logged.

Example 1

This example crops an input point cloud using a square polygon.

```json
[
    "file-input.las",
    {
        "type":"filters.crop",
        "bounds":"
```
Example 2

This example crops all points more than 500 units in any direction from a point.

```
[
  "file-input.las",
  {
    "type":"filters.crop",
    "point":"POINT(0 0 0)",
    "distance": 500
  },
  {
    "type":"writers.las",
    "filename":"file-cropped.las"
  }
]
```

Options

**bounds**

The extent of the clipping rectangle in the format "([xmin, xmax], [ymin, ymax])". This option can be specified more than once by placing values in an array.

---

**Note:** 3D bounds can be given in the form ([xmin, xmax], [ymin, ymax], [zmin, zmax]).

---

**Warning:** If a 3D bounds is given to the filter, a 3D crop will be attempted, even if the Z values are invalid or inconsistent with the data.

**polygon**

The clipping polygon, expressed in a well-known text string, eg: "POLYGON((0 0, 5000 10000, 10000 0, 0 0))". This option can be specified more than once by placing values in an array.

**outside**

Invert the cropping logic and only take points outside the cropping bounds or polygon.
[Default: false]

**point**

An array of WKT or GeoJSON 2D or 3D points (eg: "POINT(0 0 0)"). Requires **distance** (page 288).

**distance**

Distance (radius) in units of common X, Y, and Z **Dimensions** (page 359) in combination with **point** (page 288). Passing a 2D point will crop using a circle. Passing a 3D point will crop using a sphere.

**a_srs**

Indicates the spatial reference of the bounding regions. If not provided, it is assumed that the spatial reference of the bounding region matches that of the points.

**where**

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**Notes**

1. See **Clipping data with polygons** (page 456): and **Clipping with Geometries** (page 403) for example usage scenarios for **filters.crop** (page 286).

**filters.geomdistance**

The geomdistance filter computes the distance between a given polygon and points.

---

**Default Embedded Stage**

This stage is enabled by default

---

**Streamable Stage**

This stage supports streaming operations
Example 1

This example computes the 2D distance of points to the given geometry.

```
[  
  "autzen.las",
  {
    "type":"filters.geomdistance",
    "geometry":"POLYGON ((636889.412951239268295 851528.
      512293258565478 422.7001953125,636899.14233423944097 851475.
      000686757150106 422.4697265625,636899.14233423944097 851475.
      000686757150106 422.4697265625,636928.33048324030824 851494.
      459452757611871 422.5400390625,636928.33048324030824 851494.
      459452757611871 422.5400390625,636976.977398241520859 851513.
      918218758190051 424.150390625,636976.977398241520859 851513.
      918218758190051 424.150390625,637069.406536744092591 851475.
      000686757150106 438.7099609375,637132.647526245797053 851445.
      812537756282836 425.9501953125,647526245797053 851445.
      812537756282836 425.9501953125,637336.964569251285866 851411.
      759697255445644 425.8203125,637336.964569251285866 851411.
      759697255445644 425.8203125,637473.175931254867464 851158.
      795739248627797 435.6298828125,637589.928527257987298 850711.
      244121236610226 420.509765625,637244.53543074874134 850511.
      791769731207751 420.7998046875,636758.066280735656619 850667.
      461897735483944 434.609375,636539.15516322972379 851056.
      63721774588339 422.6396484375,636889.412951239268295 851528.
      512293258565478 422.7001953125))",
  },
  "dimension":"distance",
  {
    "type":"writers.las",
    "filename":"with-distance.las"
  }
]
```
Fig. 6: Normal distance mode causes any points *within* the given polygon to have a distance of 0.
Fig. 7: ring of True causes the polygon external ring to be used for distance computation, resulting in distances inside the polygon to be computed.
Options

**geometry**
The polygon, expressed in a well-known text string, eg: "POLYGON((0 0, 5000 10000, 10000 0, 0 0))".

**dimension**
The dimension to write the distance into bounds or polygon. [Default: distance]

**ring**
Use the outer ring of the polygon (so as to get distances to the exterior ring instead of all points inside the polygon having distance 0). [Default: false]

**where**
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

*filters.crop (page 286)*
Filter points inside or outside a bounding box or a polygon

*filters.geomdistance (page 288)*
Compute 2D distance from a polygon to points

Resampling

*filters.decimation*

The decimation filter retains every Nth point from an input point view.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations
Example

```
[ 
  { 
    "type": "readers.las",
    "filename": "larger.las"
  },
  { 
    "type": "filters.decimation",
    "step": 10
  },
  { 
    "type": "writers.las",
    "filename": "smaller.las"
  }
]
```

Options

**step**
Number of points to skip between each sample point. A step of 1 will skip no points. A step of 2 will skip every other point. A step of 100 will reduce the input by ~99%.
[Default: 1]

**offset**
Point index to start sampling. Point indexes start at 0. [Default: 0]

**limit**
Point index at which sampling should stop (exclusive). [Default: No limit]

**where**
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]
filters.fps

The **Farthest Point Sampling Filter** adds points from the input to the output PointView one at a time by selecting the point from the input cloud that is farthest from any point currently in the output.

**See also:**

*filters.sample* (page 296) produces a similar result, but while *filters.sample* allows us to target a desired separation of points via the `radius` parameter at the expense of knowing the number of points in the output, *filters.fps* allows us to specify exactly the number of output points at the expense of knowing beforehand the spacing between points.

---

**Default Embedded Stage**

This stage is enabled by default

---

**Options**

- **count**
  
  Desired number of output samples. [Default: 1000]

- **where**
  
  An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

- **where_merge**
  
  A strategy for merging points skipped by a ‘where’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

---

**filters.relaxationdartthrowing**

The **Relaxation Dart Throwing Filter** is a variation on Poisson sampling. The approach was first introduced by [McCool1992]. The filter operates nearly identically to *filters.sample* (page 296), except it will continue to shrink the radius with each pass through the point cloud until the desired number of output points is reached.

**See also:**

*filters.decimation* (page 292), *filters.fps* (page 294) and *filters.sample* (page 296) all perform
some form of thinning or resampling.

**Note:** The `shuffle` option does not reorder points in the PointView, but shuffles the order in which the points are visited while processing, which can improve the quality of the result.

---

**Default Embedded Stage**

This stage is enabled by default

---

**Options**

- **decay**
  - Decay rate for the radius shrinkage. [Default: 0.9]

- **radius**
  - Starting minimum distance between samples. [Default: 1.0]

- **count**
  - Desired number of points in the output. [Default: 1000]

- **shuffle**
  - Choose whether or not to shuffle order in which points are visited. [Default: true]

- **seed**
  - Seed for random number generator, used only with shuffle.

- **where**
  - An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

- **where_merge**
  - A strategy for merging points skipped by a `where` option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]
The Sample Filter performs Poisson sampling of the input PointView. The practice of performing Poisson sampling via “Dart Throwing” was introduced in the mid-1980’s by [Cook1986] and [Dippe1985], and has been applied to point clouds in other software [Mesh2009].

Our implementation of Poisson sampling is made streamable by voxelizing the space and only adding points to the output PointView if they do not violate the minimum distance criterion (as specified by radius). The voxelization allows several optimizations, first by checking for existing points within the same voxel as the point under consideration, which are mostly likely to violate the minimum distance criterion. Furthermore, we can easily visit neighboring voxels (limiting the search to those that are populated) without the need to create a KD-tree from the entire input PointView first and performing costly spatial searches.

See also:
- filters.decimation (page 292), filters.fps (page 294), filters.relaxationdartthrowing (page 294), filters.voxelcenternearestneighbor (page 302), filters.voxelcentroidnearestneighbor (page 303), and filters.voxeldownsize (page 304) also perform decimation.

Note: Starting with PDAL v2.3, the filters.sample now supports streaming mode. As a result, there is no longer an option to shuffle points (or to provide a seed for the shuffle).

Note: Starting with PDAL v2.3, a cell option has been added that works with the existing radius. The user must provide one or the other, but not both. The provided option will be used to automatically compute the other. The relationship between cell and radius is such that the radius defines the radius of a sphere that circumscribes a voxel with edge length defined by cell.

Note: Care must be taken with selection of the cell/radius option. Although the filter can now operate in streaming mode, if the extents of the point cloud are large (or conversely, if the cell size is small) the voxel occupancy map which grows as a function of these variables can still require a large memory footprint.

Note: To operate in streaming mode, the filter will typically retain the first point to occupy a voxel (subject to the minimum distance criterion set forth earlier). This means that point ordering matters, and in fact, it is quite possible that points in the incoming stream can be ordered in such a way as to introduce undesirable artifacts (e.g., related to previous tiling of the data). In our experience, processing data that is still in scan order (ordered by GpsTime, if
available) does produce reliable results, although to require this sort either internally or by inserting filters.sort (page 263) prior to sampling would break our ability to stream the data.

### Default Embedded Stage

This stage is enabled by default

### Streamable Stage

This stage supports streaming operations

### Options

- **cell**
  
  Voxel cell size. If radius is set, cell is automatically computed such that the cell is circumscribed by the sphere defined by radius.

- **radius**
  
  Minimum distance between samples. If cell is set, radius is automatically computed to defined a sphere that circumscribes the voxel cell. Whether specified or derived, radius defines the minimum allowable distance between points.

- **where**
  
  An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

- **where_merge**
  
  A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

- **filters.decimation** (page 292)
  
  Keep every Nth point.

- **filters.fps** (page 294)
  
  The Farthest Point Sampling Filter adds points from the input to the output PointView one at a time by selecting the point from the input cloud that is farthest from any point currently in the output.

- **filters.relaxationdartthrowing** (page 294)
  
  Relaxation dart throwing is a hierarchical variant of Poisson disk sampling, shrinking the

7.5. Filters
minimum radius between iterations until the target number of output points is achieved.

**filters.sample** *(page 296)*

Perform Poisson sampling and return only a subset of the input points.

** Conditional **

**filters.dem**

The **DEM filter** uses a source raster to keep point cloud data within a each cell within a computed range. For example, atmospheric or MTA noise in a scene can be quickly removed by keeping all data within 100m above and 20m below a preexisting elevation model.

**Default Embedded Stage**

This stage is enabled by default

**Example**

```json
[
  {
    "type": "filters.dem",
    "raster": "dem.tif",
    "limits": "Z[20:100]"
  }
]
```

**Options**

**limits**

A **range** *(page 315)* that defines the dimension and the magnitude above and below the value of the given dimension to filter.

For example “Z[20:100]” would keep all Z point cloud values that are within 100 units above and 20 units below the elevation model value at the given X and Y value.

**raster**

GDAL readable raster *(http://www.gdal.org/formats_list.html)* data to use for filtering.

**band**

GDAL Band number to read (count from 1) [Default: 1]
where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.iqr
The **Interquartile Range Filter** automatically crops the input point cloud based on the distribution of points in the specified dimension. The Interquartile Range (IQR) is defined as the range between the first and third quartile (25th and 75th percentile). Upper and lower bounds are determined by adding 1.5 times the IQR to the third quartile or subtracting 1.5 times the IQR from the first quartile. The multiplier, which defaults to 1.5, can be adjusted by the user.

Note: This method can remove real data, especially ridges and valleys in rugged terrain, or tall features such as towers and rooftops in flat terrain. While the number of deviations can be adjusted to account for such content-specific considerations, it must be used with care.

**Default Embedded Stage**
This stage is enabled by default

**Example**

The sample pipeline below uses the filter to automatically crop the Z dimension and remove possible outliers. The multiplier to determine high/low thresholds has been adjusted to be less aggressive and to only crop those outliers that are greater than the third quartile plus 3 times the IQR or are less than the first quartile minus 3 times the IQR.

```
[ 
    "input.las",
    {
      "type" : "filters.iqr",
}(continues on next page)```
PDAL: Point cloud Data Abstraction Library, Release 2.6.2

(continued from previous page)

```
"dimension":"Z",
"k":3.0
},
"output.laz"
```

Options

**k**

The IQR multiplier used to determine upper/lower bounds. [Default: 1.5]

**dimension**

The name of the dimension to filter.

**where**

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.mad**

The MAD filter filter crops the input point cloud based on the distribution of points in the specified dimension (page 301). Specifically, we choose the method of median absolute deviation from the median (commonly referred to as MAD), which is robust to outliers (as opposed to mean and standard deviation).

**Note:** This method can remove real data, especially ridges and valleys in rugged terrain, or tall features such as towers and rooftops in flat terrain. While the number of deviations can be adjusted to account for such content-specific considerations, it must be used with care.

**Default Embedded Stage**

This stage is enabled by default
Example

The sample pipeline below uses filters.mad to automatically crop the Z dimension and remove possible outliers. The number of deviations from the median has been adjusted to be less aggressive and to only crop those outliers that are greater than four deviations from the median.

```
[  
  "input.las",
  {
    "type":"filters.mad",
    "dimension":"Z",
    "k":4.0
  },
  "output.laz"
]
```

Options

k
The number of deviations from the median. [Default: 2.0]

dimension
The name of the dimension to filter.

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.dem (page 298)
Remove points that are in a raster cell but have a value far from the value of the raster.

filters.iqr (page 299)
Cull points falling outside the computed Interquartile Range for a given dimension.

filters.mad (page 300)
Cull points falling outside the computed Median Absolute Deviation for a given dimension.
Voxel

filters.voxelcenternearestneighbor

The VoxelCenterNearestNeighbor filter is a voxel-based sampling filter. The input point cloud is divided into 3D voxels at the given cell size. For each populated voxel, the coordinates of the voxel center are used as the query point in a 3D nearest neighbor search. The nearest neighbor is then added to the output point cloud, along with any existing dimensions.

Default Embedded Stage

This stage is enabled by default

Example

```
[  
  "input.las",
  {  
    "type":"filters.voxelcenternearestneighbor",
    "cell":10.0
  },
  "output.las"
]
```

See also:

filters.voxelcentroidnearestneighbor (page 303) offers a similar solution, using as the query point the centroid of all points falling within the voxel as opposed to the voxel center coordinates. The drawback with this approach is that all dimensional data is lost, leaving the the sampled cloud consisting of only XYZ coordinates.

Options

- **cell**
  Cell size in the X, Y, and Z dimension. [Default: 1.0]

- **where**
  An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

- **where_merge**
  A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the
skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.voxelcentroidnearestneighbor**

The VoxelCentroidNearestNeighbor Filter is a voxel-based sampling filter. The input point cloud is divided into 3D voxels at the given cell size. For each populated voxel, we apply the following ruleset. For voxels with only one point, the point is passed through to the output. For voxels with exactly two points, the point closest the voxel center is returned. Finally, for voxels with more than two points, the centroid of the points within that voxel is computed. This centroid is used as the query point in a 3D nearest neighbor search (considering only those points lying within the voxel). The nearest neighbor is then added to the output point cloud, along with any existing dimensions.

**Default Embedded Stage**

This stage is enabled by default

**Example**

```json
[
    "input.las",
    {
        "type": "filters.voxelcentroidnearestneighbor",
        "cell": 10.0
    },
    "output.las"
]
```

See also:

*filters.voxelcenternearestneighbor* (page 302) offers a similar solution, using the voxel center as opposed to the voxel centroid for the query point.
Options

cell
Cell size in the X, Y, and Z dimension. [Default: 1.0]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.voxeldownsize

The voxeldownsize filter is a voxel-based sampling filter. The input point cloud is divided into 3D voxels at the given cell size. For each populated voxel, either first point entering in the voxel or center of a voxel (depending on mode argument) is accepted and voxel is marked as populated. All other points entering in the same voxel are filtered out.

Example

```
[
  "input.las",
  {
    "type": "filters.voxeldownsize",
    "cell": 1.0,
    "mode": "center"
  },
  "output.las"
]
```

See also:

filters.voxelcenternearestneighbor (page 302) offers a similar solution, using the coordinates of the voxel center as the query point in a 3D nearest neighbor search. The nearest neighbor is then added to the output point cloud, along with any existing dimensions.
Options

cell
Cell size in the X, Y, and Z dimension. [Default: 0.001]

mode
Mode for voxel based filtering. [Default: center] center: Coordinates of the first point found in each voxel will be modified to be the center of the voxel. first: Only the first point found in each voxel is retained.

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

Warning: If you choose center mode, you are overwriting the X, Y and Z values of retained points. This may invalidate other dimensions of the point if they depend on this location or the location of other points in the input.

filters.voxelcenternearestneighbor (page 302)
Return the point within each voxel that is nearest the voxel center.

filters.voxelcentroidnearestneighbor (page 303)
Return the point within each voxel that is nearest the voxel centroid.

filters.voxeldownsize (page 304)
Retain either first point detected in each voxel or center of a populated voxel, depending on mode argument.

Position

g filters.expression

The Expression Filter applies filtering to the input point cloud based on a set of criteria on the given dimensions.
This stage is enabled by default

Streamable Stage
This stage supports streaming operations

Example

This example passes through all points whose Z value is in the range [0,100] and whose Classification equals 2 (corresponding to ground in LAS).

```json
[  
    "input.las",
    {
      "type": "filters.expression",
      "expression": "(Z >= 0 && Z <= 100) && Classification == 2"
    },
    {
      "type": "writers.las",
      "filename": "filtered.las"
    }
]
```

The equivalent pipeline invoked via the PDAL translate command would be

```
$ pdal translate -i input.las -o filtered.las -f range --filters.
expression.expression="(Z >= 0 && Z <= 100) && Classification == 2"
```
Options

expression

An expression that limits points passed to a filter.

filters.head

The **Head filter** returns a specified number of points from the beginning of a `PointView`.

**Note:** If the requested number of points exceeds the size of the point cloud, all points are passed with a warning.

Default Embedded Stage

This stage is enabled by default

Example #1

Thin a point cloud by first shuffling the point order with `filters.randomize` (page 262) and then picking the first 10000 using the HeadFilter.

```json
[
  {
    "type": "filters.randomize"
  },
  {
    "type": "filters.head",
    "count": 10000
  }
]
```

Example #2

Compute height above ground and extract the ten highest points.

```json
[
  {
    "type": "filters.smrf"
  }
]
```

(continues on next page)
See also:

`filters.tail` (page 316) is the dual to `filters.head` (page 307).

**Options**

**count**
Number of points to return. [Default: 10]

**where**
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]
filters.locate

The Locate filter searches the specified dimension (page 309) for the minimum or maximum value and returns a single point at this location. If multiple points share the min/max value, the first will be returned. All dimensions of the input PointView will be output, subject to any overriding writer options.

Default Embedded Stage

This stage is enabled by default

Example

This example returns the point at the highest elevation.

```
[  
  "input.las",
  {
    "type":"filters.locate",
    "dimension":"Z",
    "minmax":"max"
  },
  "output.las"
]
```

Options

dimension
Name of the dimension in which to search for min/max value.

minmax
Whether to return the minimum or maximum value in the dimension.

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view
is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.mongo**

The **Mongo Filter** applies query logic to the input point cloud based on a MongoDB-style query expression using the point cloud attributes.

**Default Embedded Stage**

This stage is enabled by default

---

**Streamable Stage**

This stage supports streaming operations

---

**Example**

This example passes through only the points whose Classification is non-zero.

```
[
  "input.las",
  {
    "type": "filters.mongo",
    "expression": {
      "Classification": { "$ne": 0 }
    }
  },
  "filtered.las"
]
```

This example passes through only the points whose ReturnNumber is equal to the NumberOfReturns and the NumberOfReturns is greater than 1.

```
[
  "input.las",
  {
    "type": "filters.mongo",
    "expression": {
      "$and": [
        { "ReturnNumber": "NumberOfReturns" }
      ]
    }
  }
]
```
Options

expression

A JSON query expression (page 311) containing a combination of query comparisons and logical operators.

where

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

Expression

A query expression is a combination of comparison and logical operators that define a query which can be used to select matching points by their attribute values.

Comparison operators

There are 8 valid query comparison operators:

- $eq: Matches values equal to a specified value.
- $gt: Matches values greater than a specified value.
- $gte: Matches values greater than or equal to a specified value.
- $lt: Matches values less than a specified value.
- $lte: Matches values less than or equal to a specified value.
- $ne: Matches values not equal to a specified value.
• $in: Matches any of the values specified in the array.
• $nin: Matches none of the values specified in the array.

Comparison operators compare a point cloud attribute with an operand or an array of operands. An operand is either a numeric constant or a string representing a dimension name. For all comparison operators except for $in and $nin, the comparison value must be a single operand. For $in and $nin, the value must be an array of operands.

Comparison operator specifications must be contained within an object whose key is the dimension name to be compared.

```json
{ "Classification": { "$eq": 2 } }
```

```json
{ "Intensity": { "$gt": 0 } }
```

```json
{ "Classification": { "$in": [2, 6, 9] } }
```

The $eq comparison operator may be implicitly invoked by setting an attribute name directly to a value.

```json
{ "Classification": 2 }
```

**Logical operators**

There are 4 valid logical operators:

• $and: Applies a logical and on the expressions of the array and returns a match only if all expressions match.

• $not: Inverts the value of the single sub-expression.

• $nor: Applies a logical nor on the expressions of the array and returns a match only if all expressions fail to match.

• $nor: Applies a logical or on the expressions of the array and returns a match if any of the expressions match.

Logical operators are used to logically combine sub-expressions. All logical operators except for $not are applied to arrays of expressions. $not is applied to a single expression and negates its result.

Logical operators may be applied directly to comparison expressions or may contain further nested logical operators. For example:

```json
{ "$or": [  
   { "Classification": 2 },
   ...
] }
{ "Intensity": { "$gt": 0 } }

{ "$or": [
   { "Classification": 2 },
   { "$and": [
      { "ReturnNumber": "NumberOfReturns" },
      { "NumberOfReturns": { "$gt": 1 } }
   ] }
]
}

{ "$not": {
   "$or": [
   { "Classification": 2 },
   { "$and": [
   { "ReturnNumber": { "$gt": 0 } },
   { "Z": { "$lte": 42 } }
   ] }
   ] }
}

For any individual dimension, the logical and may be implicitly invoked via multiple comparisons within the comparison object. For example:

{ "X": { "$gt": 0, "$lt": 42 } }

**filters.range**

The Range Filter applies rudimentary filtering to the input point cloud based on a set of criteria on the given dimensions.

**Default Embedded Stage**

This stage is enabled by default

**Streamable Stage**

This stage supports streaming operations
Note: We suggest you start using filters.expression (page 305) for PDAL 2.5.x+. The syntax is simpler, and it is the same syntax that is used by the where option of many stages. filters.range will be deprecated starting PDAL 3.0.

Example

This example passes through all points whose Z value is in the range [0,100] and whose Classification equals 2 (corresponding to ground in LAS).

```
[  
  "input.las",
  {
    "type":"filters.range",
    "limits":"Z[0:100],Classification[2:2]"
  },
  {
    "type":"writers.las",
    "filename":"filtered.las"
  }
]
```

The equivalent pipeline invoked via the PDAL translate command would be

```
$ pdal translate -i input.las -o filtered.las -f range --filters.range.
limits="Z[0:100],Classification[2:2]"
```

Options

limits

A comma-separated list of Ranges (page 315). If more than one range is specified for a dimension, the criteria are treated as being logically ORed together. Ranges for different dimensions are treated as being logically ANDed.

Example:

```
Classification[1:2], Red[1:50], Blue[25:75], Red[75:255], Classification[6:7]
```

This specification will select points that have the classification of 1, 2, 6 or 7 and have a blue value or 25-75 and have a red value of 1-50 or 75-255. In this case, all values are inclusive.
where

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge

A strategy for merging points skipped by a `where` option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

Ranges

A range specification is a dimension name, followed by an optional negation character (`!`), and a starting and ending value separated by a colon, surrounded by parentheses or square brackets. Either the starting or ending values can be omitted. Parentheses indicate an open endpoint that doesn’t include the adjacent value. Square brackets indicate a closed endpoint that includes the adjacent value.

Example 1:

```
Z[10:]
```

Selects all points with a Z value greater than or equal to 10.

Example 2:

```
Classification[2:2]
```

Selects all points with a classification of 2.

Example 3:

```
Red!(20:40]
```

Selects all points with red values less than or equal to 20 and those with values greater than 40.
Example 4:

Blue[:255)

Selects all points with a blue value less than 255.

Example 5:

Intensity![25:25]

Selects all points with an intensity not equal to 25.

filters.tail

The Tail Filter returns a specified number of points from the end of the PointView.

Note: If the requested number of points exceeds the size of the point cloud, all points are passed with a warning.

Default Embedded Stage

This stage is enabled by default

Example

Sort and extract the 100 lowest intensity points.

```
[
  {
    "type":"filters.sort",
    "dimension":"Intensity",
    "order":"DESC"
  },
  {
    "type":"filters.tail",
    "count":100
  }
]
```
See also:

*filters.head* (page 307) is the dual to *filters.tail* (page 316).

**Options**

**count**
Number of points to return. [Default: 10]

**where**
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

*filters.expression* (page 305)
Pass only points given an expression

*filters.head* (page 307)
Return N points from beginning of the point cloud.

*filters.locate* (page 309)
Return a single point with min/max value in the named dimension.

*filters.mongo* (page 310)
Cull points using MongoDB-style expression syntax.

*filters.range* (page 313)
Pass only points given a dimension/range.

*filters.tail* (page 316)
Return N points from end of the point cloud.

**7.5.5 New**

PDAL filters can be used to split the incoming point cloud into subsets. These filters will invalidate an existing KD-tree.
Spatial

filters.chipper

The **Chipper Filter** takes a single large point cloud and converts it into a set of smaller clouds, or chips. The chips are all spatially contiguous and non-overlapping, so the result is an irregular tiling of the input data.

**Note:** Each chip will have approximately, but not exactly, the *capacity* (page 320) point count specified.

**See also:**

The *PDAL split command* (page 46) utilizes the *filters.chipper* (page 318) to split data by capacity.

![Fig. 8: Before chipping, the points are all in one collection.](image)

Chipping is usually applied to data read from files (which produce one large stream of points) before the points are written to a database (which prefer data segmented into smaller blocks).

**Default Embedded Stage**

This stage is enabled by default
Fig. 9: After chipping, the points are tiled into smaller contiguous chips.

Example

```
[  
  "example.las",
  {
    "type": "filters.chipper",
    "capacity": "400"
  },
  {
    "type": "writers.pgpointcloud",
    "connection": "dbname='lidar' user='user'"
  }
]
```
Options

capacity
How many points to fit into each chip. The number of points in each chip will not exceed this value, and will sometimes be less than it. [Default: 5000]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.divider

The Divider Filter breaks a point view into a set of smaller point views based on simple criteria. The number of subsets can be specified explicitly, or one can specify a maximum point count for each subset. Additionally, points can be placed into each subset sequentially (as they appear in the input) or in round-robin fashion.

Normally points are divided into subsets to facilitate output by writers that support creating multiple output files with a template (LAS and BPF are notable examples).

Default Embedded Stage

This stage is enabled by default

Example

This pipeline will create 10 output files from the input file readers.las.

```json
[
  "example.las",
  {
    "type": "filters.divider",
    "count": "10"
  },
]
```

(continues on next page)
Options

mode
A mode of “partition” will write sequential points to an output view until the view meets its predetermined size. “round_robin” mode will iterate through the output views as it writes sequential points. [Default: “partition”]

count
Number of output views. [Default: none]

capacity
Maximum number of points in each output view. Views will contain approximately equal numbers of points. [Default: none]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

Warning: You must specify exactly one of either count (page 321) or capacity (page 321).
filters.splitter

The **Splitter Filter** breaks a point cloud into square tiles of a specified size. The origin of the tiles is chosen arbitrarily unless specified with the `origin_x` (page 322) and `origin_y` (page 322) option.

The splitter takes a single `PointView` as its input and creates a `PointView` for each tile as its output.

Splitting is usually applied to data read from files (which produce one large stream of points) before the points are written to a database (which prefer data segmented into smaller blocks).

### Default Embedded Stage

This stage is enabled by default

### Example

```json
[
    "input.las",
    {
      "type": "filters.splitter",
      "length": "100",
      "origin_x": "638900.0",
      "origin_y": "835500.0"
    },
    {
      "type": "writers.pgpointcloud",
      "connection": "dbname='lidar' user='user'"
    }
]
```

### Options

- **length**
  
  Length of the sides of the tiles that are created to hold points. [Default: 1000]

- **origin_x**
  
  X Origin of the tiles. [Default: none (chosen arbitrarily)]

- **origin_y**
  
  Y Origin of the tiles. [Default: none (chosen arbitrarily)]
**buffer**

Amount of overlap to include in each tile. This buffer is added onto length in both the x and the y direction. [Default: 0]

**where**

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.chipper** (page 318)

Organize points into spatially contiguous, squarish, and non-overlapping chips.

**filters.divider** (page 320)

Divide points into approximately equal sized groups based on a simple scheme.

**filters.splitter** (page 322)

Split data based on a X/Y box length.

**Dimension**

**filters.gpstimeconvert**

The `gpstimeconvert` filter converts between three GPS time standards found in lidar data:

1. GPS time (gt)
2. GPS standard time (gst), also known as GPS adjusted time
3. GPS week seconds (gws)

Since GPS week seconds are ambiguous (they reset to 0 at the start of each new GPS week), care must be taken when they are the source or destination of a conversion:

- When converting from GPS week seconds, the GPS week number must be known. This is accomplished by specifying the `start_date` (page 325) (in the GMT time zone) on which the data collection started. The filter will resolve the ambiguity using the supplied start date.

- When converting from GPS week seconds and the times span a new GPS week, the presence or absence of week second wrapping must be specified with the `wrapped` (page 325) option. Wrapped week seconds reset to 0 at the start of a new week; unwrapped week seconds are allowed to exceed 604800 (60x60x24x7) seconds.
• When converting to GPS week seconds, the week second wrapping preference should be specified with the `wrap` (page 325) option.

**Note:** The filter assumes points are ordered by ascending time, which can be accomplished by running `filters.sort` (page 263) prior to `filters.gpstimeconvert`. Note that GPS week second times that span a new GPS week should not be sorted unless they are unwrapped.

**Example #1**

Convert from GPS time to GPS standard time.

```
[  
  "input.las",
  
  {  
      "type":"filters.gpstimeconvert",
      "conversion":"gt2gst"
    },
  "output.las"
]
```

**Example #2**

Convert from GPS standard time to unwrapped GPS week seconds.

```
[  
  "input.las",
  
  {  
      "type":"filters.sort",
      "dimension":"GpsTime",
      "order":"ASC"
    },
  
  {  
      "type":"filters.gpstimeconvert",
      "conversion":"gst2gws",
      "wrap":false
    }
]
```
Example #3

Convert from wrapped GPS week seconds to GPS time.

```
[  
  "input.las",
  {
    "type": "filters.gpstimeconvert",
    "conversion": "gws2gt",
    "start_date": "2020-12-12",
    "wrapped": true
  },
  "output.las"
]
```

Options

**conversion**
The time conversion. Must be one of the following: “gst2gt”, “gst2gws”, “gt2gst”, “gt2gws”, “gws2gst”, or “gws2gt”. [Required]

**start_date**
When the input times are in GPS week seconds, the date on which the data collection started must be supplied in the GMT time zone. Must be in “YYYY-MM-DD” format. [Required for the “gws2gt” and “gws2gst” conversions]

**wrap**
Whether to output wrapped (true) or unwrapped (false) GPS week seconds. [Default: false]

**wrapped**
Specifies whether input GPS week seconds are wrapped (true) or unwrapped (false). [Default: false]

**filters.groupby**

The Groupby Filter takes a single PointView as its input and creates a PointView for each category in the named `dimension` (page 326) as its output.

Default Embedded Stage

This stage is enabled by default
Example

The following pipeline will create a set of LAS files, where each file contains only points of a single Classification.

```
[
  "input.las",
  {
    "type": "filters.groupby",
    "dimension": "Classification"
  },
  "output_#.las"
]
```

**Note:** By default the groups are ordered according to the order of first occurrence within the input. To change this, use `filters.sort` first to order the points according to `dimension`.

Options

dimension
  The dimension containing data to be grouped.

where
  An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
  A strategy for merging points skipped by a ‘where’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]
filters.returns

The Returns Filter takes a single PointView as its input and creates a PointView for each of the user-specified groups (page 327) defined below.

“first” is defined as those points whose ReturnNumber is 1 when the NumberOfReturns is greater than 1.

“intermediate” is defined as those points whose ReturnNumber is greater than 1 and less than NumberOfReturns when NumberOfReturns is greater than 2.

“last” is defined as those points whose ReturnNumber is equal to NumberOfReturns when NumberOfReturns is greater than 1.

“only” is defined as those points whose NumberOfReturns is 1.

Default Embedded Stage
This stage is enabled by default

Example
This example creates two separate output files for the “last” and “only” returns.

```
[  
    "input.las",
    {
      "type": "filters.returns",
      "groups": "last,only"
    },
    "output_.las"
]
```

Options

groups
Comma-separated list of return number groupings. Valid options are “first”, “last”, “intermediate” or “only”. [Default: “last”]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]
where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.separatescanline

The Separate scan line Filter takes a single PointView as its input and creates a PointView for each scan line as its output. PointView must contain the EdgeOfFlightLine dimension.

Default Embedded Stage
This stage is enabled by default

Example

The following pipeline will create a set of text files, where each file contains only 10 scan lines.

```json
[
  "input.text",
  {
    "type": "filters.separatescanline",
    "groupby": 10
  },
  "output_.#.text"
]
```

Options

groupby
The number of lines to be grouped by. [Default : 1]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard
mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

*filters.gpstimeconvert* *(page 323)*
Convert between three LAS format GPS time standards

*filters.groupby* *(page 325)*
Split data categorically by dimension.

*filters.returns* *(page 327)*
Split data by return order (e.g., ‘first’, ‘last’, ‘intermediate’, ‘only’).

*filters.separatescanline* *(page 328)*
Split data based on scan lines.

### 7.5.6 Join

Multiple point clouds can be joined to form a single point cloud. These filters will invalidate an existing KD-tree.

*filters.merge*

The *Merge Filter* combines input from multiple sources into a single output. In most cases, this happens automatically on output and use of the merge filter is unnecessary. However, there may be special cases where merging points prior to a particular filter or writer is necessary or desirable.

The merge filter will log a warning if its input point sets are based on different spatial references. No checks are made to ensure that points from various sources being merged have similar dimensions or are generally compatible.

---

**Default Embedded Stage**

This stage is enabled by default
Example 1

This pipeline will create an output file “output.las” that concatenates the points from “file1”, “file2” and “file3”. Note that the explicit use of the merge filter is unnecessary in this case (removing the merge filter will yield the same result).

```
[  
  "file1",
  "file2",
  "file3",
  {
    "type": "filters.merge"
  },
  "output.las"
]
```

Example 2

Here are a pair of unlikely pipelines that show one way in which a merge filter might be used. The first pipeline simply reads the input files “utm1.las”, “utm2.las” and “utm3.las”. Since the points from each input set are carried separately through the pipeline, three files are created as output, “out1.las”, “out2.las” and “out3.las”. “out1.las” contains the points in “utm1.las”. “out2.las” contains the points in “utm2.las” and “out3.las” contains the points in “utm3.las”.

```
[  
  "utm1.las",
  "utm2.las",
  "utm3.las",
  "out#.las"
]
```

Here is the same pipeline with a merge filter added. The merge filter will combine the points in its input: “utm1.las” and “utm2.las”. Then the result of the merge filter is passed to the writer along with “utm3.las”. This results in two output files: “out1.las” contains the points from “utm1.las” and “utm2.las”, while “out2.las” contains the points from “utm3.las”.

```
[  
  "utm1.las",
  "utm2.las",
  {
    "type": "filters.merge"
  },
  "utm3.las",
  ]
```
Options

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.merge (page 329)
Merge data from two different readers into a single stream.

7.5.7 Metadata

PDAL filters can be used to create new metadata. These filters will not invalidate an existing KD-tree.

Note: filters.cpd (page 265) and filters.icp (page 267) can optionally create metadata as well, inserting the computed transformation matrix.

filters.hexbin

A common questions for users of point clouds is what the spatial extent of a point cloud collection is. Files generally provide only rectangular bounds, but often the points inside the files only fill up a small percentage of the area within the bounds.

The hexbin filter reads a point stream and writes out a metadata record that contains a boundary, expressed as a well-known text polygon. The filter counts the points in each hexagonal area to determine if that area should be included as part of the boundary. In order to write out the metadata record, the pdal pipeline command must be invoked using the “–pipeline-serialization” option:
Fig. 10: Hexbin output shows boundary of actual points in point buffer, not just rectangular extents.

**Streamable Stage**

This stage supports streaming operations.

**Example 1**

The following pipeline file and command produces an JSON output file containing the pipeline’s metadata, which includes the result of running the hexbin filter:

```
[  
  "/Users/me/pdal/test/data/las/autzen_trim.las",
  
  "type" : "filters.hexbin"

]
```

```
$ pdal pipeline hexbin-pipeline.json --metadata hexbin-out.json
```

```
{
  "stages":
  {
    "filters.hexbin":
```
```
Example 2

As a convenience, the `pdal info` command will produce similar output:

```bash
$ pdal info --boundary /Users/me/test/data/las/autzen_trim.las
```

```json
{
    "boundary": {
        "area": 746772.7543,
        "avg_pt_per_sq_unit": 22.43269935,
        "avg_pt_spacing": 2.605540869,
        "boundary": "MULTIPOLYGON (((636274.38924399 848834.99817891,637242.52219686 848834.99817891,637242.79329529 849226.26445367,637145.70890157 849338.05481789,637242.52219686 849505.74036422,636016.22045656 849505.74036422,635983.94935813 849114.47408945,636113.03375184 84890.89336102,636274.38924399 848834.99817891)))",
        "boundary_json": { "type": "MultiPolygon", "coordinates": [ [ [ 636274.38924399, 848834.99817891 ], [ 637242.52219686, 848834.99817891 ], [ 637242.79329529, 849226.26445367 ], [ 637145.70890157, 849338.05481789 ], [ 637242.52219686, 849505.74036422 ], [ 636016.22045656, 849505.74036422 ], [ 635983.94935813, 849114.47408945 ], [ 636113.03375184, 84890.89336102 ], [ 636274.38924399, 848834.99817891 ] ] ] },
        "density": 0.1473004999,
        "edge_length": 0,
        "estimated_edge": 111.7903642,
        "hex_offsets": "MULTIPOINT (0 0, -32.2711 55.8952, 0 111.79, 64.5422 111.79, 96.8133 55.8952, 64.5422 0)",
        "sample_size": 5000,
        "threshold": 15
    }
}
...
```

7.5. Filters
Options

**edge_size**
If not set, the hexbin filter will estimate a hex size based on a sample of the data. If set, hexbin will use the provided size in constructing the hexbins to test.

**sample_size**
How many points to sample when automatically calculating the edge size? Only applies if `edge_size` (page 334) is not explicitly set. [Default: 5000]

**threshold**
Number of points that have to fall within a hexagon boundary before it is considered “in” the data set. [Default: 15]

**precision**
Minimum number of significant digits to use in writing out the well-known text of the boundary polygon. [Default: 8]

**preserve_topology**
Use GEOS SimplifyPreserveTopology instead of Simplify for polygon simplification with smooth option. [Default: true]
smooth

Use GEOS simplify operations to smooth boundary to a tolerance [Default: true]

where

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.info

The Info filter provides simple information on a point set as metadata. It is usually invoked by the info command, rather than by user code. The data provided includes bounds, a count of points, dimension names, spatial reference, and points meeting a query criteria.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

```
[   
  "input.las",
  {
    "type":"filters.info",
    "point":"1-5"
  }
]
```
Options

point
A comma-separated list of single point IDs or ranges of points. For example “2-6, 10, 25” selects eight points from the input set. The first point has an ID of 0. The point (page 336) option can’t be used with the query (page 336) option. [Default: no points are selected.]

query
A specification to retrieve points near a location. Syntax of the the query is X,Y[Z]/[count] where ‘X’, ‘Y’ and ‘Z’ are coordinate locations mapping to the X, Y and Z point dimension and ‘count’ is the number of points to return. If ‘count’ isn’t specified, the 10 points nearest to the location are returned. The query (page 336) option can’t be used with the point (page 336) option. [Default: no points are selected.]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.stats
The Stats Filter calculates the minimum, maximum and average (mean) values of dimensions. On request it will also provide an enumeration of values of a dimension and skewness and kurtosis.

The output of the stats filter is metadata that can be stored by writers or used through the PDAL API. Output from the stats filter can also be quickly obtained in JSON format by using the command “pdal info –stats”.

Note: The filter can compute both sample and population statistics. For kurtosis, the filter can also compute standard and excess kurtosis. However, only a single value is reported for each statistic type in metadata, and that is the sample statistic, rather than the population statistic. For kurtosis the sample excess kurtosis is reported. This seems to match the behavior of many other software packages.
Example

```
[
  "input.las",
  {
    "type": "filters.stats",
    "dimensions": "X,Y,Z,Classification",
    "enumerate": "Classification"
  },
  {
    "type": "writers.las",
    "filename": "output.las"
  }
]
```

Options

dimensions
A comma-separated list of dimensions whose statistics should be processed. If not provided, statistics for all dimensions are calculated.

enumerate
A comma-separated list of dimensions whose values should be enumerated. Note that this list does not add to the list of dimensions that may be provided in the dimensions (page 337) option.

count
Identical to the enumerate (page 337) option, but provides a count of the number of points in each enumerated category.

global
A comma-separated list of dimensions for which global statistics (median, mad, mode) should be calculated.

advanced
Calculate advanced statistics (skewness, kurtosis). [Default: false]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view
is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.hexbin** *(page 331)*
Tessellate XY domain and determine point density and/or point boundary.

**filters.info** *(page 335)*
Generate metadata about the point set, including a point count and spatial reference information.

**filters.stats** *(page 336)*
Compute statistics about each dimension (mean, min, max, etc.).

### 7.5.8 Mesh

Meshes can be computed from point clouds. These filters will invalidate an existing KD-tree.

**filters.delaunay**

The **Delaunay Filter** creates a triangulated mesh fulfilling the Delaunay condition from a collection of points.


The filter currently only supports 2D Delaunay triangulation, using the X and Y dimensions of the point cloud.

**Default Embedded Stage**

This stage is enabled by default

**Example**

```
[
    "input.las",
    {
        "type": "filters.delaunay"
    },
    {
        "type": "writers.ply",
```
Options

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.greedyprojection

The Greedy Projection Filter creates a mesh (triangulation) in an attempt to reconstruct the surface of an area from a collection of points.

GreedyProjectionTriangulation is an implementation of a greedy triangulation algorithm for 3D points based on local 2D projections. It assumes locally smooth surfaces and relatively smooth transitions between areas with different point densities. The algorithm itself is identical to that used in the PCL (http://www.pointclouds.org/documentation/tutorials/greedy_projection.php) library.

Default Embedded Stage
This stage is enabled by default
Example

```json
[
    "input.las",
    {
        "type": "filters.greedyprojection",
        "multiplier": 2,
        "radius": 10
    },
    {
        "type": "writers.ply",
        "faces": true,
        "filename": "output.ply"
    }
]
```

Options

**multiplier**
Nearest neighbor distance multiplier. [Required]

**radius**
Search radius for neighbors. [Required]

**num_neighbors**
Number of nearest neighbors to consider. [Required]

**min_angle**
Minimum angle for created triangles. [Default: 10 degrees]

**max_angle**
Maximum angle for created triangles. [Default: 120 degrees]

**eps_angle**
Maximum normal difference angle for triangulation consideration. [Default: 45 degrees]

**where**
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a `where` option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view
PDAL: Point cloud Data Abstraction Library, Release 2.6.2

is returned and it has the same point count as it did when the filter was run. [Default: auto]

**filters.poisson**

The Poisson Filter passes data Mischa Kazhdan’s poisson surface reconstruction algorithm. [Kazhdan2006] It creates a watertight surface from the original point set by creating an entirely new point set representing the imputed isosurface. The algorithm requires normal vectors to each point in order to run. If the x, y and z normal dimensions are present in the input point set, they will be used by the algorithm. If they don’t exist, the poisson filter will invoke the PDAL normal filter to create them before running.

The poisson algorithm will usually create a larger output point set than the input point set. Because the algorithm constructs new points, data associated with the original points set will be lost, as the algorithm has limited ability to impute associated data. However, if color dimensions (red, green and blue) are present in the input, colors will be reconstructed in the output point set. This filter will also run the normal filter (page 244) on the output point set.

This integration of the algorithm with PDAL only supports a limited set of the options available to the implementation. If you need support for further options, please let us know.

**Default Embedded Stage**

This stage is enabled by default

**Example**

```
[
    "dense.las",
    {
        "type":"filters.poisson"
    },
    {
        "type":"writers.ply",
        "faces":true,
        "filename":"isosurface.ply"
    }
]
```

**Note:** The algorithm is slow. On a reasonable desktop machine, the surface reconstruction shown below took about 15 minutes.
Fig. 11: Point cloud (800,000 points)
Fig. 12: Reconstruction (1.8 million vertices, 3.7 million faces)
Options

density
Write an estimate of neighborhood density for each point in the output set.

depth
Maximum depth of the tree used for reconstruction. The output is sensitive to this parameter. Increase if the results appear unsatisfactory. [Default: 8]

where
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.faceraster

The FaceRaster filter creates a raster from a point cloud using an algorithm based on an existing triangulation. Each raster cell is given a value that is an interpolation of the known values of the containing triangle. If the raster cell center is outside of the triangulation, it is assigned the nodata (page 345) value. Use writers.raster to write the output.

The extent of the raster can be defined by using the origin_x (page 345), origin_y (page 345), width (page 345) and height (page 345) options. If these options aren’t provided the raster is sized to contain the input data.

Default Embedded Stage

This stage is enabled by default

Basic Example

This pipeline reads the file autzen_trim.las and creates a raster based on a Delaunay triangulation of the points. It then creates a raster, interpolating values based on the vertices of the triangle that contains each raster cell center.
Options

**resolution**  
Length of raster cell edges in X/Y units. [Required]

**nodata**  
The value to use for a raster cell if no data exists in the input data with which to compute an output cell value. Note that this value may be different from the value used for nodata when the raster is written. [Default: NaN]

**mesh**  
Name of the triangulation to use for interpolation. If not provided, the first triangulation associated with the input points will be used. [Default: None]

**origin_x**  
X origin (lower left corner) of the grid. [Default: None]

**origin_y**  
Y origin (lower left corner) of the grid. [Default: None]

**width**  
Number of cells in the X direction. [Default: None]

**height**  
Number of cells in the Y direction. [Default: None]

**max_triangle_edge_length**  
Maximum triangle edge length; triangles larger than this size will not be rasterized. [Default: Infinity]

**where**  
An expression that limits points passed to a filter. Points that don’t pass the expression
skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.delaunay (page 338)
Create mesh using Delaunay triangulation.

filters.greedyprojection (page 339)
Create mesh using the Greedy Projection Triangulation approach.

filters.poisson (page 341)
Create mesh using the Poisson surface reconstruction algorithm [Kazhdan2006].

filters.facercaster (page 344)
Create a raster from an existing triangulation.

7.5.9 Languages

PDAL has three filters than can be used to pass point clouds to other languages. These filters will invalidate an existing KD-tree.

filters.matlab

The Matlab Filter allows Matlab (https://www.mathworks.com/products/matlab.html) software to be embedded in a Pipeline (page 55) that interacts with a struct array of the data and allows you to modify those points. Additionally, some global Metadata (page 545) is also available that Matlab functions can interact with.

The Matlab interpreter must exit and always set “ans==true” upon success. If “ans==false”, an error would be thrown and the Pipeline (page 55) exited.

See also:
writers.matlab (page 166) can be used to write .mat files.

Note: filters.matlab (page 346) embeds the entire Matlab interpreter, and it will require a fully licensed version of Matlab to execute your script.
This stage requires a dynamic plugin to operate

Example

```
[
    {
        "filename": "test\data\las\1.2-with-color.las",
        "type": "readers.las"
    },
    {
        "type": "filters.matlab",
        "script": "matlab.m"
    },
    {
        "filename": "out.las",
        "type": "writers.las"
    }
]
```

Options

**script**
When reading a function from a separate Matlab (https://www.mathworks.com/products/matlab.html) file, the file name to read from. [Example: “functions.m”]

**source**
The literal Matlab (https://www.mathworks.com/products/matlab.html) code to execute, when the script option is not being used.

**add_dimension**
The name of a dimension to add to the pipeline that does not already exist.

**struct**
Array structure name to read [Default: “PDAL”]

**where**
An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**
A strategy for merging points skipped by a ‘where’ option when running in standard
mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.python

The Python Filter allows Python (http://python.org/) software to be embedded in a Pipeline (page 55) that allows modification of PDAL points through a NumPy (http://www.numpy.org/) array. Additionally, some global Metadata (page 545) is also available that Python functions can interact with.

The function must have two NumPy (http://www.numpy.org/) arrays as arguments, ins and outs. The ins array represents the points before the filters.python filter and the outs array represents the points after filtering.

```
Warning: Make sure NumPy (http://www.numpy.org/) is installed in your Python (http://python.org/) environment.

$ python3 -c "import numpy; print(numpy.__version__)"
1.18.1
```

```
Warning: Each array contains all the Dimensions (page 359) of the incoming ins point schema. Each array in the outs list matches the NumPy (http://www.numpy.org/) array of the same type as provided as ins for shape and type.
```

Dynamic Plugin

This stage requires a dynamic plugin to operate

```
import numpy as np

def multiply_z(ins,outs):
    Z = ins['Z']
    Z = Z * 10.0
    outs['Z'] = Z
    return True
```
1) The function must always return \textit{True} upon success. If the function returned \textit{False}, an error would be thrown and the \textit{Pipeline} (page 55) exited.

2) If you want write a dimension that might not be available, you can specify it with the \textit{add\_dimension} (page 353) option:

\begin{verbatim}
"add_dimension": "NewDimensionOne"
\end{verbatim}

To create more than one dimension, this option also accepts an array:

\begin{verbatim}
"add_dimension": [ "NewDimensionOne", "NewDimensionTwo",
                  "NewDimensionThree" ]
\end{verbatim}

You can also specify the \textit{type} (page 367) of the dimension using an =.

\begin{verbatim}
"add_dimension": "NewDimensionOne=uint8"
\end{verbatim}

**Modification Example**

\begin{verbatim}
[
    "file-input.las",
    {
      "type":"filters.smrf"
    },
    {
      "type":"filters.python",
      "script":"multiply_z.py",
      "function":"multiply_z",
      "module":"anything"
    },
    {
      "type":"writers.las",
      "filename":"file-filtered.las"
    }
]
\end{verbatim}

The JSON pipeline file referenced the external \textit{multiply\_z.py} Python (http://python.org/) script, which scales the Z coordinate by a factor of 10.

```python
import numpy as np
def multiply_z(ins,outs):
    Z = ins['Z']
    Z = Z * 10.0
```

(continues on next page)
Predicates

Points can be retained/removed from the stream by setting true/false values into a special “Mask” dimension in the output point array.

The example above sets the “mask” to true for points that are in classifications 1 or 2 and to false otherwise, causing points that are not classified 1 or 2 to be dropped from the point stream.

```python
import numpy as np

def filter(ins, outs):
    cls = ins['Classification']
    keep_classes = [1, 2]

    # Use the first test for our base array.
    keep = np.equal(cls, keep_classes[0])

    # For 1:n, test each predicate and join back
to our existing predicate array
    for k in range(1, len(keep_classes)):
        t = np.equal(cls, keep_classes[k])
        keep = keep + t

    outs['Mask'] = keep
    return True
```

Note: *filters.range* (page 313) is a specialized filter that implements the exact functionality described in this Python operation. It is likely to be much faster than Python, but not as flexible. *filters.python* (page 348) is the tool you can use for prototyping point stream processing operations.

See also:

If you want to read a *Pipeline* (page 55) of operations into a numpy array, the PDAL Python extension (https://pypi.python.org/pypi/PDAL) is available.
Example pipeline

```
[  
    "file-input.las",
    {
        "type":"filters.smrf"
    },
    {
        "type":"filters.python",
        "script":"filter_pdal.py",
        "function":"filter",
        "module":"anything"
    },
    {
        "type":"writers.las",
        "filename":"file-filtered.las"
    }
]
```

Module Globals

Three global variables are added to the Python module as it is run to allow you to get Dimensions (page 359), Metadata (page 545), and coordinate system information. Additionally, the metadata object can be set by the function to modify metadata for the in-scope filters.python (page 348) pdal::Stage (page 639).

```python
def myfunc(ins,outs):
    print('schema: ', schema)
    print('srs: ', spatialreference)
    print('metadata: ', metadata)
    outs = ins
    return True
```

Setting stage metadata

**Note:** The name of the output metadata variable has changed from metadata to out_metadata.

Stage metadata can be created by using the out_metadata dictionary global variable. The name key must be set. The type of the value can usually be inferred, but can be set to one of

7.5. Filters 351
integer, nonNegativeInteger, double, bounds, boolean, spatialreference, uuid or string.

Children may be set using the children key whose value is a list of dictionaries.

```python
def myfunc(ins, outs):
    global out_metadata
    out_metadata = {
        'name': 'root', 'value': 'a string', 'type': 'string',
        'description': 'a description', 'children': [{
            'name': 'somekey', 'value': 52, 'type': 'integer',
            'description': 'a filter description', 'children': []}, {
            'name': 'readers.faux', 'value': 'another string',
            'type': 'string', 'description': 'a reader description',
            'children': []}
        ],
        'description': 'a description'}
    return True
```

**Passing Python objects**

An JSON-formatted option can be passed to the filter representing a Python dictionary containing objects you want to use in your function. This feature is useful in situations where you wish to call `pipeline` (page 41) with substitutions.

If we needed to be able to provide the Z scaling factor of *Example Pipeline* (page 351) with a Python argument, we can place that in a dictionary and pass that to the filter as a separate argument. This feature allows us to be able easily reuse the same basic Python function while substituting values as necessary.

```json
[
    "input.las",
    {
        "type": "filters.python",
        "module": "anything",
        "function": "filter",
        "script": "arguments.py",
        "pdalargs": "{"factor":0.3048, "an_argument":42, "another": "a string"}"
    },
    "output.las"
]
```

With that option set, you can now fetch the `pdalargs` (page 353) dictionary in your Python script and use it:

```python
import numpy as np
```

(continues on next page)
def multiply_z(ins, outs):
    Z = ins['Z']
    Z = Z * float(pdalargs['factor'])
    outs['Z'] = Z
    return True

Standard output and error

A redirector module is available for scripts to output to PDAL's log stream explicitly. The module handles redirecting `sys.stderr` and `sys.stdout` for you transparently, but it can be used directly by scripts. See the PDAL source code for more details.

Options

script
   When reading a function from a separate Python (http://python.org/) file, the file name to read from.

source
   The literal Python (http://python.org/) code to execute, when the script option is not being used.

module
   The Python module that is holding the function to run. [Required]

function
   The function to call. [Required]

add_dimension
   A dimension name or an array of dimension names to add to the pipeline that do not already exist.

pdalargs
   A JSON dictionary of items you wish to pass into the modules globals as the pdalargs object.

where
   An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
   A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto,
skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.julia

The Julia Filter allows Julia (https://julialang.org/) software to be embedded in a Pipeline (page 55) that allows modification of PDAL points through a TypedTables (https://github.com/JuliaData/TypedTables.jl) datatype.

The supplied julia function must take a TypedTables (https://github.com/JuliaData/TypedTables.jl) FlexTable as an argument and return the same object (with modifications).

Warning: The returned Table contains all the Dimensions (page 359) of the incoming ins Table

Dynamic Plugin

This stage requires a dynamic plugin to operate

```
module MyModule
    using TypedTables

    function multiply_z(ins)
        for n in 1:length(ins)
            ins[n] = merge(ins[n], (; :Z => row.Z * 10.0))
        end
        return ins
    end
end
```

If you want write a dimension that might not be available, you can specify it with the add_dimension option:

```
"add_dimension": "NewDimensionOne"
```
To create more than one dimension, this option also accepts an array:

::

    "add_dimension": [ "NewDimensionOne", "NewDimensionTwo", 
                      "NewDimensionThree" ]

You can also specify the :ref:`type <types>` of the dimension using an:

::

    "add_dimension": "NewDimensionOne=uint8"

**Filter Example**

```json
[ 
  "file-input.las",
  {
    "type": "filters.smrf"
  },
  {
    "type": "filters.julia",
    "script": "filter_z.jl",
    "function": "filter_z",
    "module": "MyModule"
  },
  {
    "type": "writers.las",
    "filename": "file-filtered.las"
  }
]
```

The JSON pipeline file referenced the external `filter_z.jl` Julia (https://julialang.org/) script, which removes points with the Z coordinate by less than 420.

```julia
module MyModule

using TypedTables

function filter_z(ins)
    return filter(p -> p.Z > 420, ins)

(continues on next page)```
Modification Example

```json
[
  "file-input.las",
  {
    "type":"filters.smrf"
  },
  {
    "type":"filters.julia",
    "script":"multiply_z.jl",
    "function":"multiply_z",
    "module":"MyModule"
  },
  {
    "type":"writers.las",
    "filename":"file-modified.las"
  }
]
```

The JSON pipeline file referenced the external `multiply_z.jl` Julia (https://julialang.org/) script, which scales the Z coordinate by a factor of 10.

```julia
module MyModule

using TypedTables

function multiply_z(ins)
    for n in 1:length(ins)
        ins[n] = merge(ins[n], (; :Z => row.Z * 10.0))
    end
    return ins
end

end
```
Options

script
   When reading a function from a separate Julia (https://julialang.org/) file, the file name to read from.

source
   The literal Julia (https://julialang.org/) code to execute, when the script option is not being used.

module
   The Julia module that is holding the function to run. [Required]

function
   The function to call. [Required]

add_dimension
   A dimension name or an array of dimension names to add to the pipeline that do not already exist.

where
   An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge
   A strategy for merging points skipped by a ‘where’ option when running in standard mode. If true, the skipped points are added to the first point view returned by the skipped filter. If false, skipped points are placed in their own point view. If auto, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.matlab (page 346)
   Embed MATLAB software in a pipeline.

filters.python (page 348)
   Embed Python software in a pipeline.

filters.julia (page 354)
   Embed Julia software in a pipeline.
7.5.10 Other

**filters.streamcallback**

The **Stream Callback Filter** provides a simple hook for a user-specified action to occur for each point. The stream callback filter is for use by C++ programmers extending PDAL functionality and isn’t useful to end users.

**Default Embedded Stage**

This stage is enabled by default

**Streamable Stage**

This stage supports streaming operations

**Options**

**where**

An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

**where_merge**

A strategy for merging points skipped by a ‘where’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

**filters.streamcallback** (page 358)

Provide a hook for a simple point-by-point callback.
8.1 Dimensions

All point data in PDAL is stored as a set of dimensions. Dimensions have a name and a data type. The data type is determined at runtime, but a default data type for each dimension is listed below, along with the name of the dimension and its description.

The following table provides a list of known dimension names you can use in Filters (page 192), Writers (page 139), and Readers (page 65).

Note: Types are default types. Stage developers should set the dimension type explicitly if the default dimension isn’t suitable.

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>uint16</td>
<td>Alpha</td>
</tr>
<tr>
<td>Amplitude</td>
<td>float</td>
<td>This is the ratio of the received power to the power received at the detection limit expressed in dB</td>
</tr>
<tr>
<td>Anisotropy</td>
<td>double</td>
<td>Anisotropy of a point; larger values indicate strong variance in multiple dimensions.</td>
</tr>
<tr>
<td>Azimuth</td>
<td>double</td>
<td>Scanner azimuth</td>
</tr>
<tr>
<td>BackgroundRadiation</td>
<td>float</td>
<td>A measure of background radiation.</td>
</tr>
<tr>
<td>BeamDirectionX</td>
<td>double</td>
<td>Beam direction unit vector X coordinate</td>
</tr>
<tr>
<td>BeamDirectionY</td>
<td>double</td>
<td>Beam direction unit vector Y coordinate</td>
</tr>
<tr>
<td>BeamDirectionZ</td>
<td>double</td>
<td>Beam direction unit vector Z coordinate</td>
</tr>
<tr>
<td>Name</td>
<td>Type</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------</td>
<td>----------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>BeamOriginX</td>
<td>double</td>
<td>Beam origin X coordinate of current laser shot</td>
</tr>
<tr>
<td>BeamOriginY</td>
<td>double</td>
<td>Beam origin Y coordinate of current laser shot</td>
</tr>
<tr>
<td>BeamOriginZ</td>
<td>double</td>
<td>Beam origin Z coordinate of current laser shot</td>
</tr>
<tr>
<td>Blue</td>
<td>uint16</td>
<td>Blue image channel value</td>
</tr>
<tr>
<td>ClassFlags</td>
<td>uint8</td>
<td>Class Flags - deprecated in favor of Synthetic/KeyPoint/Withheld/Overlap</td>
</tr>
<tr>
<td>Classification</td>
<td>uint8</td>
<td>ASPRS classification. 0 for no classification. See LAS specification for details.</td>
</tr>
<tr>
<td>ClusterID</td>
<td>int64_t</td>
<td>ID assigned to a point by a point-clustering algorithm.</td>
</tr>
<tr>
<td>Coplanar</td>
<td>uint8</td>
<td>Indicator of whether or not a point is part of a coplanar neighborhood.</td>
</tr>
<tr>
<td>Curvature</td>
<td>double</td>
<td>Curvature of surface at this point</td>
</tr>
<tr>
<td>DemantkeVerticality</td>
<td>double</td>
<td>Verticality of a point; larger values indicate vertical structure (Demantke’s variation).</td>
</tr>
<tr>
<td>Density</td>
<td>double</td>
<td>Estimate of point density</td>
</tr>
<tr>
<td>Deviation</td>
<td>float</td>
<td>Difference between the shape of the reference pulse and the return pulse. A larger value for deviation indicates larger distortion.</td>
</tr>
<tr>
<td>Dimension</td>
<td>uint8</td>
<td>Dimension of the points. three types of dimensions are available (Linear : points form a linear feature. Planar : points form a planar surface. Complex : random group of points).</td>
</tr>
<tr>
<td>DownPositionRMS</td>
<td>double</td>
<td>Down position RMS error</td>
</tr>
<tr>
<td>DownVelocityRMS</td>
<td>double</td>
<td>Down velocity RMS error</td>
</tr>
<tr>
<td>EastPositionRMS</td>
<td>double</td>
<td>East position RMS error</td>
</tr>
<tr>
<td>EastVelocityRMS</td>
<td>double</td>
<td>East velocity RMS error</td>
</tr>
<tr>
<td>EchoNorm</td>
<td>double</td>
<td>Difference in shape of a return signal compared to a typical return from a hard surface.</td>
</tr>
<tr>
<td>EchoPos</td>
<td>double</td>
<td>Difference in position of a peak of a return signal compared to a typical return from a hard surface.</td>
</tr>
<tr>
<td>EchoRange</td>
<td>double</td>
<td>Echo Range</td>
</tr>
<tr>
<td>EdgeOfFlightLine</td>
<td>uint8</td>
<td>Indicates the end of scanline before a direction change with a value of 1 - 0 otherwise</td>
</tr>
</tbody>
</table>
### Table 1 – continued from previous page

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigenentropy</td>
<td>double</td>
<td>Eigenentropy of a point; small values indicate more ordered regions, while large values indicate disorder.</td>
</tr>
<tr>
<td>Eigenvalue0</td>
<td>double</td>
<td>Smallest eigenvalue obtained form covariance of XYZ coordinates in k-neighborhood.</td>
</tr>
<tr>
<td>Eigenvalue1</td>
<td>double</td>
<td>Middle eigenvalue obtained form covariance of XYZ coordinates in k-neighborhood.</td>
</tr>
<tr>
<td>Eigenvalue2</td>
<td>double</td>
<td>Largest eigenvalue obtained form covariance of XYZ coordinates in k-neighborhood.</td>
</tr>
<tr>
<td>Eigenvalue-Sum</td>
<td>double</td>
<td>Sum of computed eigenvalues.</td>
</tr>
<tr>
<td>ElevationCentroid</td>
<td>double</td>
<td>Elevation Centroid</td>
</tr>
<tr>
<td>ElevationHigh</td>
<td>double</td>
<td>Elevation High</td>
</tr>
<tr>
<td>ElevationLow</td>
<td>double</td>
<td>Elevation Low</td>
</tr>
<tr>
<td>Flag</td>
<td>uint8</td>
<td>Flag</td>
</tr>
<tr>
<td>GpsTime</td>
<td>double</td>
<td>GPS time that the point was acquired</td>
</tr>
<tr>
<td>Green</td>
<td>uint16</td>
<td>Green image channel value</td>
</tr>
<tr>
<td>HeadingRMS</td>
<td>double</td>
<td>Heading RMS error</td>
</tr>
<tr>
<td>HeightAbove-Ground</td>
<td>double</td>
<td>Height Above Ground</td>
</tr>
<tr>
<td>Image</td>
<td>uint16</td>
<td>Index of the image use for texturation.</td>
</tr>
<tr>
<td>ImgNbr</td>
<td>uint8</td>
<td>Stores the number of the image from which it gets the color.</td>
</tr>
<tr>
<td>Infrared</td>
<td>uint16</td>
<td>Infrared</td>
</tr>
<tr>
<td>Intensity</td>
<td>uint16</td>
<td>Representation of the pulse return magnitude</td>
</tr>
<tr>
<td>InternalTime</td>
<td>double</td>
<td>Scanner’s internal time when the point was acquired, in seconds</td>
</tr>
<tr>
<td>IsPpsLocked</td>
<td>uint8</td>
<td>The external PPS signal was found to be synchronized at the time of the current laser shot.</td>
</tr>
<tr>
<td>KeyPoint</td>
<td>uint8</td>
<td>ASPRS Key-Point flag. See LAS specification for details.</td>
</tr>
<tr>
<td>LatitudeCentroid</td>
<td>double</td>
<td>Latitude Centroid</td>
</tr>
<tr>
<td>LatitudeHigh</td>
<td>double</td>
<td>Latitude High</td>
</tr>
<tr>
<td>LatitudeLow</td>
<td>double</td>
<td>Latitude Low</td>
</tr>
<tr>
<td>Linearity</td>
<td>double</td>
<td>Linearity of a point; larger values indicate more linear regions.</td>
</tr>
</tbody>
</table>
Table 1 – continued from previous page

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LocalOutlierFactor</td>
<td>double</td>
<td>Outlier factor based on the LocalReachabilityDistance of a point’s nearest neighbors.</td>
</tr>
<tr>
<td>LocalReachabilityDistance</td>
<td>double</td>
<td>Reachability metric based on the NNDistance of a point’s nearest neighbors.</td>
</tr>
<tr>
<td>LongitudeCentroid</td>
<td>double</td>
<td>Longitude Centroid</td>
</tr>
<tr>
<td>LongitudeHigh</td>
<td>double</td>
<td>Longitude High</td>
</tr>
<tr>
<td>LongitudeLow</td>
<td>double</td>
<td>Longitude Low</td>
</tr>
<tr>
<td>LvisLfid</td>
<td>uint64</td>
<td>LVIS_LFID</td>
</tr>
<tr>
<td>Mark</td>
<td>uint8</td>
<td>Mark</td>
</tr>
<tr>
<td>Miniball</td>
<td>double</td>
<td>Metric capturing distance from a point to the center of the smallest enclosing ball encapsulating k-nearest neighbors, scaled by radius of the ball.</td>
</tr>
<tr>
<td>NNDistance</td>
<td>double</td>
<td>Distance metric related to a point’s nearest neighbors.</td>
</tr>
<tr>
<td>NormalX</td>
<td>double</td>
<td>X component of a vector normal to surface at this point</td>
</tr>
<tr>
<td>NormalY</td>
<td>double</td>
<td>Y component of a vector normal to surface at this point</td>
</tr>
<tr>
<td>NormalZ</td>
<td>double</td>
<td>Z component of a vector normal to surface at this point</td>
</tr>
<tr>
<td>NorthPositionRMS</td>
<td>double</td>
<td>North position RMS error</td>
</tr>
<tr>
<td>NorthVelocityRMS</td>
<td>double</td>
<td>North velocity RMS error</td>
</tr>
<tr>
<td>NumberOfReturns</td>
<td>uint8</td>
<td>Total number of returns for a given pulse.</td>
</tr>
<tr>
<td>OffsetTime</td>
<td>uint32</td>
<td>Milliseconds from first acquired point</td>
</tr>
<tr>
<td>Omit</td>
<td>uint8_t</td>
<td>Used to shallowly mark a point as being omitted without removing it</td>
</tr>
<tr>
<td>Omnivariance</td>
<td>double</td>
<td>Omnivariance of a point; cube root of the product of all eigenvalues.</td>
</tr>
<tr>
<td>OptimalKNN</td>
<td>uint64</td>
<td>Optimal number of k nearest neighbors, such that eigenentropy is minimized.</td>
</tr>
<tr>
<td>OptimalRadius</td>
<td>double</td>
<td>Radius corresponding to optimal k nearest neighbors, such that eigenentropy is minimized.</td>
</tr>
<tr>
<td>OriginId</td>
<td>uint32</td>
<td>A file source ID from which the point originated. This ID is global to a derivative dataset which may be aggregated from multiple files.</td>
</tr>
<tr>
<td>Overlap</td>
<td>uint8</td>
<td>ASPRS Overlap flag. See LAS specification for details.</td>
</tr>
</tbody>
</table>

continues on next page
## Table 1 – continued from previous page

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PassiveSignal</td>
<td>int32</td>
<td>Relative passive signal</td>
</tr>
<tr>
<td>PassiveX</td>
<td>double</td>
<td>Passive X footprint</td>
</tr>
<tr>
<td>PassiveY</td>
<td>double</td>
<td>Passive Y footprint</td>
</tr>
<tr>
<td>PassiveZ</td>
<td>double</td>
<td>Passive Z footprint</td>
</tr>
<tr>
<td>Pdop</td>
<td>float</td>
<td>GPS PDOP (dilution of precision)</td>
</tr>
<tr>
<td>Pitch</td>
<td>float</td>
<td>Pitch in degrees</td>
</tr>
<tr>
<td>PitchRMS</td>
<td>double</td>
<td>Pitch RMS error</td>
</tr>
<tr>
<td>Planarity</td>
<td>double</td>
<td>Planarity of a point; larger values indicate more planar regions.</td>
</tr>
<tr>
<td>PlaneFit</td>
<td>double</td>
<td>Metric capturing current point's point to plane distance compared to those in the same k-neighborhood used to estimate the plane.</td>
</tr>
<tr>
<td>PointId</td>
<td>uint32</td>
<td>An explicit representation of point ordering within a file, which allows this usually-implicit information to be preserved when reordering points.</td>
</tr>
<tr>
<td>PointSourceId</td>
<td>uint16</td>
<td>File source ID from which the point originated. Zero indicates that the point originated in the current file</td>
</tr>
<tr>
<td>PulseWidth</td>
<td>float</td>
<td>Laser received pulse width (digitizer samples)</td>
</tr>
<tr>
<td>RadialDensity</td>
<td>double</td>
<td>Estimate of radial point density</td>
</tr>
<tr>
<td>Rank</td>
<td>uint8</td>
<td>Estimated rank of neighborhood of points.</td>
</tr>
<tr>
<td>Reciprocity</td>
<td>double</td>
<td>Metric capturing percentage of k-nearest neighbors that also contain the current point in their k-neighborhood.</td>
</tr>
<tr>
<td>Red</td>
<td>uint16</td>
<td>Red image channel value</td>
</tr>
<tr>
<td>Reflectance</td>
<td>float</td>
<td>Ratio of the received power to the power that would be received from a white diffuse target at the same distance expressed in dB. The reflectance represents a range independent property of the target. The surface normal of this target is assumed to be in parallel to the laser beam direction.</td>
</tr>
<tr>
<td>ReflectedPulse</td>
<td>int32</td>
<td>Relative reflected pulse signal strength</td>
</tr>
<tr>
<td>Reliability</td>
<td>double</td>
<td>Reliability (or confidence) of points</td>
</tr>
<tr>
<td>ReturnNumber</td>
<td>uint8</td>
<td>Pulse return number for a given output pulse. A given output laser pulse can have many returns, and they must be marked in order, starting with 1</td>
</tr>
<tr>
<td>Roll</td>
<td>float</td>
<td>Roll in degrees</td>
</tr>
<tr>
<td>RollRMS</td>
<td>double</td>
<td>Roll RMS error</td>
</tr>
</tbody>
</table>

continues on next page
Table 1 – continued from previous page

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ScanAngleRank</td>
<td>float</td>
<td>Angle degree at which the laser point was output from the system, including the roll of the aircraft. The scan angle is based on being nadir, and -90 the left side of the aircraft in the direction of flight.</td>
</tr>
<tr>
<td>ScanChannel</td>
<td>uint8</td>
<td>Scan Channel</td>
</tr>
<tr>
<td>ScanDirectionFlag</td>
<td>uint8</td>
<td>Direction at which the scanner mirror was traveling at the time of the output pulse. A value of 1 is a positive scan direction, and a bit value of 0 is a negative scan direction, where positive scan direction is a scan moving from the left side of the in-track direction to the right side and negative the opposite.</td>
</tr>
<tr>
<td>Scattering</td>
<td>double</td>
<td>Scattering of a point; larger values indicate complex (scattered) 3D regions.</td>
</tr>
<tr>
<td>ShotNumber</td>
<td>uint64</td>
<td>Shot Number</td>
</tr>
<tr>
<td>SphericalAzimuth</td>
<td>double</td>
<td>Azimuth in context of spherical coordinates.</td>
</tr>
<tr>
<td>SphericalElevation</td>
<td>double</td>
<td>Elevation in context of spherical coordinates.</td>
</tr>
<tr>
<td>SphericalRange</td>
<td>double</td>
<td>Range in context of spherical coordinates.</td>
</tr>
<tr>
<td>StartPulse</td>
<td>int32</td>
<td>Relative pulse signal strength</td>
</tr>
<tr>
<td>SurfaceVariation</td>
<td>double</td>
<td>Surface variation of a point; larger values indicate higher surface variation.</td>
</tr>
<tr>
<td>Synthetic</td>
<td>uint8</td>
<td>ASPRS Synthetic flag. See LAS specification for details.</td>
</tr>
<tr>
<td>TextureU</td>
<td>double</td>
<td>U component of a texture location at this point</td>
</tr>
<tr>
<td>TextureV</td>
<td>double</td>
<td>V component of a texture location at this point</td>
</tr>
<tr>
<td>TextureW</td>
<td>double</td>
<td>W component of a texture location at this point</td>
</tr>
<tr>
<td>UserData</td>
<td>uint8</td>
<td>Unspecified user data</td>
</tr>
<tr>
<td>Verticality</td>
<td>double</td>
<td>Verticality of a point; larger values indicate vertical structure.</td>
</tr>
<tr>
<td>W</td>
<td>double</td>
<td>W coordinate</td>
</tr>
<tr>
<td>WanderAngle</td>
<td>double</td>
<td>Wander Angle</td>
</tr>
<tr>
<td>Withheld</td>
<td>uint8</td>
<td>ASPRS Withheld flag. See LAS specification for details.</td>
</tr>
<tr>
<td>X</td>
<td>double</td>
<td>X coordinate</td>
</tr>
<tr>
<td>XBodyAccel</td>
<td>double</td>
<td>X Body Acceleration</td>
</tr>
</tbody>
</table>

continues on next page
Table 1 – continued from previous page

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>XBodyAngRate</td>
<td>double</td>
<td>X Body Angle Rate</td>
</tr>
<tr>
<td>XVelocity</td>
<td>double</td>
<td>X Velocity</td>
</tr>
<tr>
<td>Y</td>
<td>double</td>
<td>Y coordinate</td>
</tr>
<tr>
<td>YBodyAccel</td>
<td>double</td>
<td>Y Body Acceleration</td>
</tr>
<tr>
<td>YBodyAngRate</td>
<td>double</td>
<td>Y Body Angle Rate</td>
</tr>
<tr>
<td>YVelocity</td>
<td>double</td>
<td>Y Velocity</td>
</tr>
<tr>
<td>Z</td>
<td>double</td>
<td>Z coordinate</td>
</tr>
<tr>
<td>ZBodyAccel</td>
<td>double</td>
<td>Z Body Acceleration</td>
</tr>
<tr>
<td>ZBodyAngRate</td>
<td>double</td>
<td>Z Body Angle Rate</td>
</tr>
<tr>
<td>ZVelocity</td>
<td>double</td>
<td>Z Velocity</td>
</tr>
</tbody>
</table>
9.1 Types

PDAL supports the standard integral and floating point types for dimensions (page 359). This table lists the types and associated strings that can be used to describe the types in options.

<table>
<thead>
<tr>
<th>Type</th>
<th>Size in Bits</th>
<th>Text Representations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signed Integer</td>
<td>8</td>
<td>int8, int8_t, char</td>
</tr>
<tr>
<td>Signed Integer</td>
<td>16</td>
<td>int16, int16_t, short</td>
</tr>
<tr>
<td>Signed Integer</td>
<td>32</td>
<td>int32, int32_t, int</td>
</tr>
<tr>
<td>Signed Integer</td>
<td>64</td>
<td>int64, int64_t, long</td>
</tr>
<tr>
<td>Unsigned Integer</td>
<td>8</td>
<td>uint8, uint8_t, uchar</td>
</tr>
<tr>
<td>Unsigned Integer</td>
<td>16</td>
<td>uint16, uint16_t, ushort</td>
</tr>
<tr>
<td>Unsigned Integer</td>
<td>32</td>
<td>uint32, uint32_t, uint</td>
</tr>
<tr>
<td>Unsigned Integer</td>
<td>64</td>
<td>uint64, uint64_t, ulong</td>
</tr>
<tr>
<td>Floating Point</td>
<td>32</td>
<td>float, float32</td>
</tr>
<tr>
<td>Floating Point</td>
<td>64</td>
<td>double, float64</td>
</tr>
</tbody>
</table>
10.1 Python

PDAL provides Python support in two significant ways. First it embeds Python to allow you to write Python programs that interact with data using filters.python (page 348) filter. Second, it extends Python by providing an extension that Python programmers can use to leverage PDAL capabilities in their own applications.

Note: PDAL’s Python story always revolves around Numpy (http://www.numpy.org/) support. PDAL’s data is provided to both the filters and the extension as Numpy arrays.

10.1.1 Versions

PDAL supports both Python 3.5+. Continuous Integration (page 599) tests Python Linux, OSX, and Windows.

10.1.2 Embed

PDAL allows users to embed Python functions inline with other Pipeline (page 55) processing operations. The purpose of this capability is to allow users to write small programs that implement interesting actions without requiring a full C++ development activity of building a PDAL stage to implement it. A Python filter is an opportunity to interactively and iteratively prototype a data operation without strong considerations of performance or generality. If something works well enough, maybe one takes on the effort to formalize it, but that isn’t necessary. PDAL’s embed of Python allows you to be as grimy as you need to get the job done.
10.1.3 Extend

PDAL provides a Python extension (https://pypi.python.org/pypi/PDAL) that gives users access to executing pipeline (page 55) instantiations and capturing the results as Numpy (http://www.numpy.org/) arrays. This mode of operation is useful if you are looking to have PDAL simply act as your data format and processing handler.

Python extension users are expected to construct their own PDAL pipeline (page 55) using Python’s json library, or whatever other libraries they wish to manipulate JSON. They then feed it into the extension and get back the results as Numpy (http://www.numpy.org/) arrays:

```python
json = """
[  
    "1.2-with-color.las",
    {  
      "type": "filters.sort",
      "dimension": "X"
    }
  ]
"""

import pdal
pipeline = pdal.Pipeline(json)
count = pipeline.execute()
arrays = pipeline.arrays
metadata = pipeline.metadata
log = pipeline.log
```

Fig. 1: Embedding a Python function to take Z values read from a readers.las (page 89) and then output them to a writers.bpf (page 141).
Installation

The PDAL Python extension requires a working PDAL installation (page 13). Unless you choose the Conda installation method, make sure that you have a current, working version of PDAL before installing the extension.

Note: Previous to PDAL 2.1, Python support was spread across the embedded stages (readers.numpy (page 98) and filters.python (page 348)) which were installed by PDAL itself and the PDAL extension that was installed from PyPI. As of PDAL 2.1 and PDAL/python 2.3, both the embedded stages and the extension are installed from PyPI.

Installation Using pip

As administrator, you can install PDAL using pip:

```
pip install PDAL
```

Note: To install pip please read here (https://pip.pypa.io/en/stable/installing/)

Installation from Source

PDAL Python support is hosted in a separate repository than PDAL itself at GitHub (https://github.com/PDAL/python). If you have a working PDAL installation and a working Python installation, you can install the extension using the following procedure on Unix. The procedure on Windows is similar

```
$ git clone https://github.com/PDAL/python pdalextension
$ cd pdalextension
$ pip install .
```

Install using Conda

The PDAL Python support can also be installed using the Conda (https://conda.io/docs/) package manager. An advantage of using Conda to install the extension is that Conda will install PDAL. We recommend installing PDAL and the PDAL Python extension in an environment other than the base environment. To install in an existing environment, use the following
Use the following command to install PDAL and the PDAL Python extension into a new environment and activate that environment:

```
conda install -n <environment name> -c conda-forge python-pdal
```

```
conda create -n <environment name> -c conda-forge python-pdal
conda activate <environment name>
```

**Note:** The official `pdal` and `python-pdal` packages reside in the conda-forge channel, which can be added via `conda config` or manually specified with the `-c` option, as shown in the examples above.
11.1 Java

PDAL provides Java bindings to use PDAL on JVM (https://github.com/PDAL/java). It is released independently from PDAL itself as of PDAL 1.7. Native binaries are prebuilt for Linux and MacOS and delivered in a jar, so there is no need in building PDAL with a special flag or building JNI binaries manually.

The project consists of the following modules:

- **pdal-native** - with packed OS specific libraries to link PDAL to JNI proxy classes. Dependency contains bindings for x86_64-darwin and x86_64-linux, other versions are not supported yet.
- **pdal** - with the core bindings functionality.
- **pdal-scala** - a Scala API package that simplifies PDAL Pipeline construction.

11.1.1 Versions

PDAL JNI major version usually follows PDAL versioning i.e. pdal-java 1.8.x was built and tested against PDAL 1.8.x and pdal-java 2.1.x against PDAL 2.x.x.

11.1.2 Using PDAL Java bindings

PDAL provides JNI bindings (https://docs.oracle.com/javase/8/docs/technotes/guides/jni/index.html) that gives users access to executing *pipeline* (page 55) instantiations and capturing the results in Java interfaces. This mode of operation is useful if you are looking to have PDAL simply act as your data format and processing handler.

Users are expected to construct their own PDAL *pipeline* (page 55), execute it, and retrieve points into Java memory:
```java
import io.pdal_

val json = ""
  |
  | "pipeline": [        
  |   {                 
  |     "filename": "1.2-with-color.las",     
  |     "spatialreference": "EPSG:2993"    
  |   },             
  |   {             
  |     "type": "filters.reprojection",      
  |     "out_srs": "EPSG:3857"           
  |   },         
  |   {               
  |     "type": "filters.delaunay"                  
  |   }          
  | ]       
""".stripMargin

val pipeline = Pipeline(json)
pipeline.validate() // check if our JSON and options were good
pipeline.setLogLevel(8) // make it really noisy
pipeline.execute() // execute the pipeline

val metadata: String = pipeline.getMetadata() // retrieve metadata
val pvs: PointViewIterator = pipeline.getPointViews() // iterator over PointViews
val pv: PointView = pvs.next() // let's take the first PointView

// load all points into JVM memory
// PointCloud provides operations on PDAL points that are loaded in this case into JVM memory as a single Array[Byte]
val pointCloud: PointCloud = pv.getPointCloud()
val x: Double = pointCloud.getDouble(0, DimType.X) // get a point with PointId = 0 and only a single dimensions

// in some cases it is not neccesary to load everything into JVM memory // so it is possible to get only required points directly from the PointView
val y: Double = pv.getDouble(0, DimType.Y)

// it is also possible to get access to the triangular mesh generated
```
11.1.3 Using PDAL Scala

PDAL Scala project introduces a DSL to simplify PDAL Pipeline construction (this is the same pipeline from the section above):

```scala
import io.pdal._
import io.pdal.pipeline._

val expression =
  ReadLas("1.2-with-color.las", spatialreference = Some("EPSG:2993")) ~
  FilterReprojection("EPSG:3857") ~
  FilterDelaunay()

val pipeline = expression.toPipeline
pipeline.validate() // check if our JSON and options were good
pipeline.setLogLevel(8) // make it really noisy
pipeline.execute() // execute the pipeline
val metadata: String = pipeline.getMetadata() // retrieve metadata
val pvs: PointViewIterator = pipeline.getPointViews() // iterator over PointViews
val pv: PointView = pvs.next() // let's take the first PointView

// load all points into JVM memory
// PointCloud provides operations on PDAL points that
// are loaded in this case into JVM memory as a single Array[Byte]
val pointCloud: PointCloud = pv.getPointCloud()
val x: Double = pointCloud.getDouble(0, DimType.X) // get a point with PointId = 0 and only a single dimensions

// in some cases it is not neccesary to load everything into JVM memory
// so it is possible to get only required points directly from the PointView
```

(continues on next page)
val y: Double = pv.getDouble(0, DimType.Y)

// it is also possible to get access to the triangular mesh generated via PDAL
val mesh: TriangularMesh = pv.getTriangularMesh()
// the output is an Array of Triangles
// Each Triangle contains PointIds from the PDAL point table
val triangles: Array[Triangle] = mesh.asArray

It covers PDAL 2.0.x, but to use any custom DSL that is not covered by the current Scala API you can use RawExpr type to build a Pipeline Expression:

```scala
import io.pdal._
import io.pdal.pipeline._
import io.circe.syntax._

val pipelineWithRawExpr =
  ReadLas("1.2-with-color.las") ~
  RawExpr(Map("type" -> "filters.crop").asJson) ~
  WriteLas("1.2-with-color-out.las")
```

**Installation**

PDAL Java artifacts are cross published for Scala 2.13, 2.12 and 2.11. However, if it is not required, a separate artifact that has no Scala specific artifact postfix is published as well.

```scala
// pdal is published to maven central, but you can use following repos in addition
resolvers ++= Seq(
  Resolver.sonatypeRepo("releases"),
  Resolver.sonatypeRepo("snapshots") // for snapshots
)

libraryDependencies ++= Seq(
  "io.pdal" %% "pdal" % "x.x.x", // core library
  "io.pdal" % "pdal-native" % "x.x.x", // jni binaries
  "io.pdal" %% "pdal-scala" % "x.x.x" // if scala core library (if required)
)
```
The latest version is: https://search.maven.org/search?q=g:io.pdal

There is also an example SBT PDAL Demo project (https://github.com/PDAL/java/tree/master/examples/pdal-jni) in the bindings repository, that can be used for a quick start.

**Compilation**

**Development purposes (including binaries) compilation:**

1. Install PDAL (using brew / package managers (unix) / build from sources / etc)
2. Build native libs ./sbt native/nativeCompile (optionally, binaries would be built during tests run)
3. Run ./sbt core/test to run PDAL tests

**Only Java development purposes compilation:**

1. Provide $LD_LIBRARY_PATH or $DYLD_LIBRARY_PATH
2. If you don’t want to provide global variable you can pass -Djava.library.path=<path> into sbt:
   
   ./sbt -Djava.library.path=<path>
3. Set PDAL_DEPEND_ON_NATIVE=false (to disable native project build)
4. Run PDAL_DEPEND_ON_NATIVE=false ./sbt

If you would like to use your own bindings binary, it is necessary to set java.library.path:

```scala
// Mac OS X example with manual JNI installation
// cp -f native/target/resource_managed/main/native/x86_64-darwin/libpdaljni.2.1.dylib /usr/local/lib/libpdaljni.2.1.dylib
// place built binary into /usr/local/lib, and pass java.library.path to your JVM
javaOptions += "-Djava.library.path=/usr/local/lib"
```

You can use pdal-native dep in case you don’t have installed JNI bindings and to avoid steps described above. Dependency contains bindings for x86_64-darwin and x86_64-linux, other versions are not supported yet.
12.1 Tutorials

This section provides a collection of tutorials on how to use the PDAL Applications (page 27) and Pipelines (page 55) to process data.

Note: Users looking for documentation on how to contribute to PDAL should look here (page 523) and users looking to use the PDAL API in their own applications should look here (page 600).

12.1.1 Reading with PDAL

Author
Bradley Chambers

Contact
brad.chambers@gmail.com

Date
01/21/2015

Contents

• Reading with PDAL (page 379)
  – A basic inquiry example (page 380)
  – A conversion example (page 381)
    * Metadata (page 382)
  – A Pipeline Example (page 382)
This tutorial is an introduction to using PDAL to read data using pdal from the command line.

**A basic inquiry example**

Our first example to demonstrate PDAL's utility will be to simply query an [LAS](http://www.asprs.org/a/society/committees/standards/lidar_exchange_format.html) file to determine the data that are in it in the very first point.

---

**Note:** The [interesting.las](https://github.com/PDAL/PDAL/blob/master/test/data/las/interesting.las?raw=true) file in these examples can be found on github.

`pdal info` outputs JavaScript [JSON](http://www.json.org/).

```
$ pdal info interesting.las -p 0
```

```json
{
   "filename": "interesting.las",
   "pdal_version": "1.0.1 (git-version: 80644d)",
   "points":
   {
      "point":
      {
         "Blue": 88,
         "Classification": 1,
         "EdgeOfFlightLine": 0,
         "GpsTime": 245381,
         "Green": 77,
         "Intensity": 143,
         "NumberOfReturns": 1,
         "PointId": 0,
         "PointSourceId": 7326,
         "Red": 68,
         "ReturnNumber": 1,
         "ScanAngleRank": -9,
         "ScanDirectionFlag": 1,
         "UserData": 132,
         "X": 637012,
```

(continues on next page)
Conversion of data from one format to another may be lossy, in that some data in the source format may not be representable in the same format or at all in the destination format. For example, some formats don’t support spatial references for point data, some have no metadata support and others have limited dimension support. Even when data types are supported in both source and destination formats, there may be limitations with regard to data type, precision or scaling. PDAL attempts to convert data as accurately as possible, but you should make sure that you’re aware of the capabilities of the data formats you’re using.

```
$ pdal translate interesting.las output.txt
```

The text format supports all point attributes, but provides no support for metadata such as the input spatial reference system or the LAS (http://www.asprs.org/a/society/committees/standards/lidar_exchange_format.html) header fields, such as UUID (http://en.wikipedia.org/wiki/Universally_unique_identifier). You may need to preserve some more information as part of your conversion to make it useful down the road.
Metadata

PDAL carries metadata for each stage through the PDAL processing pipeline. The metadata can be written in JSON form using the pdal info command:

```
$ pdal info --metadata interesting.las
```

This produces metadata that looks like this. You can use your JSON manipulation tools to extract this information. For formats that do not have the ability to preserve this metadata internally, you can keep a .json file alongside the .txt file as auxiliary information.

A Pipeline Example

The full power of PDAL comes in the form of pipeline invocations. Pipelines allow you to take advantage of PDAL’s ability to manipulate data as they are converted. This section will provide a basic example and demonstration of pipeline usage. See the pipeline specification, for more detailed exposition of the topic.

The pipeline describes a series of processing stages to be performed in JSON format. Each stage can be provided a set of options that control the details of processing. PDAL is single-threaded and stages are executed in a linear order. Some stages support what is known as “stream mode”. If all stages in a pipeline support stream mode the command is run using stream mode to reduce the memory processing footprint. Even when run in stream mode, execution is single-threaded and can be thought of as linear.

Simple conversion

The following JSON document defines a pipeline that takes the file.las LAS file and converts it to a new file called output.las.

```json
[
    "file.las",
    "output.las"
]
```
Loop a directory and filter it through a pipeline

This bash script loops through a directory and pushes the las files through a pipeline, substituting the input and output as it goes.

```
ls *.las | cut -d. -f1 | xargs -P20 -I{} pdal pipeline -i /path/to/proj. json --readers.las.filename={}.las --writers.las.filename=output/{}.laz
```

Here is an example doing something similar with Windows PowerShell

```
$indir="Documents\inlas"
$outdir="Documents\outlas"
get-childitem $indir |
foreach-object {
    if ($_.extension -ne ".las") {
        continue
    }
    $outname = $outdir + "\" + $_.name
    pdal pipeline -i \path\to\proj.json $_.fullname $outname
}
```

### 12.1.2 Reading data from EPT

**Introduction**

This tutorial describes how to use Conda (https://conda.io), Entwine (https://entwine.io), PDAL (https://pdal.io), and GDAL (https://gdal.org) to read data from the USGS 3DEP AWS Public Dataset (https://www.usgs.gov/news/usgs-3dep-lidar-point-cloud-now-available-amazon-public-dataset). We will be using PDAL’s readers.ept (https://pdal.io/stages/readers.ept.html) to fetch data, we will filter it for noise using filters.outlier (https://pdal.io/stages/filters.outlier.html), we will classify the data as ground/not-ground using filters.smrf (https://pdal.io/stages/filters.smrf.html), and we will write out a digital terrain model with writers.gdal (page 156). Once our elevation model is constructed, we will use GDAL gdaldem (https://www.gdal.org/gdaldem.html) operations to create hillshade, slope, and color relief.
Install Conda

We first need to install PDAL, and the most convenient way to do that is by installing Miniconda (https://docs.conda.io/en/latest/miniconda.html). Select the 64-bit installer for your platform and install it as directed.

Install PDAL

Once Miniconda is installed, we can install PDAL into a new Conda Environment (https://docs.conda.io/projects/conda/en/latest/user-guide/concepts.html) that we created for this tutorial. Open your Anaconda Shell and start issuing the following commands:

1. Create the environment
   
   ```shell
   conda create -n iowa -y
   ```

2. Activate the environment
   
   ```shell
   conda activate iowa
   ```

3. Install PDAL
   
   ```shell
   conda install -c conda-forge pdal -y
   ```

4. Ensure PDAL works by listing the available drivers
   
   ```shell
   pdal --drivers
   ```

Once you confirmed you see output similar to that in your shell, your PDAL installation should be good to go.

Write the Pipeline

PDAL uses the concept of pipelines (https://pdal.io/pipeline.html) to describe the reading, filtering, and writing of point cloud data. We will construct a pipeline that will do a number of things in succession.
Fig. 1: Pipeline diagram. The data are read from the Entwine Point Tile (https://entwine.io/entwine-point-tile.html) resource at https://usgs.entwine.io for Iowa using readers.ept (page 72) and filtered through a number of steps until processing is complete. The data are then written to an iowa.laz and iowa.tif file.
Pipeline

1. Create a file called iowa.json with the following content:

```
Note: The file is also available from https://gist.github.com/hobu/ee22084e24ed7e3c0d10600798a94c31 for convenient copy/paste)

```{ 
  "pipeline": [ 
    { 
      "bounds": "([-10425171.940, -10423171.940], [516494.710, 5166494.710])",
      "type": "readers.ept",
      "tag": "readdata"
    }, 
    { 
      "limits": "Classification[7:7]",
      "type": "filters.range",
      "tag": "nonoise"
    }, 
    { 
      "assignment": "Classification[:]=0",
      "tag": "wipeclasses",
      "type": "filters.assign"
    }, 
    { 
      "out_srs": "EPSG:26915",
      "tag": "reprojectUTM",
      "type": "filters.reprojection"
    }, 
    { 
      "tag": "groundify",
      "type": "filters.smrf"
    }, 
    { 
      "limits": "Classification[2:2]",
      "type": "filters.range",
      "tag": "classify"
    } 
  ]
```

(continues on next page)
Stages

readers.ept

*readers.ept* (page 72) reads the point cloud data from the EPT resource on AWS. We give it a URL to the root of the resource in the *filename* option, and we also give it a *bounds* object to define the window in which we should select data from.

**Note:** The full URL to the EPT root file (*ept.json*) must be given to the *filename* parameter for PDAL 2.2+. This was a change in behavior of the *readers.ept* (page 72) driver.

The *bounds* object is in the form ([minx, maxx], [miny, maxy]).

**Warning:** If you do not define a *bounds* option, PDAL will try to read the data for the entire state of Iowa, which is about 160 billion points. Maybe you have enough memory for this...
Fig. 2: The EPT reader reads data from an EPT resource with PDAL. Options available in PDAL 1.9+ allow users to select data at or above specified resolutions.

**filters.range**

The data we are selecting may have noise properly classified, and we can use `filters.range` (page 313) to keep all data that does not have a `Classification Dimensions` (page 359) value of 7.

Fig. 3: The `filters.range` (page 313) filter utilizes range selection to allow users to select data for processing or removal. The `filters.mongo` (page 310) filter can be used for even more complex logic operations.

**filters.assign**

After removing points that have noise classifications, we need to reset all of the classification values in the point data. `filters.assign` (page 253) takes the expression `Classification [:] = 0` and assigns the `Classification` for each point to 0.

Fig. 4: `filters.assign` (page 253) can also take in an option to apply assignments based on a conditional. If you want to assign values based on a bounding geometry, use `filters.overlay` (page 256).
filters.reprojection

The data on the AWS 3DEP Public Dataset are stored in Web Mercator (https://en.wikipedia.org/wiki/Web_Mercator_projection) coordinate system, which is not suitable for many operations. We need to reproject them into an appropriate UTM coordinate system (EPSG:26915 (https://epsg.io/32615)).

Fig. 5: filters.reprojection (page 275) can also take override the incoming coordinate system using the a_srs option.

filters.smrf

The Simple Morphological Filter (filters.smrf (page 197)) classifies points as ground or not-ground.

Fig. 6: filters.smrf (page 197) provides a number of tuning options, but the defaults tend to work quite well for mixed urban environments on flat ground (i.e., Iowa).

filters.range

After we have executed the SMRF filter, we only want to keep points that are actually classified as ground in our point stream. Selecting for points with Classification[2:2] does that for us.

Fig. 7: Remove any point that is not ground classification for our DTM generation.

12.1. Tutorials
writers.gdal

Having filtered our point data, we’re now ready to write a raster digital terrain model with writers.gdal (page 156). Interesting options we choose here are to set the nodata value, specify only outputting the inverse distance weighted raster, and assigning a resolution of 1 (m). See writers.gdal (page 156) for more options.

Fig. 8: Output a DTM at 1m resolution.

writers.las

We can also write a LAZ file containing the same points that were used to make the elevation model in the section above. See writers.las (page 161) for more options.

Fig. 9: Also output the LAZ file as part of our processing pipeline.

Execute the Pipeline

1. Save the PDAL pipeline in Pipeline (page 386) to a file called iowa.json
2. Invoke the PDAL pipeline (https://pdal.io/pipeline.html) command

   pdal pipeline iowa.json

   Add the --debug option if you would like information about how PDAL is fetching and processing the data.

   pdal pipeline iowa.json --debug

3. Save a color scheme to dem-colors.txt
4. Invoke `gdaldem` to colorize a PNG file for your TIFF

```
gdaldem color-relief iowa.tif dem-colors.txt iowa-color.png
```

5. View your raster

## 12.1.3 LAS Reading and Writing with PDAL

### Author

Howard Butler

### Contact

howard@hobu.co

### Date

3/27/2017

### Table of Contents

- LAS Reading and Writing with PDAL (page 391)
  - Introduction (page 392)
  - LAS Versions (page 392)
  - Spatial Reference System (page 393)
  - Point Formats (page 396)
This tutorial will describe reading and writing ASPRS LAS (http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) data with PDAL, discuss the capabilities that PDAL readers.las (page 89) and writers.las (page 161) can provide for this format.

Introduction

ASPRS LAS (http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) is probably the most commonly used LiDAR (https://en.wikipedia.org/wiki/Lidar) format, and PDAL’s support of LAS is important for many users of the library. This tutorial describes and demonstrates some of the capabilities the drivers provide, points out items to be aware of when using the drivers, and hopefully provides some examples you can use to get what you need out of the LAS drivers.

LAS Versions

There are five LAS versions – 1.0 to 1.4. Each iteration added some complexity to the format in terms of capabilities it supports, possible data types it stores, and metadata. Users of LAS must balance the features they need with the use of the data by downstream applications. While LAS support in some form is quite widespread throughout the industry, most applications do not support every feature of each version. PDAL works to provide many of these features, but it is also incomplete. Specifically, PDAL doesn’t support point formats that store waveform data.

Version Example

We can use the minor_version option of writers.las (page 161) to set the version PDAL should output. The following example will write a 1.1 version LAS file. Depending on the features you need, this may or may not be what you want.

```json
[
  {
    "type" : "readers.las",
```
Note: PDAL defaults to writing a LAS 1.2 version if no minor_version is specified or the forward option of writers.las (page 161) is not used to carry along a version from a previously read file.

Spatial Reference System

LAS 1.0 to 1.3 use GeoTIFF (https://trac.osgeo.org/geotiff/) keys for storing coordinate system information, while LAS 1.4 uses Well Known Text (https://en.wikipedia.org/wiki/Well-known_text#Coordinate_reference_systems). GeoTIFF is well-supported by most software that read LAS, but it is not possible to express some coordinate system specifics with GeoTIFF. WKT is supports more coordinate systems than GeoTIFF, but vendor-specific and later versions (WKT 2) may not be handled well.

Assignment Example

The PDAL writers.las (page 161) allows you to override or assign the coordinate system to an explicit value if you need. Often the coordinate system defined by a file might be incorrect or non-existent, and you can set this with PDAL.

The following example sets the a_srs option of the writers.las (page 161) to EPSG:4326.

```json
[
  {
    "type": "readers.las",
    "filename": "input.las"
  },
  {
    "type": "writers.las",
    "a_srs": "EPSG:4326",
    "filename": "output.las"
  }
]
```
Note: Remember to set offset_x, offset_y, scale_x, and scale_y values to something appropriate if your are storing decimal degree data in LAS files. The special value auto can be used for the offset values, but you should set an explicit value for the scale values to prevent overdriving the precision of the data and disrupting Compression (page 400) with LASzip (http://laszip.org).

Vertical Datum Example

Vertical coordinate control is important in LiDAR (https://en.wikipedia.org/wiki/Lidar) and PDAL supports assignment and reprojection/transform of vertical coordinates using Proj.4 (http://proj4.org) and GDAL (http://gdal.org/). The coordinate system description magic happens in GDAL, and you assign a compound coordinate system (both vertical and horizontal definitions) using the following syntax:

**EPSG:4326+3855**

This assignment states typical 4326 horizontal coordinate system plus a vertical one that represents EGM08 (http://earth-info.nga.mil/GandG/wgs84/gravimod/egm2008/egm08_wgs84.html). In Well Known Text (https://en.wikipedia.org/wiki/Well-known_text#Coordinate_reference_systems), this coordinate system is described by:

```
$ gdalsrsinfo "EPSG:4326+3855"
```

```
COMPD_CS["WGS 84 + EGM2008 geoid height", 
GEOGCS["WGS 84", 
  DATUM["WGS_1984", 
    SPHEROID["WGS 84",6378137,298.257223563, 
      AUTHORITY["EPSG","7030"], 
      AUTHORITY["EPSG","6326"], 
      PRIMEM["Greenwich",0, 
        AUTHORITY["EPSG","8901"], 
      UNIT["degree",0.0174532925199433, 
        AUTHORITY["EPSG","9122"], 
      AUTHORITY["EPSG","4326"], 
    VERT_CS""EGM2008 geoid height", 
    VERT_DATUM["EGM2008 geoid",2005], 
```

(continues on next page)
As in Assignment Example (page 393), it is common to need to reassign the coordinate system. The following example defines both the horizontal and vertical coordinate system for a file to UTM Zone 15N NAD83 (http://epsg.io/26915) for horizontal and NAVD88 (http://epsg.io/5703) for the vertical.

```json
[
  {
    "type" : "readers.las",
    "filename" : "input.las"
  },
  {
    "type" : "writers.las",
    "a_srs" : "EPSG:26915+5703",
    "filename" : "output.las"
  }
]
```

**Note:** Any coordinate system description format supported by GDAL's SetFromUserInput (http://www.gdal.org/ogr__srs__api_8h.html#a927749db01cec3af8aa5e577d032956bk) method can be used to assign or set the coordinate system in PDAL. This includes WKT, Proj.4 (http://proj4.org) definitions, or OGC URNs. It is your responsibility, however, to escape or massage any input data to make it be valid JSON.

### Reprojection Example

A common desire is to transform the coordinates of an ASPRS LAS (http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) file from one coordinate system to another. The mechanism to do that with PDAL is `filters.reprojection` (page 275).

```json
[
  {
    "type" : "readers.las",
    "filename" : "input.las"
  },
  {
    "type" : "writers.las",
    "a_srs" : "EPSG:26915+5703",
    "filename" : "output.las"
  }
]```
Note: If the input data doesn’t specify a projection, you must specify the \texttt{in\_srs} option of \texttt{filters.reprojection} (page 275). \texttt{in\_srs} can also be used to override an existing spatial reference attached to the input point set.

### Point Formats

As each revision of LAS was released, more point formats were added. A point format is the fixed set of dimensions (page 359) that a LAS file stores for each point in the file. For any point format, the size and composition of dimensions is consistent across versions, but users should be aware of some minor interpretation changes based on LAS file version. For example, a classification value of 11 in version 1.4 indicates “Road Surface”, while that value is reserved in version 1.1.

### Point Format Example

Point format or \texttt{dataformat\_id} is an integer that defines the set of fixed dimensions (page 359) stored for each point in a LAS file. All point formats specify the following dimensions as part of a point record:

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity</td>
<td>ReturnNumber</td>
<td>NumberOfReturns</td>
</tr>
<tr>
<td>ScanDirectionFlag</td>
<td>EdgeOfFlightLine</td>
<td>Classification</td>
</tr>
<tr>
<td>ScanAngleRank</td>
<td>UserData</td>
<td>PointSourceId</td>
</tr>
</tbody>
</table>

Because LAS files have no built-in compression, it’s important to use a point format that stores the fewest fields possible that store the desired data. For example, point format 10 uses 45 more
bytes per point than point format zero.

If one wanted remove the Red/Green/Blue fields from a LAS file (one using point format 2), one could simply set the dataformat_id option to 0. The forward option can also be set to carry forward all possible header values from the source file to the new, smaller file.

```json
[
  {
    "type": "readers.las",
    "filename": "input.las"
  },
  {
    "type": "writers.las",
    "forward": "all",
    "dataformat_id": 0,
    "filename": "output.las"
  }
]
```

**Note:** The LASzip (http://laszip.org) storage of GPSTime and Red/Green/Blue fields with no data is perfectly efficient.

---

**Extra Dimensions**

A LAS Point Format ID defines the fixed set of dimensions (page 359) a file must store, but programs are allowed to store extra data beyond that fixed set. This feature of the format was regularized in LAS 1.4 as something called “extra bytes” or “extra dims”, but previous versions can also store these extra per-point attributes.

**Extra Dimension Example**

LAS 1.4 provides for the storage of dimensions not part of the chosen point format by appending them to each point record. PDAL supports this feature when writing files with the “extra_dims” option. The following example will store all source dimensions in the output file and place a description of the dimensions that aren’t part of the point format in an “extra bytes” VLR:

```json
[  {
      "some_non_las_file",
      {
        "type": "writers.las",
        ...  
  }
]  ```

(continues on next page)
Required Header Fields

Readers of the ASPRS LAS Specification will see there are many fields that softwares are required to write, with their content mandated by various options and configurations in the format. PDAL does not assume responsibility for writing these fields and coercing meaning from the content to fit the specification. It is the PDAL users’ responsibility to do so. Fields where this might matter include:

- `project_id`
- `global_encoding`
- `system_id`
- `software_id`
- `filesoure_id`

Header Fields Example

The “forward” option of `writers.las` (page 161) is the easiest way to get most of what you might want in terms of header settings copied from an input to an output file upon processing. Imagine the scenario of zero’ing out the classification values for an LAS file in preparation for using `filters.pmf` (page 194) to reassign them. During this scenario, we’d like to keep all of the other LAS header information, such as `Variable Length Records` (page 401), extent information, and format settings.
"type": "filters.pmf",
"cell_size": 2.5,
"approximate": false,
"max_distance": 25
},
{
  "type": "writers.las",
  "forward": "all",
  "filename": "output.las"
}
]

Note: If multiple input LAS files are being written to an output file, the forward option can only preserve values when they are the same in all input files. If the values differ, a default will be used (as it would if the forward option weren’t supplied). You can specify specific option values for output that will also override any forwarded data.

Coordinate Scaling

LAS stores coordinates as 32 bit integers. It is the user’s responsibility to ensure that the coordinate domain required by the data in the file fits within the 32 bit integer domain. Most coordinate values have digits to the right of the decimal point that must be preserved for sufficient accuracy. Using the scale factor allows for integers to be interpreted as floating point values when read by software.

When writing data to LAS, choosing an appropriate scale factor should take into account not just the maximum precision that can be accommodated by the format, but the actual precision of the data. Using a precision greater than the resolution of the data collection can mislead users as to the actual measurement precision of the data. In addition, it can lead to larger files when writing compressed data with LASzip (http://laszip.org).

Auto Offset Example

Users can allow PDAL select scale and offset values for data with the auto option. This can have some detrimental effects on downstream processing. auto for scale values will use the entire 32-bit integer domain. This maximizes the precision available to store the data, but this will have a detrimental effect on LASzip (http://laszip.org) storage efficiency. auto for offset calculation is just fine, however. When given the option, choose to store ASPRS LAS (http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html)
data with an explicit scale for the X, Y, and Z dimensions that represents actual expected data precision, not artificial storage precision or maximal storage precision.

```json
[
  {
    "type": "readers.las",
    "filename": "input.las"
  },
  {
    "type": "writers.las",
    "scale_x": "0.0000001",
    "scale_y": "0.0000001",
    "scale_z": "0.01",
    "offset_x": "auto",
    "offset_y": "auto",
    "offset_z": "auto",
    "filename": "output.las"
  }
]
```

### Compression

**LASzip** ([http://laszip.org](http://laszip.org)) is an open source, lossless compression technique for ASPRS LAS ([http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html](http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html)) data. It is supported by two different software libraries, and it can be used in both the C/C++ and the JavaScript execution environments. LAZ support is provided by both readers.las (page 89) and writers.las (page 161). It can be enabled by setting the compression option to laszip.

### Compression Example

Providing a filename with a .laz extension will write compressed data. Compression can be turned on explicitly as well:

```json
[
  {
    "type": "readers.las",
    "filename": "input.las"
  },
  {
    "type": "writers.las",
    "compression": "laszip",
    "filename": "output.las"
  }
]
```
Variable Length Records

Variable Length Records, or VLRs, are binary data that the LAS format supports to allow applications to store their own data. Coordinate system information is one type of data stored in VLRs, and many different LAS-using applications store data and metadata with this format capability. PDAL allows users to access VLR information, forward it along to newly written files, and create VLRs that store processing history information.

Common VLR data include:

- Coordinate system
- Metadata
- Processing history
- Indexing

Note: There are VLRs that are defined by the specification, and they have the VLR user_id of LASF_Spec or LASF_Projection. LASF_Spec VLRs provide a description of the data beyond that available in the header. LASF_Projection VLRs store the spatial coordinate system of the data.

For LAS 1.0-1.3, the VLR length could be no larger than 65535 bytes. Version 1.4 introduced extended VLRs, stored at the end of the file, which could be up to 4gb in size.

VLR Example

You can add your own VLRs to files to store processing information or whatever you want by providing a JSON block via writers.las (page 161) vlr_s option that defines the user_id and data items for the VLR. The data option must be base64 (https://en.wikipedia.org/wiki/Base64)-encoded string output. The data will be converted to binary information and stored in the VLR when the file is written.
PDAL: Point cloud Data Abstraction Library, Release 2.6.2

PDAL Metadata

The writers.las (page 161) driver supports an option, pdal_metadata, that writes two PDAL VLRs to LAS files. The first is the equivalent of info (page 38)’s --metadata output. The second is a copy of the output of the --pipeline serialization option that describes all stages and options of the pipeline that created the file. These two VLRs may be useful in tracking down processing history of data, allow you to determine which versions of PDAL may have written a file and what filter options were set when it was written, and give you the ability to store metadata and other information via pipeline user_data from your own applications.

Metadata Example

The pipeline used to construct the file and all of its Metadata (page 545) can be written into VLRs in ASPRS LAS (http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) files under the PDAL VLR key (http://www.asprs.org/misc/las-key-list.html).

```json
[
    {
        "type": "readers.las",
        "filename": "input.las"
    },
    {
        "type": "writers.las",
        "filename": "output.las",
        "vlrs": [
            {
                "description": "A description under 32 bytes",
                "record_id": 42,
                "user_id": "hobu",
                "data": "dGhpcyBpcyBzb21lIHRleHQ="
            },
            {
                "description": "A description under 32 bytes",
                "record_id": 43,
                "user_id": "hobu",
                "data": "dGhpcyBpcyBzb21lIG1vcmUgdGV4dA=="
            }
        ]
    }
]
```
Warning: LAS versions prior to 1.4 only support VLRs of at most 64K of information. It is possible, though improbable, that the metadata or pipeline stored in the VLRs will not fit in that space.

12.1.4 Clipping with Geometries

Author
Howard Butler

Contact
howard@hobu.co

Date
11/09/2015

Introduction

This tutorial describes how to construct a pipeline that takes in geometries and clips out data with given geometry attributes. It is common to desire to cut or clip point cloud data with 2D geometries, often from auxiliary data sources such as OGR (http://www.gdal.org)-readable Shapefiles (https://en.wikipedia.org/wiki/Shapefile). This tutorial describes how to construct a pipeline that takes in geometries and clips out point cloud data inside geometries with matching attributes.

Contents

- Clipping with Geometries (page 403)
  - Introduction (page 403)
  - Example Data (page 404)
  - Stage Operations (page 404)
  - Data Preparation (page 404)
  - Pipeline (page 405)
Example Data

This tutorial utilizes the Autzen dataset. In addition to typical PDAL software (fetch it from Download (page 13)), you will need to download the following two files:

- [https://github.com/PDAL/data/autzen/autzen.laz](https://github.com/PDAL/data/autzen/autzen.laz)

Stage Operations

This operation depends on two stages PDAL provides. The first is the `filters.overlay` (page 256) stage, which allows you to assign point values based on polygons read from OGR (http://www.gdal.org). The second is `filters.range` (page 313), which allows you to keep or reject points from the set that match given criteria.

See also:

`filters.python` (page 348) allow you to construct sophisticated logic for keeping or rejecting points in a more expressive environment.

Data Preparation

![Image of Autzen Stadium](image)

Fig. 10: Autzen Stadium, a 100 million+ point cloud file.
The data are mixed in two different coordinate systems. The LAZ (page 89) file is in Oregon State Plane Ft. (http://www.oregon.gov/DAS/CIO/GEO/pages/coordination/projections/projections.aspx) and the GeoJSON (http://geojson.org) defining the polygons is in EPSG:4326 (http://epsg.io/4326). We have two options – project the point cloud into the coordinate system of the attribute polygons, or project the attribute polygons into the coordinate system of the points. The latter is preferable in this case because it will be less math and therefore less computation. To make it convenient, we can utilize OGR (http://www.gdal.org)’s VRT (http://www.gdal.org/drv_vrt.html) capability to reproject the data for us on-the-fly:

```xml
<OGRVRTDataSource>
  <OGRVRTWarpedLayer>
    <OGRVRTLayer name="OGRGeoJSON">
      <SrcDataSource>attributes.json</SrcDataSource>
      <LayerSRS>EPSG:4326</LayerSRS>
    </OGRVRTLayer>
    <TargetSRS>+proj=lcc +lat_1=43 +lat_2=45.5 +lat_0=41.75 +lon_0=-120.5 +x_0=399999.9999999999 +y_0=0 +ellps=GRS80 +units=ft +no_defs</TargetSRS>
  </OGRVRTWarpedLayer>
</OGRVRTDataSource>
```

**Note:** The GeoJSON file does not have an externally-defined coordinate system, so we are explicitly setting one with the LayerSRS parameter. If your data does have coordinate system information, you don’t need to do that.

Save this VRT definition to a file, called `attributes.vrt` in the same location where you stored the `autzen.laz` and `attributes.json` files.

The attribute GeoJSON file has a couple of features with different attributes. For our scenario, we want to clip out the yellow-green polygon, marked number “5”, in the upper right hand corner.

**Pipeline**

A PDAL pipeline (page 55) is how you define a set of actions to apply to data as they are read, filtered, and written.

```json
[
  "autzen.laz",
  {
    "type":"filters.overlay",
    "dimension":"Classification",

(continues on next page)
Fig. 11: We want to clip out the polygon in the upper right hand corner. We can view the GeoJSON (http://geojson.org) geometry using something like QGIS (http://qgis.org)

```json
  "datasource": "attributes.vrt",
  "layer": "OGRGeoJSON",
  "column": "CLS"
},
  {
    "type": "filters.range",
    "limits": "Classification[5:5]"
  },
  "output.las"
```

- **readers.las** (page 89): Define a reader that can read ASPRS LAS (http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) or LASzip (http://laszip.org) data.

- **filters.overlay** (page 256): Using the VRT we defined in Data Preparation (page 404), read attribute polygons out of the data source and assign the values from the CLS column to the Classification field.

- **filters.range** (page 313): Given that we have set the Classification values for the points that have coincident polygons to 2, 5, and 6, only keep Classification values in the range of 5:5. This functionally means we’re only keeping those points with a classification value of 5.

Note: You don’t have to use only Classification to set the attributes with `filters.overlay` (page 256). Any valid dimension name could work, but most LiDAR softwares will display categorical coloring for the Classification field, and we can leverage that behavior in this scenario.

### Processing

1) Save the pipeline to a file called `shape-clip.json` in the same directory as your `attributes.json` and `autzen.laz` files.

2) Run `pdal pipeline` on the json file.

   ```
   $ pdal pipeline shape-clip.json
   ```

3) Visualize `output.las` in an environment capable of viewing it. [http://plas.io](http://plas.io) or [CloudCompare](http://www.danielgm.net/cc/) should do the trick.

### Conclusion

PDAL allows the composition of point cloud operations. This tutorial demonstrated how to use the `filters.overlay` (page 256) and `filters.range` (page 313) stages to clip points with shapefiles.
12.1.5 Ground Filter Tutorial

Author
Bradley Chambers

Contact
brad.chambers@gmail.com

Date
04/17/2017

Background

In previous tutorials we introduced our implementation of the Progressive Morphological Filter (PMF) (page 194), a ground kernel (page 33) to simplify command-line access to PMF, and a filter for removing outliers (page 203).

This tutorial will highlight some recent enhancements to the PDAL library, in the context of a ground segmentation workflow. Specifically, we will discuss:

• Constructing and executing a “filters-only” pipeline
• Resetting existing classifications prior to processing
• Using Extended Local Minimum (ELM) to identify low outliers
• Using Simple Morphological Filter (SMRF) as an alternative to PMF
• Ignoring outliers during ground segmentation
• Considering only last returns during ground segmentation
• Extracting ground returns as a post-processing step

Note: The pipeline discussed in this tutorial requires PDAL v1.5 (https://github.com/PDAL/PDAL/releases/tag/1.5.0).

The Pipeline

Begin by creating a new file called pipeline.json with the following contents.

```json
{
    "pipeline": [
        {
            "type": "filters.reprojection",
            "out_srs": "EPSG:32632"
        }
    ]
}
```

(continues on next page)
Note: For users familiar with PDAL pipelines, this example may seem to be missing a couple of very important stages, namely the reader and writer! A new feature of PDAL is the ability to provide a PDAL pipeline with no reader or writer stages to the `translate` (page 50) command. The input and output filenames can be specified on the command line and will be automatically inserted into the pipeline by the application.
The Explanation

We continue by explaining the various stages of the pipeline in order.

Reprojecting Data

Many of PDAL’s default parameters are specified in meters, and individual filter stages typically assume that units are at least uniform in X, Y, and Z. Because data will not always be provided in this way, PDAL pipelines should account for any data reprojections and parameter scaling that are required from one dataset to the next.

In this example, we show data being reprojected to EPSG:32632 with X, Y, and Z in meters.

Assigning Classification Values

Let’s assume that you have been given an LAS file that contains per point classifications, but you’d like to start with a clean slate and derive your own classifications with your PDAL pipeline.

PDAL’s assign filter has been added to assign values to a given dimension. In our example, a single option has been provided that specifies the dimension, range, and value to assign. In this case, we are stating that we would like to apply a value of 0 to the Classification dimension for every point.

Note: Previously, you could do the same thing (with a slightly different syntax) using filters.attribute, but this filter has been deprecated and split into filters.assign (page 253) and filters.overlay (page 256).
Extended Local Minimum

The *Extended Local Minimum (ELM) method* (page 201) helps to identify low noise points that can adversely affect ground segmentation algorithms. ELM was first published in [Chen2012] as part of the upward-fusion method of DTM generation. Noise points are classified with a value of 7 in keeping with the LAS specification.

```
{  
  "type":"filters.elm"
},
```

Outliers

PDAL’s *outlier filter* (page 203) provides two methods of outlier detection at the moment: radius and statistical. Both aim to identify points that are isolated and likely arise from noise sources. Noise points are classified with a value of 7 in keeping with the LAS specification.

```
{  
  "type":"filters.outlier"
},
```

Ground Segmentation

The *Simple Morphological Filter (SMRF)* (page 197) [Pingel2013] is a newer addition to PDAL that has quietly existed in an alpha state since v1.3. With the release of PDAL v1.5, our SMRF implementation is much more complete, although it only implements nearest neighbor void filling and not the authors’ preferred “Springs” algorithm.

The changes to SMRF between PDAL v1.3 and v1.5 are substantial. The original version had actually drifted quite far from the authors’ published approach, namely in the area of filling voids. We have reverted the code to match the published work, but for now are only using the nearest neighbors approach to filling voids. The morphological operations are also accelerated by moving to an iterative approach and using a diamond structuring element.

```
{  
  "type":"filters.smrf",
  "last":true,
  "ignore":"Classification[7:7]",
  "slope":0.2,
  "window":16,
  "threshold":0.45,
}
```
In addition to specifying some of the SMRF-specific arguments, our example also demonstrates the use of two optional pre-filtering capabilities: ignore and last.

The ignore option accepts a range (page 315), here indicating that we have points marked as noise (i.e., Classification of 7) that should be excluded from ground segmentation, but are kept as part of the output dataset.

The last option, when set to true indicates that we would like to only consider last returns for ground segmentation when return information is available. Again, returns that are not “last returns” are still retained in the output dataset - they are simply ignored for the purposes of ground segmentation.

Note: Many lidar systems provide return information. This includes the number of returns per pulse and the order of a particular return within the pulse. Where the return number and number of returns are equal, we call this a last return.

Last returns are not by definition ground returns. In fact, the first and only return from surfaces such as rooftops will also be last returns, and last returns within dense foliage may not ever make it all the way to ground. Still, whenever there are multiple returns within a pulse, it stands to reason that anything before the last return would not be from the ground.

Some bare earth algorithms explicitly operate on last returns only. In this case, this logic will presumably be implemented within the filter stage itself. That being said, it stands to reason that any ground segmentation approach could be improved by excluding all returns but the so-called last returns. Neither PMF nor SMRF make this assertion, but our implementations still consider only last returns by default. This behavior can be changed by setting last=false.

For an example of how to filter on last returns outside the context of SMRF and PMF, see this (https://github.com/PDAL/PDAL/blob/master/test/data/pipeline/predicate-keep-last-return.json.in) within PDAL’s source tree.

Note: SMRF is not intended to be a replacement for the Progressive Morphological Filter (PMF) (page 194) [Zhang2003]. Rather, it is offered as an alternative. PMF has been a part of PDAL since v1.0, first as part of the PCL plugin and now as filters.pmf. Since PDAL v1.4, we have fixed a number of bugs, and have accelerated the approximate mode by implementing iterative morphological operations and using a diamond structuring element.
Extracting Ground Returns

Any time we have points classified as ground, we may wish to extract just these points, e.g., to create a digital terrain model (DTM). In this case, we use a range filter (page 313) as shown.

```json
{
    "type": "filters.range",
    "limits": "Classification[2:2]"
}
```

The range filter (page 313) accepts a limits option that identifies the dimension(s) on which to filter and the range (page 315) of values to passthrough. In this case, we are indicating that the filter should only pass points whose Classification value is equal to 2.

Note: The default behavior of both PMF (page 194) and SMRF (page 197) is to classify points, which has not changed from previous versions of PDAL. The extract and classify options have been removed in PDAL v1.5. These filters now only classify points, such that ground points can be identified and filtered downstream, as we have shown with the range filter above.

Running the Pipeline

Now let’s run our pipeline.json example, using it to translate (page 50) input.las to output.las.

```
$ pdal translate input.las output.las --json pipeline.json
```

12.1.6 Applying a grid shift to point clouds

Introduction

This tutorial first appeared on Land Information New Zealand’s On-Location Blog (https://medium.com/on-location).

It describes how to use Conda (https://conda.io), PDAL (https://pdal.io), and GDAL (https://gdal.org) to apply a grid shift to point cloud files. It uses PDAL’s readers.las (https://pdal.io/stages/readers.las.html) to fetch the data, filters.reprojection (https://pdal.io/stages/filters.reprojection.html) to apply the grid shift, and writers.las (https://pdal.io/stages/writers.las.html) to write the reprojected point cloud.

The data used in this tutorial is available for free under a CC-BY 4.0 license on Land Information New Zealand’s LINZ Data Service (https://data.linz.govt.nz).
The tutorial will be reprojecting point cloud files from:

- A New Zealand local vertical datum to the New Zealand Vertical Datum 2016 (NZVD2016).
- Finally, NZVD2016 to NZGD2000 or to a local vertical datum.

**Background**

Historically in New Zealand, heights were defined in terms of 13 local vertical datums (LVD) referenced to an estimate of the local mean sea level (MSL).

In 2016, New Zealand Vertical Datum 2016 (NZVD2016), which is defined by the NZGeoid2016 geoid, became the official national vertical datum for New Zealand. The general relationship between the different datums is shown in the diagram below.


The [NZ Quasigeoid 2016](https://data.linz.govt.nz/layer/53447-nz-quasigeoid-2016-raster/), also a relationship grid, models the difference between the NZGD2000 ellipsoid and NZVD2016 (N in the above diagram).

The equations to transform heights using the published values in the relationship grids are:

**Before we begin**

We will be using multiple tools to perform the reprojection. To retrieve these tools and have them all accessible in a nice self-contained environment we will be using a system called Conda. Conda is an open source package and environment management system that runs on Windows, macOS, and Linux. Essentially we will create an environment within Conda which will contain the packages we need: PDAL, GDAL and Python.

**Install Conda**

Download [Miniconda](https://docs.conda.io/en/latest/miniconda.html), selecting the 64-bit installer for your platform and install it as directed.
LVD to NZVD2016

\[ H_{\text{NZVD2016}} = H_A - O \]

For the 13 local vertical datums in New Zealand the published value (O) will always be a negative number. Which means the NZVD2016 height will always be less than the LVD height.

NZVD2016 to NZGD2000

\[ h_{\text{NZGD2000}} = H + N \]
Create a Conda Environment

1. After installing, open the Anaconda Prompt from your start menu.
2. When you begin using conda, you already have a default environment named base. We don’t want to put programs into our base environment so we’ll create a separate environment just for doing this reprojection. To do this, type:

   ```
   conda create --name vd-reproject
   ```

3. It will check for the additional packages/dependencies that are needed, and will ask if you want to proceed. Say yes.

   ```
   Proceed ([y]/n)? y
   ```

4. To start to use the new environment and install our required packages within it, we need to activate the environment first:

   ```
   conda activate vd-reproject
   ```

   **Note:** After the environment is activated the name of the environment appears as `(vd-reproject)` at the beginning of the command line. This indicates that you’re now inside the environment.

5. Finally, we need to install the tools/packages we will be using.

   ```
   conda install -c conda-forge pdal gdal
   ```

   When these packages are installed, they will also install the packages they’re dependent on to run. Python is one of these dependent packages, so we won’t need to install it ourselves as conda would’ve already done it for us.

   Now that the packages are installed, we are ready to begin.

Step 1: Create a Datum Transformation Grid (GTX)

PDAL allows for the use of PROJ.4 strings to define the spatial reference system of the inputted or outputted data. This is great, because it gives us the ability to use `+geoidgrid` which is an option to add a grid shift file in the format of NOAA Vdatum’s GTX file format. But where to we get a GTX file from? We have two options:
Option 1 — LINZ supplied GTX file

LINZ has created GTX files for each of the relationship grids mentioned earlier. They can be downloaded from https://www.geodesy.linz.govt.nz/download/proj-datumgrid-nz

Here is a list of which GTX file belongs to which Local Vertical Datum:

- **Auckland 1946**: auckht1946-nzvd2016.gtx
- **Bluff 1955**: blufht1955-nzvd2016.gtx
- **Dunedin 1958**: duneht1958-nzvd2016.gtx
- **Dunedin-Bluff 1960**: dublht1960-nzvd2016.gtx
- **Gisborne 1926**: gisbht1926-nzvd2016.gtx
- **Lyttelton 1937**: lyttht1937-nzvd2016.gtx
- **Moturiki 1953**: motuht1953-nzvd2016.gtx
- **Napier 1962**: napiht1962-nzvd2016.gtx
- **Nelson 1955**: nelsht1955-nzvd2016.gtx
- **One Tree Point 1964**: ontpht1964-nzvd2016.gtx
- **Stewart Island 1977**: stisht1977-nzvd2016.gtx
- **Taranaki 1970**: taraht1970-nzvd2016.gtx
- **Wellington 1953**: wellht1953-nzvd2016.gtx

There is also a GTX file for the Quasigeoid which would be used if converting between NZVD2016 and the NZGD2000 ellipsoid.

- **New Zealand Quasigeoid 2016**: nzgeoid2016.gtx

Option two — Create a GTX file

You can create your own GTX file using the relationship grids available on the LDS. For example, if you intend to convert from Moturiki 1953 to NZVD2016, you have to do the following:


2. Open the Anaconda Prompt from the start menu and activate the environment we created earlier:
conda activate vd-reproject

3. Navigate to the location of the downloaded TIFF file and execute gdal_translate to convert the TIFF file to a GTX file:

```bash
cd path/to/TIFF/file
gdal_translate -ot Float32 "moturiki-1953-to-nzvd2016-conversion-raster.tif" "moturiki-1953-to-nzvd2016-conversion-raster.gtx"
```

**Note:** `-ot Float32` indicates the data type of the output image's bands. GTX files only support Float32.
Step 2: Prepare a JSON Pipeline file

We will be using a PDAL pipeline (https://pdal.io/pipeline.html) to transmit a chain of processing elements into PDAL. These elements will be represented in a JSON file.

Using a text editor, create a JSON file named pipeline.json containing the contents as below.

```json
{
    "pipeline": [
        {
            "type": "readers.las",
            "filename": "#"
        },
        {
            "type": "filters.reprojection",
            "in_srs": "EPSG:2193",
            "out_srs": "EPSG:2193"
        },
        {
            "type": "writers.las",
            "filename": "#",
            "a_srs": "EPSG:2193",
            "forward": "all"
        }
    ]
}
```

Update the srs details for `in_srs`, `out_srs` and `a_srs` to the EPSG code of the horizontal map projection your source LAS files are in. In the example above we are using New Zealand Transverse Mercator 2000 (EPSG:2193).

**Warning:** Be aware "forward": "all" under the writers.las section represents the header fields whose values should be preserved from the source LAS file. all will transfer all header fields, including scale and offset values, as well as VLRs. If you desire to transfer only specific header fields, refer to https://pdal.io/stages/writers.las.html for more information about this option.
Step 3: Use PDAL to reproject

Reprojecting one file from LVD to NZVD2016

Using the Anaconda Prompt, activate the vd-reproject environment:

```
conda activate vd-reproject
```

Then issue the following command to reproject one file (of course, replace the files and paths to suit your needs).

```
pdal pipeline "path/to/your/pipeline.json" --readers.las.filename="path/to/source_las_file.las" --writers.las.filename="path/to/reprojected_las_file.las" --filters.reprojection.out_srs="+init=EPSG:2193 +geoidgrids=path/to/your/gtx_file.gtx"
```

Reprojecting multiple files from LVD to NZVD2016

Below is a python script which executes multiple LAS files. Save to your computer as lvd_to_nzvd2016.py, then open in a text editor and update src_directory, gtxfile, jsonfile, horizontal_srs with the necessary information.

```
import os
import sys

src_directory='/path/to/directory/with/las/files'
gtxfile='/path/to/yourgridfile.gtx'
jsonfile='/path/to/pipeline.json'
horizontal_srs='EPSG:2193'

dest_directory = src_directory + '/reprojected'
if not os.path.exists(dest_directory): os.mkdir(dest_directory)

for filename in os.listdir(src_directory):
    if (filename.endswith('.las') or filename.endswith('.laz')):
        print('Reprojecting ' + filename)
        pdal_cmd = 'pdal pipeline {} --readers.las.filename={} --writers.las.filename={} --filters.reprojection.out_srs="+init={} +geoidgrids=path/to/your/gtx_file.gtx"'.format(jsonfile, filename, filename, horizontal_srs)
```

Note: The file is also available from https://gist.github.com/rclarkelinz/d48de5c0432f5c00d02a452e6d1d3bc3

(continues on next page)
To execute the script, open the Anaconda Prompt, activate the `vd-reproject` environment and then navigate to where you have saved the script and issue this command:

```python
python lvd_to_nzvd2016.py
```

This script creates a new directory called ‘reprojected’ in the same location as the LAS files. On completion the reprojected LAS files will be located in this directory, ready for your GIS needs.

You can spot check the accuracy of the conversion by using the LINZ Online converter: www.geodesy.linz.govt.nz/concord

### Reprojecting from NZGD2000 to NZVD2016

The steps to do this reprojection are the same as above except for one change:

In **Step 1**, for option one, the GTX file required will be `nzgeoid2016.gtx`. Or, if you are following option two, the relationship grid on the LDS is the **NZ Quasigeoid 2016** (https://data.linz.govt.nz/layer/53447-nz-quasigeoid-2016-raster/).

### NZVD2016 to NZGD2000 or LVD

Previously, the grid values are being *subtracted* from the point cloud value in **Step 3**. To reproject to NZGD2000 or an LVD, the grid values need to be *added* to the NZVD2016 value.

To accommodate this change in PDAL, you need to alter the following text in the PDAL command from `filters.reprojection.out_srs` to `filters.reprojection.in_srs`.

```python
+geoidgrids={}".format(jsonfile, src_directory + '/'+ filename, 
dest_directory + '/'+ filename, horizontal_srs, gtxfile)
```

```python
os.system(pdal_cmd)
```
13.1 Point Cloud Processing and Analysis with PDAL

Author
Howard Butler

Author
Pete Gadomski

Author
Dr. Craig Glennie

Author
Michael Smith

Author
Dr. Adam Steer

Contact
howard@hobu.co

Date
06/01/2023

13.1.1 Introduction

After the basic set up the workshop is divided into three 45 to 90 min sections with a final project at the end.

1. *Introduction to LiDAR* (page 427)
2. *Introduction to PDAL* (page 5)
3. *Software Installation* (page 432)
4. *Getting Started* (page 438)
5. *Manipulation* (page 453)

6. *Generation* (page 484)

7. *Final Project* (page 515)

**Materials**

**USB Drive**

A companion USB drive containing everything needed to do the workshop without internet connectivity

Note: A drive image is available for download at https://pdal.s3.amazonaws.com/workshop/PDAL-Workshop-complete.zip

Included in the USB driver are

- Conda environments for macOS (x86_64 and arm64) and Windows platforms with needed dependencies
- Copy of PDAL documentation
- Data needed for examples
- Collection of cool-lidar (https://github.com/hobuinc/cool-lidar) datasets
13.1.2 Introduction to LiDAR

LiDAR is a remote sensing technique that uses visible or near-infrared laser energy to measure the distance between a sensor and an object. LiDAR sensors are versatile and (often) mobile; they help autonomous cars avoid obstacles and make detailed topographic measurements from space. Before diving into LiDAR data processing, we will spend a bit of time reviewing some LiDAR fundamentals and discussing some terms of art.

Types of LiDAR

LiDAR systems, generally speaking, come in one of three types:

- **Pulse-based**, or linear-mode, systems emit a pulse of laser energy and measure the time it takes for that energy to travel to a target, bounce off the target, and be returned to the sensor. These systems are called linear-mode because they (generally) only have a single aperture, and so can only measure distance along a single vector at any point in time. Pulse-based systems are very common, and are usually what you would think of when you think of LiDAR.

- **Phase-based** LiDAR systems measure distance via interferometry, that is, by using the phase of a modulated laser beam to calculate a distance as a fraction of the modulated signal’s wavelength. Phase-based systems can be very precise, on the order of a few millimeters, but since they require comparatively more energy than the other two types they are usually used for short-range (e.g. indoor) scanning.

- **Geiger-mode**, or photon-counting, systems use extremely sensitive detectors that can be triggered by a single photon. Since only a single photon is required to trigger a measurement, these systems can operate at much much higher altitudes than linear mode systems. However, Geiger-mode systems are relatively new and suffer from very high amounts of noise and other operational restrictions, making them significantly less common than linear-mode systems.

Note: Unless otherwise noted, if we talk about a LiDAR scanner in this program, we will be referring to a pulse-based (linear) system.

Modes of LiDAR Collection

LiDAR collects are generally categorized into four subjective types:

- **Terrestrial LiDAR Scanning** (TLS): scanning with a stationary LiDAR sensor, usually mounted on a tripod.

- **Airborne LiDAR scanning** (ALS): also called airborne laser swath mapping (ALSM), scanning with a LiDAR scanner mounted to a fixed-wing or rotor aircraft.
Mobile LiDAR scanning (MLS): scanning from a ground-based vehicle, such as a car.

Unmanned LiDAR scanning (ULS): scanning with drones or other unmanned vehicles.

With the exception of stationary TLS, LiDAR scanning generally requires the use of an integrated GNSS/IMU (Global Navigation Satellite System/Inertial Motion Unit), which provides information about the position, rotation, and motion of the scanning platform.

Note: As stated in the class description, we will focus on mobile and airborne laser scanning (MLS/ALS), though we will also use some TLS data.

Georeferencing

LiDAR scanners collect information in the Scanner’s Own Coordinate System (SOCS); this is a coordinate system centered at the scanner. The process of rotating, translating, and (possibly) transforming a point cloud into a real-world spatial reference system is known as georeferencing.

In the case of TLS, georeferencing is simply a matter of discovering the position and orientation of the static scanner. This is usually done with GNSS control points, which are used to solve for the scanner’s position via least-squares.

For mobile or airborne LiDAR scanning, it is necessary to merge the scanner’s points with the GNSS/IMU data. This can be done on-the-fly or as a part of a post-processing workflow. Since this is a common operation for mobile and airborne LiDAR collects, we will spend a moment discussing the methods and complications for georeferencing mobile LiDAR and GNSS/IMU data.

Integrating LiDAR and GNSS/IMU data

The LiDAR georeferencing equation is well-established; we present a version here from [Gle07]:

\[ p_G^l = p_{GPS}^l + R_b^l \left( R_s^b r^s - 1^b \right) \]  

(13.1)

where:

- \( p_G^l \) are the coordinates of the target point in the global reference frame
- \( p_{GPS}^l \) are the coordinates of the GNSS sensor in the global reference frame
- \( R_b^l \) is the rotation matrix from the navigation frame to the global reference frame
- \( R_s^b \) is the rotation matrix from the scanner’s frame to the navigation frame (boresight matrix)
• \( r^s \) is the coordinates of the laser point in the scanner’s frame
• \( I^b \) is the lever-arm offset between the scanner’s original and the navigation’s origin

This equation contains fourteen unknowns, and in order to georeference a single LiDAR return we must determine all fourteen variables at the time of the pulse.

As a rule of thumb, the position, attitude, and motion of the scanning platform (aircraft, vehicle, etc) are sampled at a much lower rate than the pulse rate of the laser — rates of \(~1\text{Hz}\) are common for GNSS/IMU sampling. In order to match the GNSS/IMU sampling rate with the sampling rate of the laser, GNSS/IMU measurements are interpolated to line up with the LiDAR measurements. Then, these positions and attitudes are combined via Equation (13.1) to create a final, georeferenced point cloud.

**Note:** While lever-arm offsets are usually taken from the schematic drawings of the LiDAR mounting system, the boresight matrix cannot be reliably determined from drawings alone. The boresight matrix must therefore be determined either via manual or automated boresight calibration using actual LiDAR data of planar surfaces, such as the roof and sides of buildings. The process for determining a boresight calibration from LiDAR data is beyond the scope of this class.

### Discrete-Return vs. Full-Waveform

Pulse-based LiDAR systems use the round-trip travel time of a pulse of laser energy to measure distances. The outgoing pulse of a LiDAR system is roughly (but not exactly) a Gaussian:

This pulse can interact with multiple objects in a scene before it is returned to the sensor. Here is an example of a LiDAR return:

As you can see, this return pulse can be very complicated. While there is more information contained in the “full waveform” picture displayed above, many LiDAR consumers are only interested in detecting the presence or absence of an object — simplistically, the peaks in that waveform.

Full waveform data is used only in specialized circumstances. If you have or receive LiDAR data, it will usually be discrete return (point clouds). Processing full waveform data is beyond the scope of this class.

**Note:** PDAL is a discrete-return point cloud processing library. It does not have any functionality to analyze or process full waveform data.
Fig. 1: A real-world outgoing LiDAR pulse.
Fig. 2: A real-world incoming LiDAR return. Potential discrete-return peaks are marked in red.
13.1.3 Software Installation

Conda

What is Conda

Conda is an open source package management system and environment management system that runs on Windows, macOS and Linux. Conda quickly installs, runs, and updates packages and their dependencies. Conda easily creates, saves, loads and switches between environments on your local computer. It was created for Python programs, but it can package and distribute software for any language.

How will we use Conda?

PDAL stands on the shoulders of giants. It uses GDAL, GEOS, and *many other dependencies* (page 534). Because of this, it is very challenging to build it yourself. We could easily burn an entire workshop learning the esoteric build mysteries of PDAL and all of its dependencies. Fortunately, Conda provides us a fully-featured known configuration to run our examples and exercises without having to suffer so much, and provides it for Windows, Linux, and macOS.

**Note:** Not everyone uses Conda. Another alternative to get a known configuration is to go through the workshop using **docker** (page 587) as your platform. A previous edition of the workshop was provided using Docker, but it was found to be a bit too difficult to follow.

**Note:** PDAL does not have a python wheel package and thus is distributed via **conda-forge** conda channel. If you would like to know more about the limitations that prevent PDAL from being distributed as a pip package, you can read about it at the [pypackaging-native website](https://pypackaging-native.github.io/key-issues/native-dependencies/geospatial_stack/)

**Installing Conda Environment (Workshop USB)**

2. Once **mambaforge** ([https://github.com/conda-forge/miniforge#mambaforge](https://github.com/conda-forge/miniforge#mambaforge)) is installed, open a terminal and navigate to the location of your USB drive
3. Uncompress the environment, activate it, and use the **conda-unpack** command
   - macOS Users
$ mkdir -p "$HOME/mambaforge/envs/pdal-workshop"
$ tar -xzf conda_environments/pdal-workshop_osx-arm64.tar.gz -C "$HOME/mambaforge/envs/pdal-workshop"
$ source "$HOME/mambaforge/envs/pdal-workshop/bin/activate"

$ (pdal-workshop) $ conda-unpack

**Windows Users**

>`mkdir "%userprofile%\mambaforge\envs\pdal-workshop"
>`tar -xvf ./conda_environments/pdal-workshop-win64.zip -C "%userprofile%\mambaforge\envs\pdal-workshop"
>`call "%userprofile%\mambaforge\envs\pdal-workshop\scripts\activate"

**(pdal-workshop) > conda-unpack**

### Installing Conda

1. Copy the entire contents of your workshop USB key to a PDAL directory in your home directory (something like C:\Users\hobu\PDAL) or the equivalent for your OS. We will refer to this location for the rest of the workshop materials.

2. Download and install the mambaforge installer for your platform (https://github.com/conda-forge/miniforge#mambaforge) installer for your platform.

3. After installing mambaforge create your workshop by running

>`conda create -c conda-forge -n pdal-workshop`

4. Then *activate* the new environment

>`conda activate pdal-workshop`

5. Install PDAL, Entwine, and GDAL, and install it from **conda-forge**

    *(pdal-workshop) > mamba install -c conda-forge python-pdal gdal entwine matplotlib*  

Alternatively use the following *environment.yml* file to create your environment

```yaml
name: pdal-workshop
channels:
  - conda-forge
dependencies:
  - python=3.11
```

(continues on next page)
Note: The conda-pack package is used for packaging the pdal-workshop conda environment to go to the USB image, and is not needed otherwise.

QGIS

What is QGIS (http://qgis.org)?

QGIS (http://qgis.org) is an open source GIS. It is extensible with Python (http://python.org/), it integrates the GRASS (https://grass.osgeo.org/) analytic environment, and it works on both Windows and OS X.

How will we use QGIS?

We’re using QGIS (http://qgis.org) to visualize raster and vector processing product during our workshop. We will also use QGIS (http://qgis.org) to visualize point clouds by generating COPC (page 143) files. If you have another GIS available to you, you are welcome to use it, but because QGIS (http://qgis.org) is open source, we are installing it and using it to be sure you’ll have something to look at data with.

Installing QGIS

1. Copy the contents of your Hobu (https://hobu.co/) USB key to a PDAL directory in your home directory (something like C:\Users\hobu\PDAL). We will refer to this location for the rest of the workshop materials.

2. After your materials are copied, navigate to the c:\Users\hobu\PDAL\software directory.
Note: It is assumed your Hobu (https://hobu.co/) USB drive has all of its contents copied to the C:\Users\hobu\PDAL folder. Please adjust your locations when reading these tutorial documents accordingly.

3. Choose the install image, Windows or Mac, and install QGIS (http://qgis.org) prepare your machine to run the examples.
4. Once installed, verify you can run QGIS (http://qgis.org) by opening the application. At the top, choose Layer --> Add Layer --> Add Raster Layer.... Navigate to the `C:\Users\hobu\PDAL\exercises\analysis\colorization` directory.

5. Select the `casi-2015-04-29-weekly-mosaic.tif` image and open it for display.
13.1. Point Cloud Processing and Analysis with PDAL
Conclusion

QGIS (http://qgis.org) allows everyone to have access to a fully-featured GIS. We are going to use it to visualize raster, vector, and point cloud data used throughout the workshop.

13.1.4 Getting Started

Printing the first point

Exercise

This exercise uses PDAL to print information from the first point. Before starting, be sure to set your working directory in Conda to the location of the PDAL workshop data. For example, if the workshop folder was located on your desktop:

```
$ cd Desktop/PDAL
```

Issue the following command in your Conda Shell.

```
$ pdal info ./exercises/info/interesting.las -p 0
```

Here’s a summary of what’s going on with that command invocation

1. pdal: The pdal application :)

2. info: We want to run info (page 38) on the data. All commands are run by the pdal application.

3. ./exercises/info/interesting.las: The file we are running the command on. PDAL will be able to identify this file is an ASPRS LAS (http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) file from the extension, .las, but not every file type is easily identified. You can use a pipeline (page 41) to override which reader (page 65) PDAL will use to open the file. For this workshop, we will often output a COPC (page 143) file type. For our purposes, COPC files (In the format *.copc.laz) can be visualized in QGIS (http://qgis.org). To read more about COPC, refer to this article (https://mapscaping.com/podcast/cloud-optimized-point-clouds/).

4. -p 0: -p corresponds to “print a point”, and 0 means to print the first one (computer people count from 0).

```
$ pdal info ./exercises/info/interesting.las -p 0
{
    "file_size": 37698,
    "filename": "./exercises/info/interesting.las",
}
```

(continues on next page)
"now": "2023-05-30T16:11:25-0700",
"pdal_version": "2.5.4 (git-version: Release)",
"points":
{
  "point":
  {
    "Blue": 88,
    "Classification": 1,
    "EdgeOfFlightLine": 0,
    "GpsTime": 245380.7825,
    "Green": 77,
    "Intensity": 143,
    "NumberOfReturns": 1,
    "PointId": 0,
    "PointSourceId": 7326,
    "Red": 68,
    "ReturnNumber": 1,
    "ScanAngleRank": -9,
    "ScanDirectionFlag": 1,
    "UserData": 132,
    "X": 637012.24,
    "Y": 849028.31,
    "Z": 431.66
  }
},
"reader": "readers.las"
}

Notes


2. You can use the writers.text (page 182) writer to output point attributes to CSV (https://en.wikipedia.org/wiki/Comma-separated_values) format for other processing.

3. Output help information on the command line by issuing the --help option

4. A common query with pdal info is --all, which will print all header, metadata, and statistics about a file.
Printing file metadata

Exercise

This exercise uses PDAL to print metadata information. Issue the following command in your Conda Shell.

```bash
$ pdal info ./exercises/info/interesting.las --metadata
```

```
{
  "file_size": 37698,
  "filename": "/exercises/info/interesting.las",
  "metadata": {
    "comp_spatialreference": "PROJCS["NAD_1983_Oregon_Statewide_Lambert_Feet_Intl",
                  GEOGCS["GCS_North_American_1983"],DATUM["North_American_Datum_1983"],
                  SPHEROID["GRS_1980",6378137.298.257222101]],
    "PRIMEM["Greenwich",0],UNIT["degree",0.174532925199433],AUTHORITY["EPSG","9122"],
    PROJECTION["Lambert_Conformal_Conic_2SP"],
    PARAMETER["latitude_of_origin",41.75],PARAMETER["central_meridian",-120.5],PARAMETER["standard_parallel_1",43],PARAMETER["standard_parallel_2",45.5],PARAMETER["false_easting",400000],PARAMETER["false_northing",0],UNIT["foot",0.3048],AUTHORITY["EPSG","9002"],AXIS["Easting",EAST],AXIS["Northing",NORTH]",
    "compressed": false,
    "copc": false,
    "count": 1065,
    "creation_doy": 145,
    "creation_year": 2012,
    "dataformat_id": 3,
    "dataoffset": 1488,
    "filesource_id": 0,
    "global_encoding": 0,
    "global_encoding_base64": "AAA=",
    "gtiff": "Geotiff_Information:
Version: 1
Tagged_Information:
End_Of_Tags.
Keyed_Information:

  GTModelTypeGeoKey (Short,1): ModelTypeProjected
  GTRasterTypeGeoKey (Short,1): RasterPixelIsArea
  GTCitationGeoKey (Ascii,44): "NAD_1983_Oregon_Statewide_Lambert_Feet_Intl"
  GeographicTypeGeoKey (Short,1): User-Defined
  GeogCitationGeoKey (Ascii,106): "GCS Name = GCS_North_American_1983|Datum = D_North_American_1983|Ellipsoid = GRS_1980|Primem = Greenwich"
  GeogEllipsoidGeoKey (Short,1): User-Defined
  GeogAngularUnitsGeoKey (Short,1): Angular_Degree
(continues on next page)
```
Note: PDAL metadata (page 545) is returned in a tree structure corresponding to processing pipeline that produced it.

See also:

Use the JSON (https://en.wikipedia.org/wiki/JSON) processing capabilities of your favorite processing software to selectively access and manipulate values.

- Python JSON library (https://docs.python.org/3/library/json.html)
• jsawk (https://github.com/micha/jsawk) (like awk but for JSON data)
• jq (https://stedolan.github.io/jq/) (command line processor for JSON)
• Ruby JSON library (https://ruby-doc.org/stdlib-3.0.2/libdoc/json/rdoc/JSON.html)

**Structured Metadata Output**

Many command-line utilities output their data in a human-readable custom format. The downsides to this approach are significant. PDAL was designed to be used in the context of other software tools driving it. For example, it is quite common for PDAL to be used in data validation scenarios. Other programs might need to inspect information in PDAL’s output and then act based on the values. A human-readable format would mean that downstream program would need to write a parser to consume PDAL’s special format.

JSON (https://en.wikipedia.org/wiki/JSON) provides a nice balance between human- and machine-readable, but even then it can be quite hard to find what you’re looking for, especially if the output is long. pdal command output used in conjunction with a JSON parsing tool like jq provide a powerful inspection combination.

For example, we might only care about the system_id and compressed flag for this particular file. Our simple pdal info --metadata command gives us that, but it also gives us a bunch of other stuff we don’t need at the moment. Let’s focus on extracting what we want using the jq command.

**Note:** If you do not have jq (https://stedolan.github.io/jq/) installed into your Conda environment and are not on Windows, run the following command in your Conda Shell: conda install -c conda-forge jq. Windows users should use this link (https://github.com/jqlang/jq/releases/download/jq-1.7/jq-win64.exe) to install jq (https://stedolan.github.io/jq/)

```
$ pdal info ./exercises/info/interesting.las --metadata \
  | jq "metadata.compressed, metadata.system_id"
```

```
> pdal info ./exercises/info/interesting.las --metadata ^
  | jq "metadata.compressed, metadata.system_id"
```

Output:

false
"HOBU-SYSTEMID"

**Note:** PDAL’s JSON output is very powerfully combined with the processing capabilities of other programming languages such as JavaScript or Python. Both of these languages have
excellent built-in tools for consuming JSON, along with plenty of other features to allow you to
do something with the data inside the data structures. As we will see later in the workshop, this
PDAL feature is one that makes construction of custom data processing workflows with PDAL
very convenient.

Notes

1. PDAL uses JSON (https://en.wikipedia.org/wiki/JSON) as the exchange format when
printing information from info (page 38). JSON provides human and machine-readable
text data.

2. The PDAL metadata document (page 545) contains background and information about
specific metadata entries and what they mean.

3. Metadata available for a given file depends on the stage that produces the data. Readers
(page 65) produce same-named values where possible, but it is common that variables
are different. Filters (page 192) and even writers (page 139) can also produce metadata
entries.

4. Spatial reference system or coordinate system information is a kind of special metadata.
Spatial references are come directly from source data or are provided via options in
PDAL.

Searching near a point

Exercise

This exercise uses PDAL to find points near a given search location. Our scenario is a simple
one – we want to find the two points nearest the midpoint of the bounding cube of our
interesting.las data file.

First we need to find the midpoint of the bounding cube. To do that, we need to print the --all
info for the file and look for the bbox output:

```bash
$ pdal info ./exercises/info/interesting.las --all | jq .stats.bbox.
{       "bbox": [635619.85, 848899.7, 586.38, 853535.43], "maxx": 638982.55, "maxy": 853535.43, "maxz": 586.38, "minx": 635619.85, "miny": 848899.7,
```

(continues on next page)
Find the average the X, Y, and Z values:

\[
x = \frac{635619.85 + (638982.55 - 635619.85)}{2} = 637301.20 \\
y = \frac{848899.70 + (853535.43 - 848899.70)}{2} = 851217.57 \\
z = \frac{406.59 + (586.38 - 406.59)}{2} = 496.49
\]

With our “center point”, issue the --query option to pdal info and return the three nearest points to it:

```bash
$ pdal info ./exercises/info/interesting.las --query "637301.20, 851217.57, 496.49 /3"
```

```json
{
  "file_size": 37698,
  "filename": "/exercises/info/interesting.las",
  "now": "2023-05-30T16:17:10-0700",
  "pdal_version": "2.5.4 (git-version: Release)",
  "points":
  [
    {
      "Blue": 221,
      "Classification": 1,
      "EdgeOfFlightLine": 0,
      "GpsTime": 247565.2203,
      "Green": 211,
      "Intensity": 169,
      "NumberOfReturns": 1,
      "PointId": 762,
      "PointSourceId": 7330,
      "Red": 228,
      "ReturnNumber": 1,
      "ScanAngleRank": -4,
      "ScanDirectionFlag": 0,
      "UserData": 124,
      "X": 637323.56,
      "Y": 851555.64,
      "Z": 586.38
    },
    {
      "Blue": 221,
      "Classification": 1,
      "EdgeOfFlightLine": 0,
      "GpsTime": 247565.2203,
      "Green": 211,
      "Intensity": 169,
      "NumberOfReturns": 1,
      "PointId": 762,
      "PointSourceId": 7330,
      "Red": 228,
      "ReturnNumber": 1,
      "ScanAngleRank": -4,
      "ScanDirectionFlag": 0,
      "UserData": 124,
      "X": 637323.56,
      "Y": 851555.64,
      "Z": 586.38
    },
    {
      "Blue": 221,
      "Classification": 1,
      "EdgeOfFlightLine": 0,
      "GpsTime": 247565.2203,
      "Green": 211,
      "Intensity": 169,
      "NumberOfReturns": 1,
      "PointId": 762,
      "PointSourceId": 7330,
      "Red": 228,
      "ReturnNumber": 1,
      "ScanAngleRank": -4,
      "ScanDirectionFlag": 0,
      "UserData": 124,
      "X": 637323.56,
      "Y": 851555.64,
      "Z": 586.38
    }
  ]
}
```
"Blue": 243,
...

Note: The /3 portion of our query string tells the query command to give us the 3 nearest points. Adjust this value to return data in closest-distance ordering.

Notes


2. The --query option of info (page 38) constructs a KD-tree (https://en.wikipedia.org/wiki/K-d_tree) of the entire set of points in memory. If you have really large data sets, this isn’t going to work so well, and you will need to come up with a different solution.

Compression

Exercise

This exercise uses PDAL to compress ASPRS LAS (http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) data into LASzip (http://laszip.org).

1. Issue the following command in your Conda Shell.

$$ pdal translate ./exercises/translation/interesting.las \\
./exercises/translation/interesting.laz $$

The translate command converts files based on their extensions.

$$ > pdal translate ./exercises/translation/interesting.las ^
./exercises/translation/interesting.laz $$

Note: LAS is a very fluffy binary format. Because of the way the data are stored, there is ample redundant information, and LASzip (http://laszip.org) is an open source solution for compressing this information. Note that we are
actually inflating the data here. Its laz from the workshop and we are converting it to las.

2. Verify that the laz data is compressed over the las:

   $ ls -alh ./exercises/translation/interesting.la*  
   ...

   > dir ./exercises/translation/interesting.la*  
   ...

Output:

   -rw-r--r--@ 1 ogi staff 36K Aug 8 2019 ./exercises/translation/interesting.las
   -rw-r-xr-x@ 1 ogi staff 18K May 9 11:30 ./exercises/translation/interesting.laz

See also:

*LAS Reading and Writing with PDAL* (page 391) contains many pointers about settings for ASPRS LAS (http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) data and how to achieve specific data behaviors with PDAL.

Notes

1. Typical LASzip (http://laszip.org) compression is 5:1 to 8:1, depending on the type of LiDAR (https://en.wikipedia.org/wiki/Lidar). It is a compression format specifically for the ASPRS LAS (http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) model, however, and will not be as efficient for other types of point cloud data.

2. You can open and view LAZ data in web browsers using http://plas.io but we will be using QGIS as examples.
Reprojection

Exercise

This exercise uses PDAL to reproject ASPRS LAS (http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) data.

Issue the following command in your Conda Shell:

```
$ pdal translate ./exercises/analysis/ground/CSite1_orig-utm.laz ./exercises/translation/csite-dd.laz reprojection --filters.reprojection.out_srs="EPSG:4326"
```

Unfortunately this doesn’t produce the intended results for us. Issue the following pdal info command to see why:

```
$ pdal info ./exercises/translation/csite-dd.laz --all | jq .stats.bbox.native.bbox
```

```
|
| jq .stats.bbox.native.bbox
``` { "maxx": 9.18, "maxy": 48.79, "maxz": 426.91, "minx": 9.16, "miny": 48.78, "minz": 99.43 }
```

```
> pdal info ./exercises/translation/csite-dd.laz --all | jq .stats.bbox.native.bbox
```

```
|
| jq .stats.bbox.native.bbox
``` { "maxx": 9.18, "maxy": 48.79, "maxz": 426.91, "minx": 9.16, "miny": 48.78, "minz": 99.43 }
```

--all dumps all info (page 38) information about the file, and we can then use the jq (https://stedolan.github.io/jq/) command to extract out the “native” (same coordinate system as...
the file itself) bounding box.

We can see, the problem is we only have two decimal places of precision on the bounding box. For geographic coordinate systems, this isn’t enough precision.

Printing the first point confirms this problem:

```
$ pdal info ./exercises/translation/csite-dd.laz -p 0
{
  "file_size": 4609784,
  "filename": "./exercises/translation/csite-dd.laz",
  "pdal_version": "2.4.0 (git-version: Release)",
  "points":
  {
    "point":
    {
      "Blue": 0,
      "Classification": 0,
      "EdgeOfFlightLine": 0,
      "GpsTime": 0,
      "Green": 0,
      "Intensity": 100,
      "NumberOfReturns": 2,
      "PointId": 0,
      "PointSourceId": 0,
      "Red": 0,
      "ReturnNumber": 1,
      "ScanAngleRank": 0,
      "ScanDirectionFlag": 0,
      "UserData": 0,
      "X": 9.17,
      "Y": 48.78,
      "Z": 316.88
    }
  },
  "reader": "readers.las"
}
```

Some formats, like `writers.las` (page 161) do not automatically set scaling information. PDAL cannot really do this for you because there are a number of ways to trip up. For latitude/longitude data, you will need to set the scale to smaller values like 0.0000001. Additionally, LAS uses an offset value to move the origin of the value. Use PDAL to set that to auto so you don’t have to compute it.
$ pdal translate \
./exercises/analysis/ground/CSite1_orig-utm.laz \
./exercises/translation/csite-dd.laz reprojection \
--filters.reprojection.out_srs="EPSG:4326" \
--writers.las.scale_x=0.0000001 \
--writers.las.scale_y=0.0000001 \
--writers.las.offset_x="auto" \
--writers.las.offset_y="auto"


$ pdal info ./exercises/translation/csite-dd.laz --all \
| jq .stats.bbox.native.bbox
{
  "maxx": 9.179032939,
  "maxy": 48.78976523,
  "maxz": 426.91,
  "minx": 9.164037839,
  "miny": 48.78345443,
  "minz": 99.43
}

> pdal translate ^
./exercises/analysis/ground/CSite1_orig-utm.laz ^
./exercises/translation/csite-dd.laz reprojection ^
--filters.reprojection.out_srs="EPSG:4326" ^
--writers.las.scale_x=0.0000001 ^
--writers.las.scale_y=0.0000001 ^
--writers.las.offset_x="auto" ^
--writers.las.offset_y="auto"


Run the `pdal info` command again to verify the X, Y, and Z dimensions:

$ pdal info ./exercises/translation/csite-dd.laz --all \
| jq .stats.bbox.native.bbox
{
  "maxx": 9.179032939,
  "maxy": 48.78976523,
  "maxz": 426.91,
  "minx": 9.164037839,
  "miny": 48.78345443,
  "minz": 99.43
}

> pdal info ./exercises/translation/csite-dd.laz --all ^
| jq .stats.bbox.native.bbox
{
  "maxx": 9.179032939,
"maxy": 48.78976523,
"maxz": 426.91,
"minx": 9.164037839,
"miny": 48.78345443,
"minz": 99.43
}

Notes

1. *filters.reprojection* (page 275) will use whatever coordinate system is defined by the point cloud file, but you can override it using the `in_srs` option. This is useful in situations where the coordinate system is not correct, not completely specified, or your system doesn’t have all of the required supporting coordinate system dictionaries.

2. PDAL uses *Proj.4* (http://proj4.org) library for reprojection. This library includes the capability to do both vertical and horizontal datum transformations.

Entwine

**Exercise**

This exercise uses PDAL to fetch data from an Entwine index stored in an Amazon Web Services object store (bucket). Entwine is a point cloud indexing strategy, which rearranges points into a lossless octree structure known as EPT, for Entwine Point Tiles. The structure is described here: [https://entwine.io/entwine-point-tile.html](https://entwine.io/entwine-point-tile.html).

EPT indexes can be used for visualization as well as analysis and data manipulation at any scale.

Examples of Entwine usage can be found from very fine photogrammetric surveys to continental scale lidar management.

US Geological Survey (USGS) example data is here: [https://usgs.entwine.io/](https://usgs.entwine.io/)

We will use a sample data set from Dublin, Ireland [https://viewer.copc.io/?r=https://na-c.entwine.io/dublin/ept.json](https://viewer.copc.io/?r=https://na-c.entwine.io/dublin/ept.json)

The *JSON* (https://en.wikipedia.org/wiki/JSON) file defines the pipeline which you were previously creating in *jq* (https://stedolan.github.io/jq/). This simplifies the task and allows for easy repetition of tasks. This pipeline will collect the sample data set and convert it to a *COPC* (page 143) file.

1. View the ./exercises/translation/entwine.json file in your editor.
PDAL: Point cloud Data Abstraction Library, Release 2.6.2

{  
  "pipeline": [  
    {  
      "type": "readers.ept",
      "filename": "https://na-c.entwine.io/dublin/ept.json",
      "resolution": 5
    },  
    {  
      "type": "writers.copc",
      "filename": "dublin.copc.laz",
      "forward": "all"
    }
  ]
}

Note: If you use the Developer Console (https://developers.google.com/web/tools/chrome-devtools/console/) when visiting http://speck.ly or http://potree.entwine.io, you can see the browser making requests against the EPT resource at http://na-c.entwine.io/dublin/ept.json

2. Issue the following command in your Conda Shell.

$ pdal pipeline ./exercises/translation/entwine.json -v 7
(PDAL Debug) Debugging...
(pdal pipeline readers.ept Debug) Root resolution: 21.3828
Query resolution: 5
Actual resolution: 2.67285
Depth end: 4
Query bounds: ()
Threads: 15
(pdal pipeline Debug) Executing pipeline in stream mode.
(pdal pipeline writers.las Debug) Wrote 8034506 points to the LAS file

3. Verify that the COPC data look ok:

$ pdal info dublin.copc.laz | jq .stats.bbox.native.bbox
{
  "maxx": -694128.96,
  "maxy": 7049938.84,
}(continues on next page)
4. Visualize the data in QGIS
**Note:** QGIS also supports uploading Entwine data directly from the cloud. Under ‘Layer -> Add Layer -> Add Point Cloud Layer’, select the source type as “Protocol: HTTP(S), cloud, etc.” and insert the URL of an EPT index.

**Notes**

1. *readers.ept* (page 72) contains more detailed documentation about how to use PDAL’s EPT reader.

### 13.1.5 Manipulation

**Finding the boundary**

This exercise uses PDAL to find a tight-fitting boundary of an aerial scan. Printing the coordinates of the boundary for the file is quite simple using a single `pdal info` call, but visualizing the boundary is more complicated. To complete this exercise, we are going to use *QGIS* (page 434) to view the boundary, which means we must first install it on our system.
**Exercise**

**Note:** We are going to run using the Uncompahgre data in the ./density directory.

```
$ pdal info ./exercises/analysis/density/uncompahgre.laz --boundary
{
    "boundary": {
        "area": 90431700.63,
        "avg_pt_per_sq_unit": 20.23338738,
        "avg_pt_spacing": 2.580181288,
        "boundary": "MULTIPOLYGON (((245561.32 4208409.0,245731.84 ...
        ... a giant blizzard of coordinate output scrolls across our terminal. Not very useful.

Instead, let’s generate some kind of vector output we can visualize with QGIS (page 434). The pdal tindex is the “tile index” command, and it outputs a vector geometry file for each point cloud file it reads. It generates this boundary using the same mechanism we invoked above – filters.hexbin (page 331). We can leverage this capability to output a contiguous boundary of the uncompahgre.laz file.

```
$ pdal tindex create --tindex ./exercises/analysis/boundary/boundary.
    sqlite\  
    --filespec ./exercises/analysis/density/uncompahgre.laz \  
    -f SQLite
```

Once we’ve run the tindex (page 48), we can now visualize our output:

Open QGIS (page 434) and select Add Vector Layer:
Navigate to the exercises/analysis/boundary directory and then open the boundary.sqlite file:
Notes

1. The PDAL boundary computation is an approximation based on a hexagon tessellation. It uses the software at http://github.com/hobu/hexer to do this task.

2. `filters.hexbin` (page 331) can also be used by the density (page 31) to generate a tessellated surface. See the Visualizing acquisition density (page 471) example for steps to achieve this.

3. The `tindex` (page 48) can be used to generate boundaries for large collections of data. A boundary-based indexing scheme is commonly used in LiDAR processing, and PDAL supports it through the `tindex` application. You can also use this command to merge data together (query across boundaries, for example).

Clipping data with polygons

This exercise uses PDAL to apply to clip data with polygon geometries.

**Note:** This exercise is an adaption of the PDAL tutorial (page 403).

Exercise

The `autzen.laz` file is a staple in PDAL and libLAS examples. You can download this file here (https://github.com/PDAL/data/blob/master/autzen/autzen.laz) and move it to `./exercises/analysis/clipping` in your drive. We will use this file to demonstrate clipping points with a geometry. We’re going to clip out the stadium into a new COPC file.
Data preparation

The data are mixed in two different coordinate systems. The LAZ (page 89) file is in Oregon State Plane Ft. (http://www.oregon.gov/DAS/CIO/GEO/pages/coordination/projections/projections.aspx) and the GeoJSON (http://geojson.org) defining the polygons, attributes.json, is in EPSG:4326 (http://epsg.io/4326). We have two options – project the point cloud into the coordinate system of the attribute polygons, or project the attribute polygons into the coordinate system of the points. The latter is preferable in this case because it will be less math and therefore less computation. To make it convenient, we can utilize OGR (http://www.gdal.org)’s VRT (http://www.gdal.org/drv_vrt.html) capability to reproject the data for us on-the-fly:

```xml
<OGRVRTDataSource>
  <OGRVRTWarpedLayer>
    <OGRVRTLayer name="OGRGeoJSON">
      <SrcDataSource>/exercises/analysis/clipping/attributes.json</SrcDataSource>
      <SrcLayer>attributes</SrcLayer>
      <LayerSRS>EPSG:4326</LayerSRS>
      <TargetSRS>+proj=lcc +lat_1=43 +lat_2=45.5 +lat_0=41.75 +lon_0=-120.5 +x_0=399999.9999999999 +y_0=0 +ellps=GRS80 +units=ft +no_defs</TargetSRS>
    </OGRVRTLayer>
  </OGRVRTWarpedLayer>
</OGRVRTDataSource>
```

13.1. Point Cloud Processing and Analysis with PDAL
Note: This VRT file is available in your workshop materials in the ./exercises/analysis/clipping/attributes.vrt file. You will need to open this file, go to line 4 and replace ./ with the correct path for your machine.

A GDAL or OGR VRT is a kind of “virtual” data source definition type that combines a definition of data and a processing operation into a single, readable data stream.

Overlaying Attributes

To add our attributes.vrt file, perform the following:

1. In QGIS, select Layer -> Add Layer -> Add Vector Layer
2. Add attributes.vrt as the Vector Layer
3. Right click the new layer and select properties
4. Under “Symbology” on the left, select “categorized” from the drop-down
5. Change value from $id to cls
6. Below, select “Classify” and confirm
7. In the “Layer Rendering” drop-down, set “Opacity” to 50%
8. On the left, select “Labels”. Set the drop-down to “Single Labels”
9. Change value from id to cls and select “OK” on the bottom right
**Note:** Notice the numbers on the buildings and trees. These are the classifications given in the LIDAR Point Classes or LAS Specification (https://www.asprs.org/wp-content/uploads/2019/03/LAS_1_4_r14.pdf). You can sort and single out these in JSON filters. ex. "expression": "Classification >= 3 && Classification <= 4" which only shows classes 3 to 4 which are medium and high vegetation.
Table 1: ASPRS Standard LiDAR Point Classes (Point Data Record Format 0-5)

<table>
<thead>
<tr>
<th>Classification Value (bits 0:4)</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Created, never classified</td>
</tr>
<tr>
<td>1</td>
<td>Unclassified</td>
</tr>
<tr>
<td>2</td>
<td>Ground</td>
</tr>
<tr>
<td>3</td>
<td>Low Vegetation</td>
</tr>
<tr>
<td>4</td>
<td>Medium Vegetation</td>
</tr>
<tr>
<td>5</td>
<td>High Vegetation</td>
</tr>
<tr>
<td>6</td>
<td>Building</td>
</tr>
<tr>
<td>7</td>
<td>Low Point (noise)</td>
</tr>
<tr>
<td>8</td>
<td>Model Key-point (mass point)</td>
</tr>
<tr>
<td>9</td>
<td>Water</td>
</tr>
<tr>
<td>10</td>
<td>Reserved for ASPRS Definition</td>
</tr>
<tr>
<td>11</td>
<td>Reserved for ASPRS Definition</td>
</tr>
<tr>
<td>12</td>
<td>Overlap Points</td>
</tr>
<tr>
<td>13-31</td>
<td>Reserved for ASPRS Definition</td>
</tr>
</tbody>
</table>

**Note:** The GeoJSON file does not have an externally-defined coordinate system, so we are explicitly setting one with the LayerSRS parameter. If your data does have coordinate system information, you don’t need to do that. See the OGR VRT documentation (http://www.gdal.org/drv_vrt.html) for more details.

**Pipeline breakdown**

```json
{
    "pipeline": [
        "./exercises/analysis/clipping/autzen.laz",
        {
            "column": "CLS",
            "datasource": "./exercises/analysis/clipping/attributes.vrt",
            "dimension": "Classification",
            "layer": "OGRGeoJSON",
            "type": "filters.overlay"
        },
        {
            "expression": "Classification == 6",
            "type": "filters.expression"
        }
    ]
}
```


Note: This pipeline is available in your workshop materials in the ./exercises/analysis/clipping/clipping.json file. Remember to replace each of the three occurrences of ./ in this file with the correct location for your machine.

1. Reader

autzen.laz is the LASzip (http://laszip.org) file we will clip.

2. filters.overlay

The filters.overlay (page 256) filter allows you to assign values for coincident polygons. Using the VRT we defined in Data preparation (page 457), filters.overlay (page 256) will assign the values from the CLS column to the Classification field.

3. filters.expression

The attributes in the attributes.json file include polygons with values 2, 5, and 6. We will use filters.expression (page 305) to keep points with Classification values in the range of 6:6.

4. Writer

We will write our content back out using a writers.las (page 161).
Execution

Invoke the following command, substituting accordingly, in your Conda Shell:

The `--nostream` option disables stream mode. The point-in-polygon check (see notes) performs poorly in stream mode currently.

```
$ pdal pipeline ./exercises/analysis/clipping/clipping.json --nostream
```

Visualization

Use one of the point cloud visualization tools you installed to take a look at your `./exercises/analysis/clipping/stadium.copc.laz` output. In the example below, we opened the file to view it using QGIS.
Notes

1. *filters.overlay* (page 256) does point-in-polygon checks against every point that is read.
2. Points that are *on* the boundary are included.

Colorizing points with imagery

This exercise uses PDAL to apply color information from a raster onto point data. Point cloud data, especially LiDAR (https://en.wikipedia.org/wiki/Lidar), do not often have coincident color information. It is possible to project color information onto the points from an imagery source. This makes it convenient to see data in a larger context.

Exercise

PDAL provides a *filter* (page 192) to apply color information from raster files onto point cloud data. Think of this operation as a top-down projection of RGB color values on the points.

Because this operation is somewhat complex, we are going to use a pipeline to define it.

```json
{
    "pipeline": [
        "/exercises/analysis/thinning/uncompahgre.laz",
        {
            "type": "filters.colorization",
            "raster": "/exercises/analysis/colorization/casi-2015-04-29-weekly-mosaic.tif"
        },
        {
            "type": "filters.expression",
            "expression": "Red >= 1"
        },
        {
            "type": "writers.las",
            "compression": "true",
            "minor_version": "2",
            "dataformat_id": "3",
            "filename": "/exercises/analysis/colorization/uncompahgre-colored.laz"
        },
        {
            "type": "writers.copc",
            "filename": "/exercises/analysis/colorization/uncompahgre-colored.copc"
        }
    ]
}
```

(continues on next page)
Pipeline breakdown

1. Reader

After our pipeline errata, the first item we define in the pipeline is the point cloud file we’re going to read.

```
colored.copc.laz",
    "forward": "all"
  ]
}
```

2. filters.colorization

The `filters.colorization` (page 223) PDAL filter does most of the work for this operation. We’re going to use the default data scaling options. This filter will create PDAL dimensions Red, Green, and Blue.

```
{
    "type": "filters.colorization",
    "raster": ".exercises/analysis/colorization/casi-2015-04-29-weekly-
 gelding.tif"
}
```
3. filters.expression

A small challenge is the raster will colorize many points with NODATA values. We are going to use the filters.expression (page 305) to filter keep any points that have Red >= 1.

```
{
    "type": "filters.expression",
    "expression": "Red >= 1"
}
```

4. writers.las

We could just define the uncompahgre-colored.laz filename, but we want to add a few options to have finer control over what is written. These include:

```
{
    "type": "writers.las",
    "compression": "true",
    "minor_version": "2",
    "dataformat_id": "3",
    "filename": "/exercises/colorization/analysis/uncompahgre-colored.laz"
}
```

1. compression: LASzip (http://laszip.org) data is ~6x smaller than ASPRS LAS.
2. minor_version: We want to make sure to output LAS 1.2, which will provide the widest compatibility with other softwares that can consume LAS.
3. dataformat_id: Format 3 supports both time and color information

5. writers.copc

We will then turn the uncompahgre-colored.laz into a COPC file for vizualization with QGIS using the stage below.

```
{
    "type": "writers.copc",
    "filename": "/exercises/analysis/colorization/analysis/uncompahgre-colored.copc.laz",
    "forward": "all"
}
```
1. **forward**: List of header fields to be preserved from LAS input file. In this case, we want all fields to be preserved.

**Note:** *writers.las* (page 161) and *writers.copc* (page 143) provide a number of possible options to control how your LAS files are written.

### Execution

Invoke the following command, substituting accordingly, in your *Conda Shell*:

```bash
$ pdal pipeline ./exercises/analysis/colorization/colorize.json
```

### Visualization

Use one of the point cloud visualization tools you installed to take a look at your `uncompahgre-colored.laz` output. In the example below, we simply opened the file using QGIS.
Notes

1. Applying color information that is not time-coincident with the point cloud data will mean you will see discontinuities.
2. GDAL is used to read the image source. Any GDAL-readable data format can be used.
3. There are performance considerations to be aware of depending on the raster format and type being used. See filters.colorization (page 223) for more information.

Removing noise

This exercise uses PDAL to remove unwanted noise in an airborne LiDAR collection.

Exercise

PDAL provides the outlier filter (page 203) to apply a statistical filter to data.

Because this operation is somewhat complex, we are going to use a pipeline to define it.

```json
{
    "pipeline": [
        "./exercises/analysis/denoising/18TWK820985.laz",
        
        
        
        
        
        "type": "filters.outlier",
        "method": "statistical",
        "multiplier": 3,
        "mean_k": 8
    ],
    
    "type": "filters.expression",
    "expression": "(Classification != 7) && (Z >= -100 && Z <= 3000)"
},

"type": "writers.las",
"compression": "true",
"minor_version": "2",
"dataformat_id": "0",
"filename": "./exercises/analysis/denoising/clean.laz"
}
```

(continues on next page)
Note: This pipeline is available in your workshop materials in the
./exercises/analysis/denoising/denoise.json file.

Pipeline breakdown

1. Reader

After our pipeline errata, the first item we define in the pipeline is the point cloud file we’re going to read.

"./exercises/analysis/denoising/18TWK820985.laz",

2. filters.outlier

The PDAL outlier filter (page 203) does most of the work for this operation.

```json
{
   "type": "filters.outlier",
   "method": "statistical",
   "multiplier": 3,
   "mean_k": 8
}
```
3. filters.expression

At this point, the outliers have been classified per the LAS specification as low/noise points with a classification value of 7. The range filter (page 305) can remove these noise points by constructing a range (page 305) with the value Classification $\neq 7$, which passes every point with a Classification value not equal to 7.

Even with the filters.outlier (page 203) operation, there is still a cluster of points with extremely negative Z values. These are some artifact or mis-computation of processing, and we don’t want these points. We can construct another range (page 305) to keep only points that are within the range $-100 \leq Z \leq 3000$.

Both ranges (page 305) are passed as a AND-separated list to the expression based range filter (page 305) via the expression option.

```
{
    "type": "filters.expression",
    "expression": "Classification != 7 && (Z >= -100 && Z <= 3000)"
},
```

4. writers.las

We could just define the clean.laz filename, but we want to add a few options to have finer control over what is written. These include:

```
{
    "type": "writers.las",
    "compression": "true",
    "minor_version": "2",
    "dataformat_id": "0",
    "filename": "/exercises/analysis/denoising/clean.laz"
}
```

1. compression: LASzip (http://laszip.org) data is ~6x smaller than ASPRS LAS.

2. minor_version: We want to make sure to output LAS 1.2, which will provide the widest compatibility with other softwares that can consume LAS.

3. dataformat_id: Format 0 supports both time and color information
5. writers.copc

We will then turn the clean.laz file into a COPC file for visualization with QGIS using the stage below.

```
{
    "type": "writers.copc",
    "filename": "./exercises/analysis/colorization/clean.copc.laz"
    "forward": "all"
}
```

1. **forward**: List of header fields to be preserved from LAS input file. In this case, we want all fields to be preserved.

---

**Note:** *writers.las* (page 161) and *writers.copc* (page 143) provide a number of possible options to control how your LAS files are written.

---

**Execution**

Invoke the following command, substituting accordingly, in your `Shell`

```
$ pdal pipeline ./exercises/analysis/denoising/denoise.json
```

**Visualization**

Use one of the point cloud visualization tools you installed to take a look at your clean.copc.laz output. In the example below, we simply opened the file using QGIS.
Notes

1. Control the aggressiveness of the algorithm with the mean_k parameter.

2. *filters.outlier* (page 203) requires the entire set in memory to process. If you have really large files, you are going to need to *split* (page 322) them in some way.

Visualizing acquisition density

This exercise uses PDAL to generate a density surface. You can use this surface to summarize acquisition quality.

Exercise

PDAL provides an *application* (page 31) to compute a vector field of hexagons computed with *filters.hexbin* (page 331). It is a kind of simple interpolation, which we will use for visualization in QGIS (http://qgis.org).
**Command**

Invoke the following command, substituting accordingly, in your *Shell*:

```bash
$ pdal density ./exercises/analysis/density/uncompahgre.laz \
-o ./exercises/analysis/density/density.sqlite \
-f SQLite
```

> pdal density ./exercises/analysis/density/uncompahgre.laz ^
- o ./exercises/analysis/density/density.sqlite ^
-f SQLite

**Visualization**

The command uses GDAL to output a *SQLite* (http://sqlite.org) file containing hexagon polygons. We will now use QGIS (http://qgis.org) to visualize them.

1. Add a vector layer

2. Navigate to the output directory
3. Add the `density.sqlite` file to the view.

4. Right click on the `density.sqlite` layer in the Layers panel and then choose Properties.

5. Within the Symbology tab, change Single Symbol to Graduated in the drop down.
6. Choose the Count column to visualize
7. Choose the Classify button to add intervals
8. Adjust the visualization as desired
Notes

1. You can control how the density hexagon surface is created by using the options in `filters.hexbin` (page 331).

   The following settings will use a hexagon edge size of 24 units.

   ```
   --filters.hexbin.edge_size=24
   ```

2. You can generate a contiguous boundary using PDAL (https://pdal.io/)'s tindex (page 48).

Thinning

This exercise uses PDAL to subsample or thin point cloud data. This might be done to accelerate processing (less data), normalize point density, or ease visualization.

Exercise

As we showed in the Visualizing acquisition density (page 471) exercise, the points in the uncompahgre.laz file are not evenly distributed across the entire collection. While we will not get into reasons why that particular property is good or bad, we note there are three different sampling strategies we could choose. We can attempt to preserve shape, we can try to randomly sample, and we can attempt to normalize posting density. PDAL provides capability for all three:

- Poisson using the `filters.sample` (page 296)
- Random using a combination of `filters.decimation` (page 292) and `filters.randomize` (page 262)
- Voxel using `filters.voxelcentroidnearestneighbor` (page 303)

In this exercise, we are going to thin with the Poisson method, but the concept should operate similarly for the `filters.voxelcentroidnearestneighbor` (page 303) approach.

Command

Invoke the following command, substituting accordingly, in your Conda Shell:

```bash
pdal translate ./exercises/analysis/density/uncompahgre.laz \
./exercises/analysis/thinning/uncompahgre-thin.copc.laz \
sample --filters.sample.radius=20
```
Fig. 3: Thinning strategies available in PDAL
By specifying our radius, we set the minimum distance between points to 20 meters.

**Visualization**

QGIS has the ability to switch on/off multiple data sets, and we are going to use that ability to view both the `uncompahgre.laz` and the output `uncompahgre-thin.copc.laz` file.

![Fig. 4: Selecting multiple data sets in QGIS](image)

13.1. Point Cloud Processing and Analysis with PDAL
Fig. 5: Uncompahgre thinned at a radius of 20m
Notes

1. Poisson sampling is non-destructive. Points that are filtered with `filters.sample` (page 296) will retain all attribute information.

Identifying ground

This exercise uses PDAL to classify ground returns using the Simple Morphological Filter (SMRF) technique.

Note: This exercise is an adaptation of the Ground Filter Tutorial (page 408) tutorial on the PDAL website by Brad Chambers. You can find more detail and example invocations there.

Exercise

The primary input for Digital Terrain Model generation is a point cloud with ground vs. not-ground classifications. In this example, we will use an algorithm provided by PDAL, the Simple Morphological Filter technique to generate a ground surface.

See also:

You can read more about the specifics of the Simple Morphological Filter (SMRF) (page 197)

Command

Invoke the following command, substituting accordingly, in your Conda Shell:

```
$ pdal translate ./exercises/analysis/ground/CSite1_orig-utm.laz \
-o ./exercises/analysis/ground/ground.copc.laz \
smrф \
-v 4
```

As we can see, the algorithm does a great job of discriminating the points, but there’s a few issues.
There’s noise underneath the main surface that will cause us trouble when we generate a terrain surface.
Filtering

We do not yet have a satisfactory surface for generating a DTM. When we visualize the output of this ground operation, we notice there’s still some noise. We can stack the call to SMRF with a call to a the `filters.outlier` technique we learned about in Removing noise (page 467).

1. Let us start by removing the non-ground data to just view the ground data:

   ```sh
   $ pdal translate \
   ./exercises/analysis/ground/CSite1_orig-utm.laz \
   -o ./exercises/analysis/ground/ground.copc.laz \
   smrf expression \
   --filters.expression.expression="Classification == 2"
   -v 4
   
   > pdal translate 
   ^
   ./exercises/analysis/ground/CSite1_orig-utm.laz ^
   -o ./exercises/analysis/ground/ground.copc.laz ^
   smrf expression ^
   --filters.expression.expression="Classification == 2"^  
   -v 4
   
   2. Now we will instead use the `translate` (page 50) command to stack the `filters.outlier` (page 203) and `filters.smrf` (page 197) stages:

   ```sh
   $ pdal translate ./exercises/analysis/ground/CSite1_orig-utm.laz \
   -o ./exercises/analysis/ground/denoised-ground-only.copc.laz \
   outlier smrf expression \
   --filters.outlier.method="statistical" \
   --filters.outlier.mean_k=8 --filters.outlier.multiplier=3.0 \
   --filters.smrf.ignore="Classification[7:7]" \
   --filters.expression.expression="Classification == 2"
   
   > pdal translate ./exercises/analysis/ground/CSite1_orig-utm.laz ^  
   -o ./exercises/analysis/ground/denoised-ground-only.copc.laz ^ 
   outlier smrf expression ^  
   --filters.outlier.method="statistical" ^  
   --filters.outlier.mean_k=8 --filters.outlier.multiplier=3.0 ^  
   --filters.smrf.ignore="Classification[7:7]" ^  
   --filters.expression.expression="Classification == 2"
   
   In this invocation, we have more control over the process. First the outlier filter merely classifies outliers with a Classification value of 7. These outliers are then ignored during
SMRF processing with the `ignore` option. Finally, we add a range filter to extract only the ground returns (i.e., `Classification` value of 2).

The result is a more accurate representation of the ground returns.

13.1.6 Generation

Generating a DTM

This exercise uses PDAL to generate an elevation model surface using the output from the Identifying ground (page 481) exercise, PDAL’s `writers.gdal` (page 156) operation, and GDAL (http://gdal.org/) to generate an elevation and hillshade surface from point cloud data.

Exercise

**Note:** The primary input for Digital Terrain Model (https://en.wikipedia.org/wiki/Digital_elevation_model) generation is a point cloud with ground classifications. We created this file, called `denoised-ground-only.laz`, in the Identifying ground (page 481) exercise. Please produce that file by following that exercise before starting this one.
Command

PDAL capability to generate rasterized output is provided by the *writers.gdal* (page 156) stage. There is no *application* (page 27) to drive this stage, and we must use a pipeline.

Pipeline breakdown

```json
{
    "pipeline": [
        "../exercises/analysis/ground/denoised-ground-only.copc.laz",
        
        {
            "filename": "../exercises/analysis/dtm/dtm.tif",
            "gdaldriver": "GTiff",
            "output_type": "all",
            "resolution": "2.0",
            "type": "writers.gdal"
        }
    ]
}
```

**Note:** This pipeline is available in your workshop materials in the 
./exercises/analysis/dtm/gdal.json file. Make sure to edit the filenames to match your paths.

1. Reader

denoised-ground-only is the COPC (https://copc.io) file we will clip. You should have created this output as part of the *Identifying ground* (page 481) exercise.

2. *writers.gdal*

The *writers.gdal* (page 156) writer that bins the point cloud data into an elevation surface.
PDAL: Point cloud Data Abstraction Library, Release 2.6.2

Execution

$ pdal pipeline ./exercises/analysis/dtm/gdal.json

Visualization

Something happened, and some files were written, but we cannot really see what was produced. Let us use QGIS (page 434) to visualize the output.

1. Open QGIS (page 434) and Add Raster Layer:

2. Add the dtm.tif file from your ./exercises/analysis/dtm directory.
3. Go to Raster -> Analyze -> Fill nodata... and select the default values
4. Classify the DTM by right-clicking on the Filled and choosing Properties. Pick the singleband pseudocolor for the rendering type, and then choose a color ramp and click Classify.

5. QGIS (page 434) provides access to GDAL (http://gdal.org/) processing tools, and we are going to use that to create a hillshade of our surface. Choose Raster→Analysis→Hillshade:
6. Click the window for the Output file and select a location to save the hillshade.tif file.
7. Click OK and the hillshade of your DTM is now available.
Notes

1. gdaldem (http://www.gdal.org/gdaldem.html), which powers the QGIS (page 434) DEM tools, is a very powerful command line utility you can use for processing data.

2. writers.gdal (page 156) can be used for large data, but it does not interpolate a typical TIN (https://en.wikipedia.org/wiki/Triangulated_irregular_network) surface model.

3. If you are missing the Raster tab, check your plugins in QGIS. If you have none you may need to reinstall QGIS.

Creating surface meshes

This exercise uses PDAL to create surface meshes. PDAL is able to use a number of meshing filters: https://pdal.io/en/latest/stages/filters.html. Three of these are ‘in the box’, without needing plugins compiled. These are 2D Delaunay triangulation, Greedy projection meshing and Poisson surface meshing.

In this exercise we’ll create a Poisson surface mesh - a watertight isosurface - from our input point cloud.
Exercise

We will create mesh models of a building and its surrounds using an entwine data input source. After running each command, the output .ply file can be viewed in Meshlab or CloudCompare (https://www.danielgm.net/cc/).

Note: Since QGIS doesn’t support .ply files we can’t use it for this exercise. In order to use QGIS you can covert the files to OBJ or .copc using PDAL.

See also:

PDAL implements Mischa Kazhdan’s Poisson surface reconstruction algorithm. For details see [Kazhdan2006]_.

Note: This example will be using the output of using Clipping data with polygons (page 456) exercise, specifically using stadium.copc.laz file. Please produce that file by following that exercise before starting this one.

Note: writers.ply will write out mesh vertices by default. In this exercise we set the attribute faces=”true”. Try using the ply writer without it. Also, if you’re using a machine with a lot of processing power, try increasing the depth parameter for a more detailed mesh.

Mesh Command

Invoke the following command, substituting accordingly, in your Conda Shell:

```bash
$ pdal translate -i ./exercises/analysis/clipping/stadium.copc.laz
-o ./exercises/analysis/meshing/first-mesh.ply
poisson --filters.poisson.depth=16
--verbose 4
```

> pdal translate -i ./exercises/analysis/clipping/stadium.copc.laz
^o ./exercises/analysis/meshing/first-mesh.ply
^poisson --filters.poisson.depth=16
^--verbose 4

(PDAL Debug) Debugging...
(pdal translate Debug) Executing pipeline in standard mode.
(pdal translate filters.poisson Debug) Computing normal vectors
You can view the mesh in Cloud Compare, you should see something similar to:

To colorize the points, select `first-mesh` in the left window. Under Properties set Colors to RGB. You should see the following:
Filtering

If we want to just mesh a building, or just terrain, or both we can apply a range filter based on point classification. These data have ground labeled as class 2, and buildings as 6.

In this exercise we will create a poisson mesh surface of a building and the ground surrounding it, using the same data subset as above and adding a filters.expression (page 305) stage to limit the set of points used in mesh creation.

Command

Invoke the following command, substituting accordingly, in your Conda Shell:

```bash
$ pdal translate -i ./exercises/analysis/clipping/stadium.copc.laz \
-o ./exercises/analysis/meshing/building-exercise.ply \
range poisson \
--filters.range.limits="Classification[2:2],Classification[6:6]"
```

(continues on next page)
Rasterizing Attributes

This exercise uses PDAL to generate a raster surface using a fully classified point cloud with PDAL’s `writers.gdal` (page 156).

Exercise

**Note:** The exercise fetches its data from an Entwine (https://entwine.io) service that organizes the point cloud collection for the entire country of Denmark. You can view the data online at http://potree.entwine.io/data/denmark.html
Command

PDAL capability to generate rasterized output is provided by the `writers.gdal` (page 156) stage. There is no `application` (page 27) to drive this stage, and we must use a pipeline.

Pipeline breakdown

{  
  "pipeline": [  
    {  
      "type": "readers.ept",  
      "filename": "https://na-c.entwine.io/dk/ept.json",  
      "bounds": "([1401016, 1410670], [7476527, 7484590])",  
      "resolution": 5  
    },  
    {  
      "type": "writers.gdal",  
      "filename": "denmark-classification.tif",  
      "dimension": "Classification",  
      "data_type": "uint16_t",  
      "output_type": "mean",  
      "resolution": 5  
    }  
  ]  
}

Note: This pipeline is available in your workshop materials in the `./exercises/analysis/rasterize/classification.json` file. Make sure to edit the filenames to match your paths.

1. Reader

{  
  "type": "readers.ept",  
  "filename": "https://na-c.entwine.io/dk/ept.json",  
  "bounds": "([1401016, 1410670], [7476527, 7484590])",  
  "resolution": 5  
}
The data is read from an EPT resource that contains the Denmark data. We're going to download a small patch of data by the Copenhagen airport area that is limited to a spatial resolution of 5m.

### 2. writers.gdal

The `writers.gdal` (page 156) writer that bins the point cloud data with classification values.

```json
{
  "type": "writers.gdal",
  "filename": "denmark-classification.tif",
  "dimension": "Classification",
  "data_type": "uint16_t",
  "output_type": "mean",
  "resolution": 5
}
```

### Execution

Issue the `pipeline` (page 55) operation to execute the interpolation:

```
$ pdal pipeline ./exercises/analysis/rasterize/classification.json -v 3
(PDAL Debug) Debugging...
(pdal pipeline readers.ept Debug) Root resolution: 3108.53
Query resolution: 5
Actual resolution: 3.03568
Depth end: 11
Query bounds: ([1402800, 1408800], [7478000, 7483000], [-1.797693134862316e+308, 1.797693134862316e+308])
Threads: 15
(pdal pipeline Debug) Executing pipeline in stream mode.
```
Basic interpolation of data with "writers.gdal" (page 156) will output raw classification values into the resulting raster file. We will need to add a color ramp to the data for a satisfactory preview.

Unfortunately, this does not give us a very satisfactory image to view. The reason is there is no color ramp associated with the file, and we’re looking at pixel values with values from 0-31 according to the ASPRS LAS specification.

We want colors that correspond to the classification values a bit more directly. We can use a color ramp to assign explicit values. "QGIS" (page 434) allows us to create a text file color ramp that gdaldem can consume to apply colors to the data. The filename is "./exercises/analysis/rasterize/ramp.txt".

```
# QGIS Generated Color Map Export File
2 139 51 38 255 Ground
3 143 201 157 255 Low Veg
4 5 159 43 255 Med Veg
5 47 250 11 255 High Veg
6 209 151 25 255 Building
7 232 41 7 255 Low Point
```
With this ramp, you can load the color values into QGIS as a color ramp if you change the layer to Palatted/Unique Values, and then load the color ramp file:
With the ramp, we can also use `gdaldem` (http://www.gdal.org/gdaldem.html) to apply it to a new image:

```
$ gdaldem color-relief denmark-classification.tif ramp.txt classified-color.png -of PNG
```
Intensity

With PDAL’s ability to override pipeline via commands, we can generate a relative intensity image:

```bash
$ pdal pipeline ./exercises/analysis/rasterize/classification.json
  --writers.gdal.dimension="Intensity"
  --writers.gdal.data_type="float"
  --writers.gdal.filename="intensity.tif"
  -v 3
(PDAL Debug) Debugging...
(pdal pipeline readers.ept Debug) Root resolution: 3108.53
Query resolution: 5
Actual resolution: 3.03568
Depth end: 11
Query bounds: ([1402800, 1408800], [7478000, 7483000], [-1.797693134862316e+308, 1.797693134862316e+308])
Threads: 15
(pdal pipeline Debug) Executing pipeline in stream mode.
$ gdal_translate intensity.tif intensity.png -of PNG
```

(continues on next page)
Input file size is 1201, 1001
Warning 6: PNG driver doesn't support data type Float32. Only eight bit (Byte) and sixteen bit (UInt16) bands supported. Defaulting to Byte 0...10...20...30...40...50...60...70...80...90...100 - done.

> pdal pipeline ./exercises/analysis/rasterize/classification.json ^
   --writers.gdal.dimension="Intensity" ^
   --writers.gdal.data_type="float" ^
   --writers.gdal.filename="intensity.tif" ^
   -v 3
(PDAL Debug) Debugging...
(pdal pipeline readers.ept Debug) Root resolution: 3108.53
Query resolution: 5
Actual resolution: 3.03568
Depth end: 11
Query bounds: ([1402800, 1408800], [7478000, 7483000], [-1.797693134862316e+308, 1.797693134862316e+308])
Threads: 15
(pdal pipeline Debug) Executing pipeline in stream mode.
> gdal_translate intensity.tif intensity.png -of PNG
Input file size is 1201, 1001
Warning 6: PNG driver doesn't support data type Float32. Only eight bit (Byte) and sixteen bit (UInt16) bands supported. Defaulting to Byte 0...10...20...30...40...50...60...70...80...90...100 - done.

The same pipeline can be used to generate a preview image of the Intensity channel of the data by overriding pipeline arguments at the command line.
Notes

1. *writers.gdal* (page 156) can output any dimension PDAL can provide, but it is up to the user to interpolate the values. For categorical data, neighborhood smoothing might produce undesirable results, for example.

2. *Pipeline* (page 55) contains more information about overrides and organizing complex pipelines.

Plotting a histogram

Exercise

PDAL doesn’t provide every possible analysis option, but it strives to make it convenient to link PDAL to other places with substantial functionality. One of those is the Python/Numpy universe, which is accessed through PDAL’s *Python* (page 369) bindings and the *filters.python* (page 348) filter. These tools allow you to manipulate point cloud data with convenient Python tools rather than constructing substantial C/C++ software to achieve simple tasks, compute simple statistics, or investigate data quality issues.
This exercise uses PDAL to create a histogram plot of all of the dimensions of a file. matplotlib (https://matplotlib.org/) is a Python package for plotting graphs and figures, and we can use it in combination with the Python (page 369) bindings for PDAL to create a nice histogram. These histograms can be useful diagnostics in an analysis pipeline. We will combine a Python script to make a histogram plot with a pipeline (page 41).

Note: Python allows you to enhance and build functionality that you can use in the context of other Pipeline (page 55) operations.

PDAL Pipeline

We’re going to create a PDAL Pipeline (page 55) to tell PDAL to run our Python script in a filters.python (page 348) stage.

```json
{
   "pipeline": [
      {
         "filename": ".exercises/python/athletic-fields.laz"
      },
      {
         "type": "filters.python",
         "function": "make_plot",
         "module": "anything",
         "pdalargs": "{"filename":"./exercises/python/histogram.png"},
         "script": ".exercises/python/histogram.py"
      },
      {
         "type": "writers.null"
      }
   ]
}
```

Note: This pipeline is available in your workshop materials in the ./exercises/python/histogram.json file.
Python script

The following Python script will do the actual work of creating the histogram plot with matplotlib (https://matplotlib.org/). Store it as histogram.py next to the histogram.json Pipeline (page 55) file above. The script is mostly regular Python except for the `ins` and `outs` arguments to the function – those are special arguments that PDAL expects to be a dictionary of Numpy dictionaries.

**Note:** This Python file is available in your workshop materials in the ./exercises/python/histogram.py file.

```python
# import numpy
import numpy as np

# import matplotlib stuff and make sure to use the # AGG renderer.
import matplotlib
matplotlib.use('Agg')
import matplotlib.pyplot as plt
import matplotlib.mlab as mlab

# This only works for Python 3. Use # StringIO for Python 2.
from io import BytesIO

# The make_plot function will do all of our work. The # filters.programmable filter expects a function name in the # module that has at least two arguments -- "ins" which # are numpy arrays for each dimension, and the "outs" which # the script can alter/set/adjust to have them updated for # further processing.

def make_plot(ins, outs):
    # figure position and row will increment
    figure_position = 1
    row = 1

    fig = plt.figure(figure_position, figsize=(6, 8.5), dpi=300)

    for key in ins:
        dimension = ins[key]
        ax = fig.add_subplot(len(ins.keys()), 1, row)
```

(continues on next page)
# histogram the current dimension with 30 bins
```
n, bins, patches = ax.hist(dimension, 30,
   density=0,
   facecolor='grey',
   alpha=0.75,
   align='mid',
   histtype='stepfilled',
   linewidth=None)
```

# Set plot particulars
```
ax.set_ylabel(key, size=10, rotation='horizontal')
ax.get_xaxis().set_visible(False)
ax.set_yticklabels('')
ax.set_xticks((),)
ax.set_xlim(min(dimension), max(dimension))
ax.set_ylim(min(n), max(n))
```

# increment plot position
```
row = row + 1
figure_position = figure_position + 1
```

# We will save the PNG bytes to a BytesIO instance
# and the nwrite that to a file.
output = BytesIO()
plt.savefig(output, format="PNG")

# a module global variable, called 'pdalargs' is available
# to filters.programmable and filters.predicate modules that
# contains
# a dictionary of arguments that can be explicitly passed into
# the module by the user. We passed in a filename arg in our `pdal
# pipeline` call
filename = pdalargs['filename'] if 'filename' in pdalargs else 'histogram.png'

# open up the filename and write out the
# bytes of the PNG stored in the BytesIO instance
```
with open(filename, 'wb') as o:
    o.write(output.getvalue())
```

# filters.programmable scripts need to
Run pdal pipeline

```
$ pdal pipeline ./exercises/python/histogram.json
anything:47: UserWarning: Attempting to set identical low and high x-lims makes transformation singular; automatically expanding.
```

# return True to tell the filter it was successful.
return True
Output
Notes

1. *writers.null* (page 170) simply swallows the output of the pipeline. We don’t need to write any data.

2. The `pdalargs` JSON needs to be escaped because a valid Python dictionary entry isn’t always valid JSON.

Georeferencing

As discussed in the introduction (page 428), laser returns from a mobile LiDAR (https://en.wikipedia.org/wiki/Lidar) system must be georeferenced, i.e. placed into a local or global coordinate system by combining data from the laser and from a GNSS/IMU. As of this writing, PDAL does not include generic georeferencing tools — this is considered future work. However, the Optech (http://www.teledyneoptech.com/) csd file format includes both laser return and GNSS/IMU data in the same file, and the PDAL csd reader includes built in georeferencing support.

In this section, we will demonstrate how to georeference an Optech (http://www.teledyneoptech.com/) csd file and reproject that file into a UTM projection.

**Note:** Optech’s (http://www.teledyneoptech.com/) csd format is just one of several vendor-specific data formats PDAL supports; we also support data files directly from RIEGL (http://riegl.com/) sensors and from several project-specific government platforms.

Exercise

The file *S1C1_csd_004.csd* contains airborne data from an Optech (http://www.teledyneoptech.com/) sensor. Without georeferencing these points, they would be impossible to interpret — once they are georeferenced, we will be able to inspect and analyze these points like any other point cloud.

In addition to georeferencing, we are going to make two other tweaks to our point cloud:

- The point cloud is, by default, in WGS84 (https://en.wikipedia.org/wiki/Geodetic_datum), but we will reproject these points to a UTM (https://en.wikipedia.org/wiki/Universal_Transverse_Mercator_coordinate_system) coordinate system for visualization purposes.

- Because these are raw data coming from the sensor, these data are noisy. In particular, there are a few points very close to the sensor which were probably caused by air returns or laser light reflecting off of part of the airplane or sensor. These points have very high...
intensity values, which will screw up our visualization. We will use the filters.expression (page 305) PDAL filter to drop all points with very high intensity values.

**Note:** These data were provided by Dr. Craig Glennie and were collected by NCALM (http://ncalm.cive.uh.edu/), the National Center for Airborne Laser Mapping. The collect area is southwest of Austin, TX.

---

**Command**

Invoke the following command, substituting accordingly, into your Conda Shell:

```
$ pdal translate \
./exercises/georeferencing/S1C1_csd_004.csd \
./exercises/georeferencing/S1C1_csd_004.copc.laz \
reprojection expression \
--filters.reprojection.out_srs="EPSG:32614" \
--filters.expression.expression="Intensity >= 0 && Intensity <= 500"
```

> pdal translate ^

```
./exercises/georeferencing/S1C1_csd_004.csd ^
./exercises/georeferencing/S1C1_csd_004.copc.laz ^
reprojection expression ^
--filters.reprojection.out_srs="EPSG:32614" ^
--filters.expression.expression="Intensity >= 0 && Intensity <= 500"
```

**Visualization**

View your georeferenced point cloud in QGIS.

**Batch Processing**

PDAL doesn’t handle matching multiple file inputs except for glob handling for merge operations, but does allow for command line substitution parameters to make batch processing simpler, substitutions. Substitutions work with both Pipeline (page 55) operations as well as with other applications such as translate (page 50).
Fig. 6: Our airborne laser point cloud after georeferencing, reprojection, and intensity filtering.
Operating system variations

How substitutions are passed generally depends on the operating system and tools available. In the unix/linux environments, this is primarily using the `find` and `ls` programs to get lists of files (either with directories or just filenames) and the `xargs` or `parallel` program to pass those files to the `pdal` application (although `-exec with find` can also be used). These tools are available in the `docker` environment if you are running PDAL under docker. They are also available under Windows one installs Cygwin or MinGW. They are also available if Git for Windows is installed. They are also available as win32 command line programs installed from the GNU Findutils (https://www.gnu.org/software/findutils/findutils.html). They are available for MacOS and Linux.

Windows native tools

Substitutions can be handled directly in windows using `PowerShell` syntax.

While there are a number of ways to generate lists of files, the `Get-ChildItem` is used here, along with the `foreach` option to pass each separate filepath to the pdal application.

Example - Batch compression of LAS files to LAZ - PowerShell:

To compress a series of LAS files in one directory into compressed LAZ files in another directory, the `PowerShell` syntax would be:

```
PS ./exercises/batch> Get-ChildItem .\DIR1\*.las | foreach {pdal translate -i .\DIR1\$($_.BaseName).las -o .\DIR2\$($_.BaseName).laz}
```

Note the use of the `$($_.BaseName)` syntax for the files passed. This option on the `$(_)` shortcut for the full filename, removes the directory and the extension on the file and allows the user to set the path and extension manually.

Example - Parallel Batch compression of LAS files to LAZ - PowerShell:

This use of the `PowerShell` syntax doesn’t allow a user to execute more than one process at a time. There is a free download of the `xargs` program that provides parallel execution available at http://www.pirosa.co.uk/demo/wxargs/ppx2.exe. A clone of this program can be found at https://github.com/ghuls/ppx2. For this tool, the file names are passed with using the `{}` syntax.

```
PS ./exercises/batch> Get-ChildItem .\dir1\ | Select-Object -ExpandProperty BaseName ^
| \ppx2.exe -P 3 pdal translate -i "."\dir1{}.las" -o ".\dir2{}.laz"
```
Unix/Linux native tools

Example - Batch compression of LAS files to LAZ - Bash:

To compress a series of LAS files in one directory into compressed LAZ files in another
directory, the Bash syntax would be:

$$
\text{ls ./dir1/*.las | parallel -I{} \}
\text{pdal translate -i ./dir1/{/.}.las -o ./dir2/{/.}.laz}
$$

In Parallel, then {/} syntax means strip the directory and the extension and just use the
basename of the file. This allows you to easily change the output format and the location.

Example - Parallel Batch compression of LAS files to LAZ - Bash:

Parallel, as its name implies, allows parallel operations. Adding the -j syntax indicates the
number simultaneous jobs to run

$$
\text{ls ./dir1/*.las | parallel -I{} -j 4 \}
\text{pdal translate -i ./dir1/{/.}.las -o ./dir2/{/.}.laz}
$$

Exercise - Pipeline Substitutions:

For the most flexibility, pipelines are used to apply a series of operations to a file (or group of
files). In this exercise, we build on the Generating a DTM (page 484) pipeline example, but run
this pipeline over 4 files and reproject, calculate a bare earth using the filters.smrf (page 197)
filter, remove those points that aren’t bare earth with filters.expression (page 305) and then
write the output using the writers.gdal (page 156).

The pipeline we are using is:

```
{
   "pipeline": [
       {
           "type":"readers.las"
       },
       {
           "type": "filters.reprojection"
       },
       {
           "type": "filters.smrf"
       },
   ]
}
```

(continues on next page)
You might have spotted that this pipeline doesn’t have any input or output file references, or a value for the output spatial reference. We will be adding those at the command line, not within the actual pipeline and using the substitutions syntax to do this.

```
PS ./exercises/batch> Get-ChildItem ./exercises/batch_processing/source/*.laz | ^
  foreach {pdal pipeline ./exercises/batch_processing/batch_srs_gdal.json ^
  --readers.las.filename=./source/$($_.BaseName).laz ^
  --writers.gdal.filename=./dtm/$($_.BaseName).tif ^
  --filters.reprojection.in_srs=epsg:3794 ^
  --filters.reprojection.out_srs=epsg:32733}
```

```
$ ls ./exercises/batch_processing/source/*.laz | \
  parallel -I{} pdal pipeline ./exercises/batch_processing/batch_  \
  srs_gdal.json \
  --readers.las.filename={} \
  --writers.gdal.filename=./exercises/batch_processing/dtm{/.}.tif \
  --filters.reprojection.in_srs=epsg:3794 \
  --filters.reprojection.out_srs=epsg:32733
```

Once you have your dtms created with pdal, combine them to a single file with:

```
$ gdalbuildvrt ./exercises/batch_processing/dtm.vrt ./exercises/batch_  
  processing/dtm*.tif
```

You can then visualize the vrt with qgis. Add the vrt twice, and set the properties of the lower layer to hillshade. Set the upper layer to Singleband PseudoColor and choose a pleasing color ramp. Then set the transparency of the upper layer to 50% and you’ll get a nice display of the terrain.
13.1.7 Final Project

The final project brings together a number of PDAL processing workflow operations into a single effort. It builds upon the exercises to enable you to use the capabilities of PDAL in a coherent processing strategy, and it will give you ideas about how to orchestrate PDAL in the context of larger data processing scenarios.

Given the following pipeline for fetching the data, complete the rest of the tasks:

```
{
  "pipeline": [
    ...
  ]
```

(continues on next page)
Read data from an EPT resource using `readers.ept` (page 72) (See Entwine (page 450))

Note: The particular data we are pulling has some high classification values due to how it was processed. These aren’t useful to us, and we can use `filters.expression` (page 305) in the pipeline to only write points with a classification value under 20.

- Thin it to 1.0 meter spacing using `filters.sample` (page 296) (See Thinning (page 477))
- Filter out noise using `filters.outlier` (page 203) (See Removing noise (page 467))
- Classify ground points using `filters.smrf` (page 197) (See Identifying ground (page 481))
- Compute height above ground using `filters.hag_nn` (page 215)
- Generate a digital terrain model (DTM) using `writers.gdal` (page 156) (See Generating a DTM (page 484))
- Find the average vegetative height model using `writers.gdal` (page 156)
Note: You should review specific exercises for specifics on how to achieve each task.

13.1.8 Notes

Notes
Notes
Notes
14.1 Development

Developer documentation, such as how to update the docs, where the test frameworks are, who develops the software, and conventions to use when developing new code can be found in this section.

**Note:** Users looking for documentation on how to use PDAL’s command line applications should look here (page 27) and users looking to use the PDAL API in their own applications should look here (page 600).

14.1.1 PDAL Architecture Overview

**Author**
Andrew Bell

**Contact**
andrew@hobu.co

**Date**
5/15/2016

PDAL is a set of applications and library to facilitate translation of point cloud data between various formats. In addition, it provides some facilities for transformation of data between various geometric projections and can calculate some statistical, boundary and density data. PDAL also provides point classification algorithms. PDAL provides an API that can be used by programmers for integration into their own projects or to allow extension of existing capabilities.
The PDAL model

PDAL reads data from a set of input sources using format-specific readers. Point data can be passed through various filters that transform data or create metadata. If desired, points can be written to an output stream using a format-specific writer. PDAL can merge data from various input sources into a single output source, preserving attribute data where supported by the input and output formats.

The above diagram shows a possible arrangement of PDAL readers, filters and writers, all of which are known as stages. Any merge operation or filter may be placed after any reader. Output filters are distinct from other filters only in that they may create more than one set of points to be further filtered or written. The arrangement of readers, filters and writers is called a PDAL pipeline. Pipelines can be specified using JSON as detailed later.

Extending PDAL

PDAL is simple to extend by implementing subclasses of existing stages. All processing in PDAL is completely synchronous. No parallel processing occurs, eliminating locking or other concurrency issues. Understanding of several auxiliary classes is necessary to effectively create a new stage.
Dimension

Point cloud formats support various data elements. In order to be useful, all formats must provide some notion of location for points (X, Y and perhaps Z), but beyond that, the data collected in formats may or may not have common data fields. Some formats predefine the elements that make up a point. Other formats provide this information in a header or preamble. PDAL calls each of the elements that make up a point a dimension. PDAL predefines the dimensions that are in common use by the formats that it currently supports. Readers may register their use of a predefined dimension or may have PDAL create a dimension with a name and type as requested. Dimensions are described in a JSON file, Dimension.json.

PDAL has a default type (Double, Float, Signed32, etc.) for each of its predefined dimensions which is believed to be sufficient to accurately hold the necessary data. Only when the default data type is deemed insufficient should a request be made to “upgrade” a storage datatype. There is no simple facility to “downsize” a dimension type to save memory, though it can be done by creating a custom PointLayout object. Dimension.json can be examined to determine the default storage type of each predefined dimension. In most cases knowledge of the storage data type for a dimension isn’t required. PDAL properly converts data to and from the internal storage type transparently. Invalid conversions raise an exception.

When a storage type is explicitly requested for a dimension, PDAL examines the existing storage type and requested type and chooses the storage type so that it can hold both types. In some cases this results in a storage type different from either the existing or requested storage type. For instance, if the current storage type is a 16 bit signed integer (Signed16) and the requested type is a 16 bit unsigned integer (Unsigned16), PDAL will use a 32 bit signed integer as the storage type for the dimension so that both 16 bit storage types can be successfully accommodated.

Point Layout

PDAL stores the dimension information in a point layout structure (PointLayout object). It stores information about the physical layout of data of each point in memory and also stores the type and name of each dimension.

Point Table

PDAL stores points in what is called a point table (PointTable object). Each point table has an associated point layout describing its format. All points in a single point table have the same dimensions and all operations on a PDAL pipeline make use of a single point table. In addition to storing points, a point table also stores pipeline metadata that may be created as pipeline stages are executed. Most functions receive a PointTableRef object, which refers to the active point table. A PointTableRef can be stored or copied cheaply.
A subclass of PointTable called FixedPointTable exists to allow a pipeline to run without loading all points in memory. A FixedPointTable holds a fixed number of points. Some filters can’t operate in streaming mode and an attempt to run a pipeline with a stage that doesn’t support streaming will raise an exception. A custom implementation of this can be created by inheriting from a class called StreamPointTable.

**Point View**

A point view (PointView object) stores references to points. Storage and retrieval of points is done through a point view rather than directly through a point table. Point data is accessed from a point view through a point ID (type PointId), which is an integer value. The first point reference in a point view has a point ID of 0, the second has a point ID of 1, the third has a point ID of 2 and so on. There are no null point references in a point view. The size of a point view is the number of point references contained in the view. A point view acts like a self-expanding array or vector of point references, but it is always full. For example, one can’t set the field value of point with a PointId of 9 unless there already exist at least 8 point references in the point view.

Point references can be copied from one point view to another by appending an existing reference to a destination point view. The point ID of the appended point in the destination view may be different than the point ID of the same point in the source view. The point ID of an appended point reference is the same as the size of the point view after the operation. Note that appending a point reference does not create a new point. Rather, it creates another reference to an existing point. There are currently no built-in facilities for creating copies of points.

**Point Reference**

Some functions take a reference to a single point (PointRef object). In streaming mode, stages implement the processOne() function which operates on a point reference instead of a point view.

**Making a Stage (Reader, Filter or Writer):**

All stages (Stage object) share a common interface, though readers, filters and writers each have a simplified interface if the generic stage interface is more complex than necessary. One should create a new stage by creating a subclass of reader (Reader object), filter (Filter object) or writer (Writer object). When a pipeline is made, each stage is created using its default constructor.

When a pipeline is started, each of its stages is processed in two distinct steps. First, all stages are prepared.
Stage Preparation

Preparation of a stage is done by calling the prepare() function of the stage at the end of the pipeline. prepare() executes the following private virtual functions calls, none of which need to be implemented in a stage unless desired. Each stage is guaranteed to be prepared after all stages that precede it in the pipeline.

1) void addArgs(ProgramArgs& args)

   Stages can accept various options to control processing. These options can be declared and bound to variables in this function. When arguments are added, the stage also provides a description and optionally a default value for the argument.

2) void initialize() OR void initialize(PointTableRef)

   Some stages, particularly readers, may need to do things such as open files to extract header information before the next step in processing. Other general processing that needs to take place before any stage is executed should occur at this time. If the initialization requires knowledge of the point table, implement the function that accepts one, otherwise implement the no-argument version. Whether to place initialization code at this step or in prepared() or ready() (see below) is a judgment call, but detection of errors earlier in the process allows faster termination of a command. Files opened in this step should also be closed before returning.

3) void addDimensions(PointLayoutPtr layout)

   This method allows stages to inform a point table’s layout of the dimensions that it would like as part of the record of each point. Usually, only readers add dimensions to a point table, but there is no prohibition on filters or writers from adding dimensions if necessary. Dimensions should not be added to the layout outside of this method.

4) void prepared(PointTableRef)

   Called after dimensions are added. It can be used to verify state and raise exceptions before stage execution.

Stage Execution

After all stages are prepared, processing continues with the execution of each stage by calling execute(). Each stage will be executed only after all stages preceding it in a pipeline have been executed. A stage is executed by invoking the following private virtual methods. It is important to note that ready() and done() are called only once for each stage while run() is called once for each point view to be processed by the stage.

1) void ready(PointTablePtr table)
This function allows preprocessing to be performed prior to actual processing of the points in a point view. For example, filters may initialize internal data structures or libraries, readers may connect to databases and writers may write a file header. If there is a choice between performing operations in the preparation stage (in the initialize() method) or the execution stage (in ready()), prefer to defer the operation until this point.

2) PointViewSet run(PointViewPtr buf)

This is the method in which processing of individual points occurs. One might read points into the view, transform point values in some way, or distribute the point references in the input view into numerous output views. This method is called once for each point view passed to the stage.

3) void done(PointTablePtr table)

This function allows a stage to clean up resources not released by a stage’s destructor. It also allows other execution of termination functions, such as closing of databases, writing file footers, rewriting headers or closing or renaming files.

Streaming Stage Execution

PDAL normally processes all points through each stage before passing the points to the next stage. This means that all point data is held in memory during processing. There are some situations that may make this undesirable. As an alternative, PDAL allows execution of data with a point table that contains a fixed number of points (StreamPointTable). When a StreamPointTable is passed to the execute() function, the private run() function detailed above isn’t called, and instead processOne() is called for each point. If a StreamPointTable is passed to execute() but a pipeline stage doesn’t implement processOne(), an exception is thrown.

bool processOne(PointRef& ref)

This method allows processing of a single point. A reader will typically read a point from an input source. When a reader returns ‘false’ from this function, it indicates that there are no more points to be read. When a filter returns ‘false’ from this function, it indicates that the point just processed should be filtered out and not passed to subsequent stages for processing.
Implementing a Reader

A reader is a stage that takes input from a point cloud format supported by PDAL and loads points into a point table through a point view.

A reader needs to register or assign those dimensions that it will reference when adding point data to the point table. Dimensions that are predefined in PDAL can be registered by using the point table’s registerDim() method. Dimensions that are not predefined can be added using assignDim(). If dimensions are determined as named entities from a point cloud source, it may not be known whether the dimensions are predefined or not. In this case the function registerOrAssignDim() can be used. When a dimension is assigned, rather than registered, the reader needs to inform PDAL of the type of the variable using the enumeration Dimension::Type.

In this example, the reader informs the point table’s layout that it will reference the dimensions X, Y and Z.

```cpp
void Reader::addDimensions(PointLayoutPtr layout)
{
    layout->registerDim(Dimension::Id::X);
    layout->registerDim(Dimension::Id::Y);
    layout->registerDim(Dimension::Id::Z);
}
```

Here a reader determines dimensions from an input source and registers or assigns them. All of the input dimension values are in this case double precision floating point.

```cpp
void Reader::addDimensions(PointLayoutPtr layout)
{
    FileHeader header;

    for (auto di = header.names.begin(), di != header.names.end(); ++di)
    {
        std::string dimName = *di;
        Dimension::Id id = layout->registerOrAssignDim(dimName,
                                                        Dimension::Type::Double);
    }
}
```

If a reader implements initialize() and opens a source file during the function, the file should be closed again before exiting the function to ensure that file handles aren’t exhausted when processing a large number of files.

Readers should use the ready() function to reset the input data to a state where the first point can be read from the source. The done() function should be used to free resources or reset the state initialized in ready().
Readers should implement a function, \texttt{read()}, that will place the data from the input source into the provided point view:

\[
\text{point\_count\_t read(PointViewPtr\ view, point\_count\_t count)}
\]

The reader should read at most 'count' points from the input source and place them in the view. The reader must keep track of its current position in the input source and points should be read until no points remain or 'count' points have been added to the view. The current location in the input source is typically tracked with an integer variable called the index.

As each point is read from the input source, it must be placed at the end of the point view. The ID of the end of the point view can be determined by calling \texttt{size()} function of the point view. \texttt{read()} should return the number of points read by during the function call.

\[
\text{point\_count\_t MyFormat::read(PointViewPtr\ view, point\_count\_t count)}
\]

\{
  // Determine the number of points remaining in the input.
  \text{point\_count\_t remainingInput = m\_totalNumPts - m\_index;}

  // Determine the number of points to read.
  \text{count = std::min(count, remainingInput);}

  // Determine the ID of the next point in the point view
  \text{PointId nextId = view->size();}

  // Determine the current input position.
  \text{auto pos = m\_pointSize * m\_index;}

  \text{point\_count\_t remaining = count;}

  \text{while (remaining--)}
  \{
    \text{double x, y, z;}

    // Read X, Y and Z from input source.
    \text{x = m\_file.read\langle double\rangle(pos);}
    \text{pos += sizeof(double);} 
    \text{y = m\_file.read\langle double\rangle(pos);}
    \text{pos += sizeof(double);} 
    \text{z = m\_file.read\langle double\rangle(pos);}
    \text{pos += sizeof(double);} 

    // Set X, Y and Z into the pointView.
    \text{view->setField(Dimension::Id::X, nextId, x);} 
  \}
\}

(continues on next page)
view->setField(Dimension::Id::Y, nextId, y);
view->setField(Dimension::Id::Z, nextId, z);

    nextId++;
}
    m_index += count;
return count;
}

Note that we don’t read more points than requested, we don’t read past the end of
the input stream and we keep track of our location in the input so that subsequent
calls to read() will result in all points being read.

Here’s the same function written so that streaming can be supported:

point_count_t MyFormat::read(PointViewPtr view, point_count_t count)
{
    // Determine the number of points remaining in the input.
    point_count_t remainingInput = m_totalNumPts - m_index;

    // Determine the number of points to read.
    count = std::min(count, remainingInput);

    // Determine the ID of the next point in the point view
    PointId nextId = view->size();

    // Determine the current input position.
    auto pos = m_pointSize * m_index;

    point_count_t remaining = count;
    while (remaining--)
    {
        PointRef point(view->point(nextId));
        processOne(point);
        nextId++;
    }
    m_index += count;
return count;
}

bool MyFormat::processOne(PointRef& point)
{
{  
  double x, y, z;

  // Read X, Y and Z from input source.
  x = m_file.read<double>(pos);
  pos += sizeof(double);
  y = m_file.read<double>(pos);
  pos += sizeof(double);
  z = m_file.read<double>(pos);
  pos += sizeof(double);

  point.setField(Dimension::Id::X, x);
  point.setField(Dimension::Id::Y, y);
  point.setField(Dimension::Id::Z, z);
  return m_file.ok();
}

Implementing a Filter

A filter is a stage that allows processing of data after it has been read into a pipeline’s point table. In many filters, the only function that need be implemented is filter(), a simplified version of the stage’s run() method whose input and output is a point view provided by the previous stage:

void filter(PointViewPtr view)

  One should implement filter() instead of run() if its interface is sufficient. The expectation is that a filter will iterate through the points currently in the point view and apply some transformation or gather some data to be output as pipeline metadata.

Here as an example is the actual filter function from the reprojection filter:

void Reprojection::filter(PointViewPtr view)
{
  for (PointId id = 0; id < view->size(); ++id)
  {
    double x = view->getFieldAs<double>(Dimension::Id::X, id);
    double y = view->getFieldAs<double>(Dimension::Id::Y, id);
    double z = view->getFieldAs<double>(Dimension::Id::Z, id);
    (continues on next page)
The filter simply loops through the points, retrieving the X, Y and Z values of each point, transforms those value using a reprojection algorithm and then stores the transformed values in the point table using the point view’s setField() function.

A filter may need to use the run() function instead of filter(), typically because it needs to create multiple output point views from a single input view. The following example puts every other input point into one of two output point views:

```cpp
PointViewSet Alternator::run(PointViewPtr view)
{
    PointViewSet viewSet;
    PointViewPtr even = view();
    PointViewPtr odd = view();
    viewSet.insert(even);
    viewSet.insert(odd);
    for (PointId idx = 0; idx < view->size(); ++idx)
    {
        PointViewPtr out = idx % 2 ? even : odd;
        out->appendPoint(*view.get(), idx);
    }
    return viewSet;
}
```

### Implementing a Writer:

Analogous to the filter() method in a filter is the write() method of a writer. This function is usually the appropriate one to override when implementing a writer – it would be unusual to need to implement run(). A typical writer will open its output file when ready() is called, write individual points in write() and close the file in done().

Like a filter, a writer may receive multiple point views during processing of a pipeline. This will result in the write() function being called once for each of the input point views. Writers may produce a separate output file for each input point view or may produce a single output file. The documentation should clearly state this behavior. Placing a merge filter in front of a
writer in the pipeline will make sure that a single point view is passed to the writer.

As new writers are created, developers should try to make sure that they behave reasonably if passed multiple point views – they correctly handle write() being called multiple times after a single call to ready().

```cpp
void write(const PointViewPtr view)
{
    ostream& out = *m_out;

    for (PointId id = 0; id < view->size(); ++id)
    {
        out << setw(10) << view->getFieldAs<double>(Dimension::Id::X, id);
        out << setw(10) << view->getFieldAs<double>(Dimension::Id::Y, id);
        out << setw(10) << view->getFieldAs<double>(Dimension::Id::Z, id);
    }
}

bool processOne(PointRef& point)
{
    out << setw(10) << point.getFieldAs<double>(Dimension::Id::X);
    out << setw(10) << point.getFieldAs<double>(Dimension::Id::Y);
    out << setw(10) << point.getFieldAs<double>(Dimension::Id::Z);
}
```

### 14.1.2 Compilation

This section describes how to build and install PDAL under Windows, Linux, and Mac.

**See also:**

*Download* (page 13) contains links to installable binaries for Windows, OSX, and RHEL Linux systems.

Contents:
Unix Compilation

PDAL comes with support for building with CMake (https://cmake.org). PDAL requires at least version 3.5 of CMake. CMake is a cross-platform meta-build system that provides a unified system for building applications on multiple platforms with various build tools. CMake has generators (https://cmake.org/cmake/help/v3.5/manual/cmake-generators.7.html) for many build tools, though PDAL has been tested only with Ninja (https://ninja-build.org/) and GNU Makefiles (https://www.gnu.org/software/make/manual/make.html) on Unix/OSX. Ninja builds PDAL faster, so the following instructions use that build tool, though building with GNU Makefiles works similarly (simply replace “ninja” with “make” when running the build tool).

Note: The PDAL continuous integration (https://github.com/PDAL/PDAL/tree/master/scripts/ci) provides example configuration and build recipes for Linux, Windows, and OSX.

Dependencies

Building PDAL successfully depends on having other libraries configured and installed. These dependencies (page 542) can be built from source or can be installed via a packaging system (apt (https://help.ubuntu.com/lts/serverguide/apt.html) works well on Ubuntu and Debian-based Linux systems. Conda (https://conda.io/en/latest/) works well on most systems. Some have had success with brew (https://brew.sh/) on OSX systems.) Often, the only package that needs to be installed prior to building PDAL is GDAL. Installing a GDAL package will normally install other PDAL dependencies automatically.

$ apt install libgdal-dev
OR

$ conda install gdal
OR

$ brew install gdal
Using Ninja on Linux or OSX

Get the source code

PDAL can be cloned from GitHub (page 14) or you can download a release bundle (page 13)

Prepare a build directory

CMake allows you to generate different builders for a project. Here we’re using Mac OSX, but the procedure and output are nearly identical on Linux distributions.

```
$ cd PDAL
$ mkdir build
$ cd build
```

Run CMake

Running CMake uses the specified generator to create an environment suitable for building PDAL with the requested tool. (Ninja in this case).

```
$ cmake -G Ninja ..
-- Numpy output: /usr/lib/python2.7/dist-packages/numpy/core/include
1.13.3

-- Could NOT find LIBEXECINFO (missing: LIBEXECINFO_LIBRARY)
-- Could NOT find LIBUNWIND (missing: LIBUNWIND_LIBRARY LIBUNWIND_INCLUDE_DIR)
-- The following features have been enabled:

* PostgreSQL PointCloud plugin, read/write PostgreSQL PointCloud objects
* Python plugin, add features that depend on python
* Unit tests, PDAL unit tests

-- The following OPTIONAL packages have been found:

* PkgConfig
* LibXml2
* Curl

-- The following REQUIRED packages have been found:
```

(continues on next page)
PDAL: Point cloud Data Abstraction Library, Release 2.6.2

(continued from previous page)

* GDAL (required version >= 2.2.0)
  Provides general purpose raster, vector, and reference system support
...
-- The following RECOMMENDED packages have not been found:

* LASzip (required version >= 3.1)
  Provides LASzip compression

-- Configuring done
-- Generating done
-- Build files have been written to: /home/foo/pdal/build

**Issue the ninja command**

If cmake runs to completion (reports that build files have been written), you can run Ninja to build PDAL.

```
$ ninja
```

If no errors are reported, Ninja will have created the `pdal` program in the `bin` directory. A set of necessary support libraries will have been created in the `lib` directory.

```
$ ls bin/pdal
bin/pdal

$ ls lib/libpdalcpp*
lib/libpdalcpp.8.dylib
lib/libpdalcpp.dylib
lib/libpdalcpp.9.0.0.dylib
```

**Checking the build and running PDAL tests**

You can quickly check that PDAL has built properly by running the `pdal info` command.

```
$ bin/pdal info ../test/data/las/autzen_trim.las
{
  "filename": "../test/data/las/autzen_trim.las",
  "pdal_version": "1.8.0 (git-version: c39e62)",
  "stats":
```
CMake will normally build a set of tests that can be used to verify that PDAL executes most functions properly. You can run these tests yourself if desired, though it’s not typically necessary.

```
$ ctest
Test project /Users/foo/pdal.master/build
  Start 1: pdal_filters_pcl_block_test
1/97 Test #1: pdal_filters_pcl_block_test ........... Passed 0.
  ↳ 23 sec
  Start 2: pdal_filters_icp_test
2/97 Test #2: pdal_filters_icp_test .................. Passed 0.
  ↳ 12 sec
  Start 3: pdal_filters_python_test
3/97 Test #3: pdal_filters_python_test ............... Passed 3.
  ↳ 52 sec
  Start 4: pdal_io_numpy_test
4/97 Test #4: pdal_io_numpy_test ..................... Passed 0.
  ↳ 31 sec
...
93/96 Test #93: pdal_io_ilvis2_metadata_test ........... Passed 0.
  ↳ 03 sec
  Start 94: pdal_io_ilvis2_reader_metadata_test
94/96 Test #94: pdal_io_ilvis2_reader_metadata_test .... Passed 0.
  ↳ 05 sec
  Start 95: xml_schema_test
95/96 Test #95: xml_schema_test ....................... Passed 0.
  ↳ 04 sec
```
Start 96: pdal_io_ilvis2_test
96/96 Test #96: pdal_io_ilvis2_test .................... Passed 0.
~04 sec

100% tests passed, 0 tests failed out of 96

Total Test time (real) = 39.54 sec

Failed tests may not indicate problems other than a lack of support for some feature on your system. For example, tests for database drivers will fail if the database isn’t installed or configured properly.

Install PDAL

PDAL can be installed to the default location (usually subdirectories of /usr/local) using Ninja.

$ ninja install

Building Under Windows

Author
Howard Butler

Contact
howard at hobu.co

Date
11/20/2020

Note: Conda (page 16) contains a pre-built up-to-date 64 bit Windows binary. It is fully-featured, and if you do not need anything custom, it is likely the fastest way to get going.

Introduction

Pre-built binary packages for Windows are available via Conda (page 16) (64-bit version), and all of the prerequisites required for compilation of a fully featured build are also available via that packaging system. This document assumes you will be using Conda Forge as your base, and anything more advanced is beyond the scope of the document.
**Note:** The GitHub Action build system uses the PDAL project’s configuration on the Conda Forge system. It contains a rich resource of known working examples. See https://github.com/PDAL/PDAL/blob/master/.github/workflows/win.yml and https://github.com/PDAL/PDAL/tree/master/scripts/ci/win for inspiration.

### Required Compiler

PDAL is known to compile on Visual Studio 2015 (https://www.visualstudio.com/vs/older-downloads/), and 2013 might work with some source tree adjustments. PDAL makes heavy use of C++11, and a compiler with good support for those features is required.

### Prerequisite Libraries

PDAL uses the GitHub Actions (https://github.com/PDAL/PDAL/actions) continuous integration platform for building and testing itself on Windows. The configuration that PDAL uses is valuable raw materials for configuring your own environment because the PDAL team must keep it up to date with both the Conda (page 16) environment and the Microsoft compiler situation.

You can see the current configuration at https://github.com/PDAL/PDAL/blob/master/.github/workflows/win.yml The most interesting bits are the Setup step, the CMake step, and the Compile scripts. The configuration already has Miniconda installed, and the setup.sh script installs all of PDAL’s prerequisites via the command line.

```bash
conda install geotiff laszip nitro curl ^
   gdal pcl cmake eigen ninja libgdal ^
   zstd numpy xz libxml2 laz-perf qhull ^
   sqlite hdf5 tiledb conda-build ninja -y
```

**Note:** The package list here might change over time. The canonical location to learn the prerequisite list for PDAL is the scripts/ci/win directory in PDAL’s source tree.
Fetching the Source

Get the source code for PDAL. Presumably you have GitHub for Windows (https://desktop.github.com/) or something like it. Run a “git shell” and clone the repository into the directory of your choice.

```
c:\dev> git clone https://github.com/PDAL/PDAL.git
```

Switch to the -maintenance branch.

```
c:\dev> git checkout 1.9-maintenance
```

**Note:** PDAL’s active development branch is master, and you are welcome to build it, but is not as stable as the major-versioned release branches are likely to be.

Configuration

PDAL uses CMake (http://www.cmake.org) for its build configuration. You will need to install CMake and have it available on your path to configure PDAL.

Invoke your `cmake` command to configure the PDAL.

```
cmake -G "NMake Makefiles" .
```

A fully-featured build will require more specification of libraries, enabled features, and their locations. For more information on this, users can refer to the `examples.sh` step in the Action.

**Note:** Placing your command in a `.bat` file will make for easy reuse.

Building

If you chose `NMake Makefiles` as your CMake generator, you can invoke the build by calling `nmake`:

```
nmake /f Makefile
```

If you chose “Visual Studio 14 Win64” as your CMake generator, open `PDAL.sln` and chose your configuration to build.
Running

After you’ve built the tree, you can run `pdal.exe` by issuing it

```
c:\dev\pdal\bin\pdal.exe
```

**Note:** You may need to have your Conda environment active to enable access to PDAL’s dependencies.

Dependencies

**Note:** The absolute best source of build and configuration examples is the PDAL GitHub repository. Specifically, the continuous integration scripts at [https://github.com/PDAL/PDAL/tree/master/scripts/ci](https://github.com/PDAL/PDAL/tree/master/scripts/ci)

PDAL depends on a number of libraries to do its work. Make sure those dependencies are installed on your system before installing PDAL or use a packaging system that will automatically load prerequisites. Packaging system such as **apt** ([https://help.ubuntu.com/lts/serverguide/apt.html](https://help.ubuntu.com/lts/serverguide/apt.html)) or **Conda** ([https://conda.io/en/latest/](https://conda.io/en/latest/)) can be used to install dependencies on your system.

Required Dependencies

**GDAL (3.0+)**

PDAL uses GDAL for spatial reference system description manipulation, and image reading supporting for the NITF driver. In conjunction with **GeoTIFF** ([http://trac.osgeo.org/geotiff](http://trac.osgeo.org/geotiff)), GDAL is used to convert GeoTIFF keys and OGC WKT SRS description strings into formats required by specific drivers.

**Source:** [https://github.com/OSGeo/gdal](https://github.com/OSGeo/gdal)
**Conda:** [https://anaconda.org/conda-forge/gdal](https://anaconda.org/conda-forge/gdal)
GeoTIFF (1.3+)

PDAL uses GeoTIFF in conjunction with GDAL for GeoTIFF key support in the LAS driver. GeoTIFF is typically a dependency of GDAL, so installing GDAL from a package will generally install GeoTIFF as well.

Source: https://github.com/OSGeo/libgeotiff
Conda: https://anaconda.org/conda-forge/geotiff

Note: GDAL surreptitiously embeds a copy of GeoTIFF (http://trac.osgeo.org/geotiff) in its library build but there is no way for you to know this. In addition to embedding libgeotiff, it also strips away the library symbols that PDAL needs, meaning that PDAL can’t simply link against GDAL (http://www.gdal.org). If you are building both of these libraries yourself, make sure you build GDAL using the “External libgeotiff” option, which will prevent the insanity that can ensue on some platforms. Conda Forge (https://anaconda.org/conda-forge/pdal) users, including those using that platform to link and build PDAL themselves, do not need to worry about this issue.

Plugin Dependencies

PDAL comes with optional plugin stages that require other libraries in order to run. Many of these libraries are licensed in a way incompatible with the PDAL license or they may be commercial products that require purchase.

Nitro (Requires specific source package)

Nitro is a library that provides NITF (http://en.wikipedia.org/wiki/National_Imagery_Transmission_Format) support for PDAL to write LAS-in-NITF files for writers.nitf (page 168). You must use the specific version of Nitro referenced below for licensing and compatibility reasons.

Source: http://github.com/hobu/nitro
TileDB (1.4.1+)

TileDB (https://www.tiledb.io) is an efficient multi-dimensional array management system which introduces a novel on-disk format that can effectively store dense and sparse array data with support for fast updates and reads. It features excellent compression, and an efficient parallel I/O system with high scalability. It is used by writers.tiledb (page 184) and readers.tiledb (page 133):  

Source: https://github.com/TileDB-Inc/TileDB  
Conda: https://anaconda.org/conda-forge/tiledb

14.1.3 Errors and Error Handling

Exceptions

PDAL typically throws a std::runtime_error for error conditions that is catchable as pdal::pdal_error.

PDAL Position on (Non)conformance

PDAL proudly and unabashedly supports formal standards/specifications for file formats. We recognize, however, that in some cases files will not follow a given standard precisely, due to an unclear spec or simply out of carelessness.

When reading files that are not formatted correctly:

- PDAL may try to compensate for the error. This is typically done when as a practical matter the market needs support for well-known or pervasive, but nonetheless “broken”, upstream implementations.
- PDAL may explicitly reject such files. This is typically done where we do not wish to continue to promote or support mistakes that should be fixed upstream.

PDAL will strive to write correctly formatted files. In some cases, however, PDAL may choose to offer as an option the ability to break the standard if, as a practical matter, doing so would significantly aid the market. Such an option would never be the default behavior, however.

For files that are conformant but which lie, such as the extents in the header being wrong, we will generally offer both the ability to propagate the “wrong” information and the ability to helpfully correct it on the fly; the latter is generally our default position.
14.1.4 Metadata

In addition to point data, PDAL stores metadata during the processing of a pipeline. Metadata is stored internally as strings, though the API accepts a variety of types that are automatically converted as necessary. Each item of metadata consists of a name, a description (optional), a value and a type. In addition, each item of metadata can have a list of child metadata values.

Metadata is made available to users of PDAL through a JSON tree. Commands such as `pdal pipeline` (page 41) and `pdal translate` (page 50) provide options to allow the JSON-formatted metadata created by PDAL to be written to a file.

Metadata Nodes

Each item of metadata is stored in an object known as a `MetadataNode`. Metadata nodes are reference types that can be copied cheaply. Metadata nodes are annotated with the original data type to allow better interpretation of the data. For example, when binary data is stored in a base 64-encoded format, knowing that the data doesn’t ultimately represent a string can allow algorithms to convert it back to its binary representation when desired. Similarly, knowing that data is numeric allows it to be written as a JSON numeric type rather than as a string.

The name of a metadata node is immutable. If you wish to add a copy of metadata (and subchildren) to some node using a different name, you need to call the provided function “clone()”.

A metadata node is added as a child to another node using `add()`. Usually the type of the data assigned to the metadata node is determined through overloading, but there are instances where this is impossible and the programmer must call a specific function to set the type of the metadata node. Binary data that has been converted to a string by base 64 encoding can be tagged as such by calling `addEncoded()`. Programmers can specify the type of a node explicitly by calling `addWithType()`. Currently supported types are: “boolean”, “string”, “float”, “double”, “bounds”, “nonNegativeInteger”, “integer”, “uuid” and “base64Binary”.

Metadata nodes can be presented as lists when transformed to JSON. If multiple nodes with the same name are added to a parent node, those subnodes will automatically be tagged as list nodes and will be enclosed in square brackets. Single nodes can be forced to be treated as JSON lists by calling `addList()` instead of `add()` on a parent node.

Metadata and Stages

Stages in PDAL each have a base metadata node. You can retrieve a stage’s metadata node by calling `getMetadata()`. When a PDAL pipeline is run, its metadata is organized as a list of stage nodes to which subnodes have been added. From within the implementation of a stage, metadata is typically added similarly to the following:
```java
MetadataNode root = getMetadata();
root.add("nodename", "Some string data");
root.add("intlist", 45);
root.add("intlist", 55);
Uuid nullUuid;
MetadataNode pnode("parent");
root.add(pnode);
pnode.add("nulluuidnode", nullUuid);
pnode.addList("num_in_list", 66);
```

If the above code was part of a stage “writers.test”, a transformation to JSON would produce the following output:

```json
{
   "writers.test":
   {
      "intlist": [
      45,
      55
      ],
      "nodename": "Some string data",
      "parent":
      {
         "nulluuidnode": "00000000-0000-0000-0000-000000000000",
         "num_in_list": [
      66
      ]
      }
   }
}
```

### 14.1.5 Writing with PDAL

**Author**

Bradley Chambers

**Contact**

brad.chambers@gmail.com

**Date**

11/02/2017
This tutorial will describe a complete example of using PDAL C++ objects to write a LAS file. The example will show fetching data from your own data source rather than interacting with a PDAL stage.

**Note:** If you implement your own *Readers* (page 65) that conforms to PDAL’s *pdal::Stage* (page 639), you can implement a simple read-filter-write pipeline using *Pipeline* (page 55) and not have to code anything explicit yourself.

**Includes**

First, our code.

```cpp
#include <pdal/PointView.hpp>
#include <pdal/PointTable.hpp>
#include <pdal/Dimension.hpp>
#include <pdal/Options.hpp>
#include <pdal/StageFactory.hpp>

#include <io/BufferReader.hpp>

#include <vector>

void fillView(pdal::PointViewPtr view)
{
    struct Point
    {
        double x;
        double y;
        double z;
    };

    for (int i = 0; i < 1000; ++i)
    {
        Point p;

        p.x = -93.0 + i*0.001;
        p.y = 42.0 + i*0.001;
        p.z = 106.0 + i;

        view->setField(pdal::Dimension::Id::X, i, p.x);
        view->setField(pdal::Dimension::Id::Y, i, p.y);
        view->setField(pdal::Dimension::Id::Z, i, p.z);
    }
}
```

(continues on next page)
int main(int argc, char* argv[])
{
    using namespace pdal;

    Options options;
    options.add("filename", "myfile.las");

    PointTable table;
    table.layout()->registerDim(Dimension::Id::X);
    table.layout()->registerDim(Dimension::Id::Y);
    table.layout()->registerDim(Dimension::Id::Z);

    PointViewPtr view = new PointView(table);

    fillView(view);

    BufferReader reader;
    reader.addView(view);

    StageFactory factory;

    // StageFactory always "owns" stages it creates. They'll be
    // destroyed with the factory.
    Stage *writer = factory.createStage("writers.las");

    writer->setInput(reader);
    writer->setOptions(options);
    writer->prepare(table);
    writer->execute(table);
}

Take a closer look. We will need to include several PDAL headers.

```cpp
#include <pdal/PointView.hpp>
#include <pdal/PointTable.hpp>
#include <pdal/Dimension.hpp>
#include <pdal/Options.hpp>
#include <pdal/StageFactory.hpp>
```
BufferReader will not be required by all users. Here is it used to populate a bare PointBuffer. This will often be accomplished by a Reader stage.

Instead of directly including headers for individual stages, e.g., LasWriter, we rely on the StageFactory which has the ability to query available stages at runtime and return pointers to the created stages.

We proceed by providing a mechanism for generating dummy data for the x, y, and z dimensions.

void fillView(pdal::PointViewPtr view)
{
    struct Point
    {
        double x;
        double y;
        double z;
    };

    for (int i = 0; i < 1000; ++i)
    {
        Point p;

        p.x = -93.0 + i*0.001;
        p.y = 42.0 + i*0.001;
        p.z = 106.0 + i;

        view->setField(pdal::Dimension::Id::X, i, p.x);
        view->setField(pdal::Dimension::Id::Y, i, p.y);
        view->setField(pdal::Dimension::Id::Z, i, p.z);
    }
}

int main(int argc, char* argv[])
{
    using namespace pdal;

    Options options;
    options.add("filename", "myfile.las");

    PointTable table;

    Finally, the main code which creates the dummy data, puts it into a BufferReader and sends it to a writer.

14.1. Development
```cpp
int main(int argc, char* argv[])
{
    using namespace pdal;

    Options options;
    options.add("filename", "myfile.las");

    PointTable table;
    table.layout()->registerDim(Dimension::Id::X);
    table.layout()->registerDim(Dimension::Id::Y);
    table.layout()->registerDim(Dimension::Id::Z);

    PointViewPtr view(new PointView(table));
    fillView(view);

    BufferReader reader;
    reader.addView(view);

    StageFactory factory;

    // StageFactory always "owns" stages it creates. They'll be destroyed with the factory.
    Stage *writer = factory.createStage("writers.las");

    writer->setInput(reader);
    writer->setOptions(options);
    writer->prepare(table);
    writer->execute(table);
}
```

### Compiling and running the program

**Note:** Refer to *Compilation* (page 534) for information on how to build PDAL.

To build this example, simply copy the files tutorial.cpp and CMakeLists.txt from the examples/writing directory of the PDAL source tree.

```bash
cmake_minimum_required(VERSION 3.6)
project(WritingTutorial)
find_package(PDAL 2.0.0 REQUIRED CONFIG)
```
set(CMAKE_CXX_STANDARD 17)
set(CMAKE_CXX_STANDARD_REQUIRED ON)

add_executable(tutorial tutorial.cpp)

target_link_libraries(tutorial PRIVATE ${PDAL_LIBRARIES})
target_include_directories(tutorial PRIVATE
  ${PDAL_INCLUDE_DIRS}
  ${PDAL_INCLUDE_DIRS}/pdal)

Note: Refer to CMake (page 579) for an explanation of the basic CMakeLists.

Begin by configuring your project using CMake (shown here on Unix) and building using make.

$ cd /PATH/TO/WRITING/TUTORIAL
$ mkdir build
$ cd build
$ cmake ..
$ make

After the project is built, you can run it by typing:

$ ./tutorial

Streaming

Writing in streaming mode creates and writes the cloud one point at a time, and the implementation is somewhat different. An example is given in examples/writing-streamer.

14.1.6 Writing and building a PDAL Plugin

Author
Andrew Bell

Contact
andrew.bell.ia@gmail.com

Date
11/09/2021
A PDAL plugin is a specially-named dynamically linked library that serves as a stage or a kernel (PDAL command). The PDAL program will be able to use a properly-made plugin when it is placed in an appropriate location. PDAL will search the following paths (relative to the current working directory) for plugins: ..../lib, ../lib, ./bin, ../bin. You can also override the default search path by setting the environment variable PDAL_DRIVER_PATH to a list of directories that pdal should search for plugins.

PDAL stage plugins must be named:

```
libpdal_plugin_<plugin type>_<plugin name>._<shared library extension>
```

where plugin name is one of reader, writer or filter.

PDAL kernel plugins must be named:

```
libpdal_plugin_kernel_<plugin name>._<shared library extension>
```

See the tutorials Writing a reader (page 561), Writing a filter (page 553) or Writing a writer (page 571) for step-by-step instructions on creating a PDAL stage plugin. See Writing a kernel (page 557) for similar information on creating a PDAL kernel plugin. The tutorials provide a sample CMakeLists.txt that can serve as a basis for building your plugin with a PDAL installation. A simple macro, PDAL_CREATE_PLUGIN, is now provided with PDAL that makes it even easier to build a plugin. You can use the macro by creating a file called CMakeLists.txt like this:

```
cmake_minimum_required(VERSION 3.5)
project(MY_READER LANGUAGES CXX)
find_package(PDAL REQUIRED)

set(SRCS MyGoodReader.cpp)

PDAL_CREATE_PLUGIN(
    TYPE reader
    NAME mygood
    VERSION 1.0
    SOURCES ${SRCS}
)
```

Once your plugin is built, copy it to an appropriate location so that it can be found by PDAL and it should load and run. If your plugin doesn’t load, Use the PDAL –debug option to get information about the plugin loading process.
14.1.7 Writing a filter

PDAL can be extended through the development of filter functions.

See also:

For more on filters and their role in PDAL, and their lifecycle please refer to *PDAL Architecture Overview* (page 523).

Every filter stage in PDAL is implemented as a plugin (sometimes referred to as a “driver”). Filters native to PDAL, such as *filters.ferry* (page 258), are implemented as static filters and are statically linked into the PDAL library. Filters that require extra/optional dependencies, or are external to the core PDAL codebase altogether, such as *filters.python* (page 348), are implemented as shared filters, and are built as individual shared libraries, discoverable by PDAL at runtime.

In this tutorial, we will give a brief example of a filter, with notes on how to make it static or shared.

The header

First, we provide a full listing of the filter header.

```cpp
// MyFilter.hpp

#pragma once

#include <pdal/pdal_internal.hpp>
#include <pdal/Filter.hpp>

namespace pdal {

class PDAL_DLL MyFilter : public Filter {

public:
    MyFilter() : Filter() {}
    std::string getName() const;

private:
    double m_value;
    Dimension::Id m_myDimension;

    virtual void addDimensions(PointLayoutPtr layout);

```
virtual void addArgs(ProgramArgs& args);
virtual PointViewSet run(PointViewPtr view);

MyFilter& operator=(const MyFilter&); // not implemented
MyFilter(const MyFilter&); // not implemented

};
} // namespace pdal

This header should be relatively straightforward, but we will point out one method that must be declared for the plugin interface to be satisfied.

std::string getName() const;

In many instances, you should be able to copy this header template verbatim, changing only the filter class name, includes, and member functions/variables as required by your implementation.

The source

Again, we start with a full listing of the filter source.

// MyFilter.cpp

#include "MyFilter.hpp"
#include <pdal/pdal_internal.hpp>

namespace pdal
{

static PluginInfo const s_info
{
    "filters.name",
    "My awesome filter",
    "http://link/to/documentation"
};

CREATE_SHARED_STAGE(MyFilter, s_info)

std::string MyFilter::getName() const { return s_info.name; }

void MyFilter::addArgs(ProgramArgs& args)
For your filter to be available to PDAL at runtime, it must adhere to the PDAL plugin interface. As a convenience, we provide macros to do just this.

We begin by creating a `PluginInfo` struct containing three identifying elements - the filter name, description, and a link to documentation.

```cpp
static PluginInfo const s_info
{
    "filters.name",
    "My awesome filter",
    "http://link/to/documentation"
};
```

PDAL requires that filter names always begin with `filters.`, and end with a string that uniquely identifies the filter. The description will be displayed to users of the PDAL CLI (`pdal --drivers`). When making a shared plugin, the name of the shared library must correspond with the name of the filter provided here. The name of the generated shared object must be

```
libpdal_plugin_filter_<filter name>.<shared library extension>
```

Next, we pass the following to the `CREATE_SHARED_STAGE` macro, passing in the name of the stage and the `PluginInfo` struct.
CREATE_SHARED_STAGE(MyFilter, s_info)

To create a static stage, we simply change CREATE_SHARED_STAGE to CREATE_STATIC_STAGE.

Finally, we implement a method to get the plugin name, which is primarily used by the PDAL CLI when using the --drivers or --options arguments.

```cpp
std::string MyFilter::getName() const { return s_info.name; }
```

Now that the filter has implemented the proper plugin interface, we will begin to implement some methods that actually implement the filter. The addArgs() method is used to register and bind any provided options to the stage. Here, we get the value of param, if provided, else we populate m_value with the default value of 1.0. Option names, descriptions, and default values specified in addArgs() will be displayed via the PDAL CLI with the --options argument.

```cpp
void MyFilter::addArgs(ProgramArgs& args)
{
    args.add("param", "Some parameter", m_value, 1.0);
}
```

In addDimensions() we make sure that the known Intensity dimension is registered. We can also add a custom dimension, MyDimension, which will be populated within run().

```cpp
void MyFilter::addDimensions(PointLayoutPtr layout)
{
    layout->registerDim(Dimension::Id::Intensity);
    m_myDimension = layout->registerOrAssignDim("MyDimension",
        Dimension::Type::Unsigned8);
}
```

Finally, we define run(), which takes as input a PointViewPtr and returns a PointViewSet. It is here that we can transform existing dimensions, add data to new dimensions, or selectively add/remove individual points.

We suggest you take a closer look at our existing filters to get an idea of the power of the Filter stage and inspiration for your own filters!
Compilation

Set up a CMakeLists.txt file to compile your filter against PDAL:

```cmake
# Set up CMakeLists
cmake_minimum_required(VERSION 3.13)
project(FilterTutorial)

# Find PDAL
find_package(PDAL 2.5 REQUIRED CONFIG)

# Set CMake flags
set(CMAKE_CXX_STANDARD 17)
set(CMAKE_CXX_STANDARD_REQUIRED ON)

# Add library
add_library(pdal_plugin_filter_myfilter SHARED MyFilter.cpp)

target_link_libraries(pdal_plugin_filter_myfilter PRIVATE ${PDAL_LIBRARIES})
target_include_directories(pdal_plugin_filter_myfilter PRIVATE ${PDAL_INCLUDE_DIRS})
target_link_directories(pdal_plugin_filter_myfilter PRIVATE ${PDAL_LIBRARY_DIRS})
```

Note: CMakeLists.txt contents may vary slightly depending on your project requirements, operating system, and compiler.

14.1.8 Writing a kernel

**Author**
Bradley Chambers

**Contact**
brad.chambers@gmail.com

**Date**
11/02/2017

PDAL’s command-line application can be extended through the development of kernel functions. In this tutorial, we will give a brief example.
The header

First, we provide a full listing of the kernel header.

```cpp
// MyKernel.hpp

#pragma once

#include <pdal/Kernel.hpp>

#include <string>

namespace pdal
{
  class PDAL_DLL MyKernel : public Kernel
  {
    public:
      MyKernel();

      std::string getName() const;
      int execute(); // override

    private:
      void addSwitches(ProgramArgs& args);

      std::string m_input_file;
      std::string m_output_file;
  };
}
// namespace pdal
```

As with other plugins, the MyKernel class needs to return a name.

```cpp
std::string getName() const;
```

The source

Again, we start with a full listing of the kernel source.

```cpp
// MyKernel.cpp

#include "MyKernel.hpp"
```

(continues on next page)
#include <pdal/Filter.hpp>
#include <pdal/Kernel.hpp>
#include <pdal/Options.hpp>
#include <pdal/PointTable.hpp>

#include <memory>
#include <string>

namespace pdal {

static PluginInfo const s_info {
    "kernels.mykernel",
    "MyKernel",
    "http://link/to/documentation"
};

CREATE_SHARED_KERNEL(MyKernel, s_info);
std::string MyKernel::getName() const { return s_info.name; }

MyKernel::MyKernel() : Kernel() {}

void MyKernel::addSwitches(ProgramArgs& args) {
    args.add("input,i", "Input filename", m_input_file).
        setPositional();
    args.add("output,o", "Output filename", m_output_file).
        setPositional();
}

int MyKernel::execute() {
    PointTable table;

    Stage& reader = makeReader(m_input_file, "readers.las");

    // Options should be added in the call to makeFilter, makeReader, 
    // or makeWriter so that the system can override them with those 
    // provided on the command line when applicable.
    Options filterOptions;

(continues on next page)
In your kernel implementation, you will use a macro defined in pdal Macros. This macro registers the plugin with the PluginManager.

```cpp
CREATE_SHARED_KERNEL(MyKernel, s_info);
```

To build up a processing pipeline in this example, we need to create two objects: the `pdal::PointTable`.

```cpp
int MyKernel::execute()
{
    PointTable table;

    Stage& reader = makeReader(m_input_file, "readers.las");

    // Options should be added in the call to makeFilter, makeReader, // or makeWriter so that the system can override them with those // provided on the command line when applicable.
    Options filterOptions;
    filterOptions.add("step", 10);
    Stage& filter = makeFilter("filters.decimation", reader, filterOptions);

    Stage& writer = makeWriter(m_output_file, filter, "writers.text");
    writer.prepare(table);
    writer.execute(table);

    return 0;
}
```

To implement the actual kernel logic we implement `execute()`. In this case, the kernel reads a las file, decimates the data (eliminates some points) and writes the result to a text file. The base
kernel class provides functions (makeReader, makeFilter, makeWriter) to create stages with options as desired. The pipeline that has been created can be run by preparing and executing the last stage in the pipeline.

When compiled, a dynamic library file will be created; in this case, `libpdal_plugin_kernel_mykernel.dylib`

Put this file in whatever directory `PDAL_DRIVER_PATH` is pointing to. Then, if you run `pdal --drivers`, you should see `mykernel` listed in the possible commands.

To run this kernel, you would use `pdal mykernel -i <input las file> -o <output text file>`.

**Compilation**

Set up a `CMakeLists.txt` file to compile your kernel against PDAL:

```cmake
# CMakeLists.txt

cmake_minimum_required(VERSION 3.13)
project(KernelTutorial)

find_package(PDAL 2.5 REQUIRED CONFIG)

set(CMAKE_CXX_STANDARD 17)
set(CMAKE_CXX_STANDARD_REQUIRED ON)

add_library(pdal_plugin_kernel_mykernel SHARED MyKernel.cpp)
target_link_libraries(pdal_plugin_kernel_mykernel PRIVATE ${PDAL_LIBRARIES})
target_include_directories(pdal_plugin_kernel_mykernel PRIVATE ${PDAL_INCLUDE_DIRS})
target_link_directories(pdal_plugin_kernel_mykernel PRIVATE ${PDAL_LIBRARY_DIRS})
```

**14.1.9 Writing a reader**

**Authors**
Bradley Chambers, Scott Lewis

**Contact**
brad.chambers@gmail.com

**Date**
11/02/2017
PDAL’s command-line application can be extended through the development of reader functions. In this tutorial, we will give a brief example.

The header

First, we provide a full listing of the reader header.

```cpp
// MyReader.hpp

#pragma once

#include <pdal/PointView.hpp>
#include <pdal/Reader.hpp>
#include <pdal/util/IStream.hpp>

namespace pdal
{
    class MyReader : public Reader
    {
        public:
            MyReader() : Reader() {}
            std::string getName() const;

        private:
            std::unique_ptr<ILeStream> m_stream;
            point_count_t m_index;
            double m_scale_z;

            virtual void addDimensions(PointLayoutPtr layout);
            virtual void addArgs(ProgramArgs& args);
            virtual void ready(PointTableRef table);
            virtual point_count_t read(PointViewPtr view, point_count_t count);
            virtual void done(PointTableRef table);
    }
}
```

```
std::unique_ptr<ILeStream> m_stream;
point_count_t m_index;
double m_scale_z;
```

m_stream is used to process the input, while m_index is used to track the index of the records. m_scale_z is specific to MyReader, and will be described later.
Various other override methods for the stage. There are a few others that could be overridden, which will not be discussed in this tutorial.

**Note:** See ./include/pdal/Reader.hpp of the source tree for more methods that a reader can override or implement.

### The source

Again, we start with a full listing of the reader source.
layout->registerDim(Dimension::Id::X);
layout->registerDim(Dimension::Id::Y);
layout->registerDim(Dimension::Id::Z);
layout->registerOrAssignDim("MyData", Dimension::Type::Unsigned64);
}

void MyReader::ready(PointTableRef)
{
    m_index = 0;
    SpatialReference ref("EPSG:4385");
    setSpatialReference(ref);
}

template <typename T>
T convert(const StringList& s, const std::string& name, size_t fieldno)
{
    T output;
    bool bConverted = Utils::fromString(s[fieldno], output);
    if (!bConverted)
    {
        std::stringstream oss;
        oss << "Unable to convert " << name << "", " << s[fieldno] << ", to double";
        throw pdal_error(oss.str());
    }

    return output;
}

point_count_t MyReader::read(PointViewPtr view, point_count_t count)
{
    PointLayoutPtr layout = view->layout();
    PointId nextId = view->size();
    PointId idx = m_index;
    point_count_t numRead = 0;

    m_stream.reset(new ILeStream(m_filename));

    size_t HEADERSIZE(1);
    size_t skip_lines((std::max)(HEADERSIZE, (size_t)m_index));
    size_t line_no(1);
for (std::string line; std::getline(*m_stream->stream(), line), line_no++)
{
    if (line_no <= skip_lines)
    {
        continue;
    }

    // MyReader format: X::Y::Z::Data
    StringList s = Utils::split2(line, ':');

    unsigned long u64(0);
    if (s.size() != 4)
    {
        std::stringstream oss;
        oss << "Unable to split proper number of fields. Expected 4, got ";
        oss << s.size();
        throw pdal_error(oss.str());
    }

    std::string name("X");
    view->setField(Dimension::Id::X, nextId, convert<double>(s, name, 0));

    name = "Y";
    view->setField(Dimension::Id::Y, nextId, convert<double>(s, name, 1));

    name = "Z";
    double z = convert<double>(s, name, 2) * m_scale_z;
    view->setField(Dimension::Id::Z, nextId, z);

    name = "MyData";
    view->setField(layout->findProprietaryDim(name),
                   nextId,
                   convert<unsigned int>(s, name, 3));

    nextId++;
    if (m_cb)
        m_cb(*view, nextId);
}

m_index = nextId;
In your reader implementation, you will use a macro to create the plugin. This macro registers the plugin with the PDAL PluginManager. In this case, we are declaring this as a SHARED stage, meaning that it will be loaded at runtime instead of being linked to the main PDAL installation. The macro is supplied with the class name of the plugin and a PluginInfo object. The PluginInfo objection includes the name of the plugin, a description, and a link to documentation.

When making a shared plugin, the name of the shared library must correspond with the name of the reader provided here. The name of the generated shared object must be

```
libpdal_plugin_reader_<reader name>_<shared library extension>
```

This method will process a options for the reader. In this example, we are setting the z_scale value to a default of 1.0, indicating that the Z values we read should remain as-is. (In our reader, this could be changed if, for example, the Z values in the file represented mm values, and we want to represent them as m in the storage model). `addArgs` will bind values given for the argument to the `m_scale_z` variable of the stage.

```
void MyReader::addArgs(ProgramArgs& args)
{
    args.add("z_scale", "Z Scaling", m_scale_z, 1.0);
}
```
This method registers the various dimensions the reader will use. In our case, we are using the X, Y, and Z built-in dimensions, as well as a custom dimension MyData.

```cpp
void MyReader::addDimensions(PointLayoutPtr layout)
{
    layout->registerDim(Dimension::Id::X);
    layout->registerDim(Dimension::Id::Y);
    layout->registerDim(Dimension::Id::Z);
    layout->registerOrAssignDim("MyData", Dimension::Type::Unsigned64);
}
```

This method is called when the Reader is ready for use. It will only be called once, regardless of the number of PointViews that are to be processed.

```cpp
void MyReader::ready(PointTableRef)
{
    m_index = 0;
    SpatialReference ref("EPSG:4385");
    setSpatialReference(ref);
}
```

This is a helper function, which will convert a string value into the type specified when it’s called. In our example, it will be used to convert strings to doubles when reading from the input stream.

```cpp
template <typename T>
T convert(const StringList& s, const std::string& name, size_t fieldno)
{
    T output;
    bool bConverted = Utils::fromString(s[fieldno], output);
    if (!bConverted)
    {
        std::stringstream oss;
        oss << "Unable to convert " << name << ", " << s[fieldno] << ", to double";
        throw pdal_error(oss.str());
    }

    return output;
}
```

This method is the main processing method for the reader. It takes a pointer to a PointView which we will build as we read from the file. We initialize some variables as well, and then reset the input stream with the filename used for the reader. Note that in other readers, the contents of this method could be very different depending on the format of the file being read, but this should serve as a good start for how to build the PointView object.
In preparation for reading the file, we prepare to skip some header lines. In our case, the header is only a single line.

```cpp
size_t HEADERSIZE(1);
size_t skip_lines((std::max)(HEADERSIZE, (size_t)m_index));
```

Here we begin our main loop. In our example file, the first line is a header, and each line thereafter is a single point. If the file had a different format the method of looping and reading would have to change as appropriate. We make sure we are skipping the header lines here before moving on.

```cpp
size_t line_no(1);
for (std::string line; std::getline(*m_stream->stream(), line); line_no++)
{
    if (line_no <= skip_lines)
    {
        continue;
    }
```

Here we take the line we read in the for block header, split it, and make sure that we have the proper number of fields.

```cpp
// MyReader format: X::Y::Z::Data
StringList s = Utils::split2(line, ':');
unsigned long u64(0);
if (s.size() != 4)
{
    std::stringstream oss;
    oss << "Unable to split proper number of fields. Expected 4, got "
        << s.size();
    throw pdal_error(oss.str());
```

Here we take the values we read and put them into the PointView object. The X and Y fields are simply converted from the file and put into the respective fields. MyData is done likewise with the custom dimension we defined. The Z value is read, and multiplied by the scale_z option (defaulted to 1.0), before the converted value is put into the field.
When putting the value into the PointView object, we pass in the Dimension that we are assigning it to, the ID of the point (which is incremented in each iteration of the loop), and the dimension value.

```cpp
std::string name("X");
view->setField(Dimension::Id::X, nextId, convert<double>(s, name, \rightarrow 0));

name = "Y";
view->setField(Dimension::Id::Y, nextId, convert<double>(s, name, \rightarrow 1));

name = "Z";
double z = convert<double>(s, name, 2) * m_scale_z;
view->setField(Dimension::Id::Z, nextId, z);

name = "MyData";
view->setField(layout->findProprietaryDim(name), nextId,

Finally, we increment the nextId and make a call into the progress callback if we have one with our nextId. After the loop is done, we set the index and number read, and return that value as the number of points read. This could differ in cases where we read multiple streams, but that won't be covered here.

```cpp
nextId++;
if (m_cb)
    m_cb(*view, nextId);
}
m_index = nextId;
numRead = nextId;
```

When the read method is finished, the done method is called for any cleanup. In this case, we simply make sure the stream is reset.

```cpp
void MyReader::done(PointTableRef)
{
    m_stream.reset();
}
```
Compiling and Usage

The MyReader.cpp code can be compiled. For this example, we’ll use cmake. Here is the CMakeLists.txt file we will use:

```cpp
1 cmake_minimum_required(VERSION 3.13)
2 project(ReaderTutorial)
3
4 find_package(PDAL 2.5 REQUIRED CONFIG)
5
6 set(CMAKE_CXX_STANDARD 17)
7 set(CMAKE_CXX_STANDARD_REQUIRED ON)
8
9 add_library(pdal_plugin_reader_myreader SHARED MyReader.cpp)
10 target_link_libraries(pdal_plugin_reader_myreader PRIVATE ${PDAL_LIBRARIES})
11 target_include_directories(pdal_plugin_reader_myreader PRIVATE ${PDAL_INCLUDE_DIRS})
12 target_link_directories(pdal_plugin_reader_myreader PRIVATE ${PDAL_LIBRARY_DIRS})
```

If this file is in the directory containing MyReader.hpp and MyReader.cpp, simply run cmake ., followed by make. This will generate a file called libpdal_plugin_reader_myreader.dylib.

Put this dylib file into the directory pointed to by PDAL_DRIVER_PATH, and then when you run pdal --drivers, you should see an entry for readers.myreader.

To test the reader, we will put it into a pipeline and output a text file.


In the directory with those two files, run `pdal pipeline pipeline-myreader.json`. You should have an output file called output.txt, which will have the same data as in the input file, except in a CSV style format, and with the Z values scaled by .001.
14.1.10 Writing a writer

Authors
   Bradley Chambers, Scott Lewis

Contact
   brad.chambers@gmail.com

Date
   10/26/2016

PDAL’s command-line application can be extended through the development of writer functions. In this tutorial, we will give a brief example.

The header

First, we provide a full listing of the writer header.

```cpp
// MyWriter.hpp
#pragma once

#include <pdal/Writer.hpp>
#include <string>

namespace pdal{

typedef std::shared_ptr<std::ostream> FileStreamPtr;

class MyWriter : public Writer
{
public:
   MyWriter()
   {

   }

   std::string getName() const;

private:
   virtual void addArgs(ProgramArgs& args);
   virtual void initialize();
   virtual void ready(PointTableRef table);
   virtual void write(const PointViewPtr view);
   virtual void done(PointTableRef table);
}
```

(continues on next page)
In your MyWriter class, you will declare the necessary methods and variables needed to make the writer work and meet the plugin specifications.

```cpp
typedef std::shared_ptr<std::ostream> FileStreamPtr;
```

FileStreamPtr is defined to make the declaration of the stream easier to manage later on.

```cpp
std::string getName() const;
```

Every stage must return a unique name.

```cpp
virtual void addArgs(ProgramArgs& args);
virtual void initialize();
virtual void ready(PointTableRef table);
virtual void write(const PointViewPtr view);
virtual void done(PointTableRef table);
```

These methods are used during various phases of the pipeline. There are also more methods, which will not be covered in this tutorial.

```cpp
std::string m_filename;
std::string m_newline;
std::string m_datafield;
int m_precision;
FileStreamPtr m_stream;
Dimension::Id m_dataDim;
```

These are variables our Writer will use, such as the file to write to, the newline character to use, the name of the data field to use to write the MyData field, precision of the double outputs, the output stream, and the dimension that corresponds to the data field for easier lookup.

As mentioned, there can be additional configurations done as needed.
The source

We will start with a full listing of the writer source.

```cpp
// MyWriter.cpp

#include "MyWriter.hpp"
#include <pdal/util/FileUtils.hpp>
#include <pdal/util/ProgramArgs.hpp>

namespace pdal
{
    static PluginInfo const s_info
    {
        "writers.mywriter",
        "My Awesome Writer",
        "http://path/to/documentation"
    };

    CREATE_SHARED_STAGE(MyWriter, s_info);

    std::string MyWriter::getName() const { return s_info.name; }

    struct FileStreamDeleter
    {
        template <typename T>
        void operator()(T* ptr)
        {
            if (ptr)
            {
                ptr->flush();
                FileUtils::closeFile(ptr);
            }
        }
    };

    void MyWriter::addArgs(ProgramArgs& args)
    {
        // setPositional() Makes the argument required.
        args.add("filename", "Output filename", m_filename).setPositional();
        args.add("newline", "Line terminator", m_newline, "\n");
        args.add("datafield", "Data field", m_datafield, "UserData");
        args.add("precision", "Precision", m_precision, 3);
    }
}
```

(continues on next page)
void MyWriter::initialize()
{
    m_stream = FileStreamPtr(FileUtils::createFile(m_filename, true),
                             FileStreamDeleter());
    if (!m_stream)
    {
        std::stringstream out;
        out << "writers.mywriter couldn't open " << m_filename << " for output."
            << std::endl;
        throw pdal_error(out.str());
    }
}

void MyWriter::ready(PointTableRef table)
{
    m_stream->precision(m_precision);
    *m_stream << std::fixed;

    Dimension::Id d = table.layout()->findDim(m_datafield);
    if (d == Dimension::Id::Unknown)
    {
        std::ostringstream oss;
        oss << "Dimension not found with name " << m_datafield << "."
            << std::endl;
        throw pdal_error(oss.str());
    }

    m_dataDim = d;

    *m_stream << "#X:Y:Z:MyData" << std::endl;
}

void MyWriter::write(PointViewPtr view)
{
    for (PointId idx = 0; idx < view->size(); ++idx)
    {
        double x = view->getFieldAs<double>(Dimension::Id::X, idx);
        double y = view->getFieldAs<double>(Dimension::Id::Y, idx);
        double z = view->getFieldAs<double>(Dimension::Id::Z, idx);
        unsigned int myData = 0;
    }
if (!m_datafield.empty()) {
    myData = (int)(view->getFieldAs<double>(m_dataDim, idx) + 0.5);
}

*m_stream << x << "":"" << y << "":"" << z << "":""
    << myData << m_newline;
}

void MyWriter::done(PointTableRef)
{
    m_stream.reset();
}
}

In the writer implementation, we will use a macro defined in pdal_macros, which is included in
the include chain we are using.

static PluginInfo const s_info
{
    "writers.mywriter",
    "My Awesome Writer",
    "http://path/to/documentation"
};

CREATE_SHARED_STAGE(MyWriter, s_info);

Here we define a struct with information regarding the writer, such as the name, a description,
and a path to documentation. We then use the macro to create a SHARED stage, which means
it will be external to the main PDAL installation. When using the macro, we specify the name
of the Stage and the PluginInfo struct we defined earlier.

When making a shared plugin, the name of the shared library must correspond with the name
of the writer provided here. The name of the generated shared object must be

libpdal_plugin_writer_<writer name>.<shared library extension>

struct FileStreamDeleter
{
    template <typename T>
    void operator()(T* ptr)
{  
    if (ptr)  
    {  
        ptr->flush();  
        FileUtils::closeFile(ptr);  
    }  
}  

This struct is used for helping with the FileStreamPtr for cleanup.

```cpp
void MyWriter::addArgs(ProgramArgs& args)  
{
    // setPositional() Makes the argument required.
    args.add("filename", "Output filename", m_filename).setPositional();
    args.add("newline", "Line terminator", m_newline, "\n");
    args.add("datafield", "Data field", m_datafield, "UserData");
    args.add("precision", "Precision", m_precision, 3);
}
```

This method defines the arguments the writer provides and binds them to private variables.

```cpp
void MyWriter::initialize()  
{
    m_stream = FileStreamPtr(FileUtils::createFile(m_filename, true), FileStreamDeleter());
    if (!m_stream)  
    {  
        std::stringstream out;
        out << "writers.mywriter couldn't open '" << m_filename << "' for output."
        throw pdal_error(out.str());  
    }  
}
```

This method initializes our file stream in preparation for writing.

```cpp
void MyWriter::ready(PointTableRef table)  
{
    m_stream->precision(m_precision);
    *m_stream << std::fixed;
    Dimension::Id d = table.layout()->findDim(m_datafield);
}
```
if (d == Dimension::Id::Unknown)
{
    std::ostringstream oss;
    oss << "Dimension not found with name '" << m_datafield << "'";
    throw pdal_error(oss.str());
}

m_dataDim = d;

*m_stream << "#X:Y:Z:MyData" << m_newline;
}

The ready method is used to prepare the writer for any number of PointViews that may be passed in. In this case, we are setting the precision for our double writes, looking up the dimension specified as the one to write into MyData, and writing the header of the output file.

void MyWriter::write(PointViewPtr view)
{
    for (PointId idx = 0; idx < view->size(); ++idx)
    {
        double x = view->getFieldAs<double>(Dimension::Id::X, idx);
        double y = view->getFieldAs<double>(Dimension::Id::Y, idx);
        double z = view->getFieldAs<double>(Dimension::Id::Z, idx);
        unsigned int myData = 0;

        if (!m_datafield.empty()) {
            myData = (int)(view->getFieldAs<double>(m_dataDim, idx) + 0.5);
        }

        *m_stream << x << ":" << y << ":" << z << ":" << myData << m_newline;
    }
}

This method is the main method for writing. In our case, we are writing a very simple file, with data in the format of X:Y:Z:MyData. We loop through each index in the PointView, and for each one we take the X, Y, and Z values, as well as the value for the specified MyData dimension, and write this to the output file. In particular, note the reading of MyData; in our case, MyData is an integer, but the field we are reading might be a double. Converting from double to integer is done via truncation, not rounding, so by adding .5 before making the conversion will ensure rounding is done properly.

Note that in this case, the output format is pretty simple. For more complex outputs, you may...
need to generate helper methods (and possibly helper classes) to help generate the proper output. The key is reading in the appropriate values from the PointView, and then writing those in whatever necessary format to the output stream.

```cpp
void MyWriter::done(PointTableRef)
{
    m_stream.reset();
}
```

This method is called when the writing is done. In this case, it simply cleans up the output stream by resetting it.

**Compiling and Usage**

To compile this reader, we will use cmake. Here is the CMakeLists.txt file we will use for this process:

```cpp
cmake_minimum_required(VERSION 3.13)
project(WriterTutorial)

find_package(PDAL 2.5 REQUIRED CONFIG)

set(CMAKE_CXX_STANDARD 17)
set(CMAKE_CXX_STANDARD_REQUIRED ON)

add_library(pdal_plugin_writer_mywriter SHARED MyWriter.cpp)
target_link_libraries(pdal_plugin_writer_mywriter PRIVATE ${PDAL_LIBRARIES})

target_link_directories(pdal_plugin_writer_mywriter PRIVATE ${PDAL_LIBRARY_DIRS})
target_include_directories(pdal_plugin_writer_mywriter PRIVATE ${PDAL_INCLUDE_DIRS})
```

If this file is in the directory with the MyWriter.hpp and MyWriter.cpp files, simply run `cmake .` followed by `make`. This will generate a file called `libpdal_plugin_writer_mywriter.dylib`.

Put this dylib file into the directory pointed to by `PDAL_DRIVER_PATH`, and then when you run `pdal --drivers`, you will see an entry for `writers.mywriter`.

To test the writer, we will put it into a pipeline and read in a LAS file and covert it to our output format. For this example, use `interesting.las` ([https://github.com/PDAL/PDAL/blob/master/test/data/interesting.las?raw=true](https://github.com/PDAL/PDAL/blob/master/test/data/interesting.las?raw=true)), and run it through `pipeline-mywriter.json`
If those files are in the same directory, you would just run the command `pdal pipeline pipeline-mywriter.json`, and it will generate an output file called `output.txt`, which will be in the proper format. From there, if you wanted, you could run that output file through the MyReader that was created in the previous tutorial, as well.

### 14.1.11 CMake

**Author**
Bradley Chambers

**Contact**
brad.chambers@gmail.com

**Date**
01/21/2015

This tutorial will explain how to use PDAL in your own projects using CMake. A more complete, working example can be found [here](page 546).

---

**Note:** We assume you have either built or installed (page 534) PDAL.

---

**Basic CMake configuration**

Begin by creating a file named `CMakeLists.txt` that contains:

```cmake
# CMakeLists.txt

if(IMPOSSIBLE humans)
    message(FATAL_ERROR "This is an example of a command that does not exist."
    )
else()
    message("Example: This is a command that does exist."
    )
endif()
```

---

**14.1. Development**

---
CMakelists explained

```cmake
cmake_minimum_required(VERSION 2.8.12)
```

The `cmake_minimum_required` command specifies the minimum required version of CMake. We use some recent additions to CMake in PDAL that require version 2.8.12.

```cmake
project(MY_PDAL_PROJECT)
```

The CMake `project` command names your project and sets a number of useful CMake variables.

```cmake
find_package(PDAL 1.0.0 REQUIRED CONFIG)
```

We next ask CMake to locate the PDAL package, requiring version 1.0.0 or higher.

```cmake
include_directories(${PDAL_INCLUDE_DIRS})
link_directories(${PDAL_LIBRARY_DIRS})
add_definitions(${PDAL_DEFINITIONS})
```

If PDAL is found, the following variables will be set:

- `PDAL_FOUND`: set to 1 if PDAL is found, otherwise unset
- `PDAL_INCLUDE_DIRS`: set to the paths to PDAL installed headers and the dependency headers
- `PDAL_LIBRARIES`: set to the file names of the built and installed PDAL libraries
- `PDAL_LIBRARY_DIRS`: set to the paths where PDAL libraries and 3rd party dependencies reside
- `PDAL_VERSION`: the detected version of PDAL
- `PDAL_DEFINITIONS`: list the needed preprocessor definitions and compiler flags

```cmake
set(CMAKE_CXX_FLAGS "-std=c++11")
```

We haven’t quite implemented the setting of `PDAL_DEFINITIONS` within the `PDALConfig.cmake` file, so for now you should specify the c++11 compiler flag, as we use it extensively throughout PDAL.

```cmake
add_executable(tutorial tutorial.cpp)
```

We use the `add_executable` command to tell CMake to create an executable named `tutorial` from the source file `tutorial.cpp`.

```cmake
target_link_libraries(tutorial PRIVATE ${PDAL_LIBRARIES})
```
We assume that the tutorial executable makes calls to PDAL functions. To make the linker aware of the PDAL libraries, we use `target_link_libraries` to link `tutorial` against the `PDAL_LIBRARIES`.

**Compiling the project**

Make a *build* directory, where compilation will occur:

```bash
$ cd /PATH/TO/MY/PDAL/PROJECT
$ mkdir build
```

Run cmake from within the build directory:

```bash
$ cd build
$ cmake ..
```

Now, build the project:

```bash
$ make
```

The project is now built and ready to run:

```bash
$ ./tutorial
```

### 14.2 Project

Project resources, such as how to update the docs, where the test frameworks are, who develops the software, and conventions to use when developing new code can be found in this section.

#### 14.2.1 Coding Conventions

To the extent possible and reasonable, we value consistency of source code formatting, class and variable naming, and so forth. Please follow existing code, rather than introducing your own (of course, better) formatting or change existing code unless you’re changing behavior.

This note lists some such conventions that we would like to follow, where it makes sense to do so.
Source Formatting

We use astyle (http://astyle.sourceforge.net) as a tool to reformat C++ source code files in a consistent fashion. The file astylerc, at the top of the github repo, contains the default settings we use.

Our conventions are:

- Lines should be kept to 80 characters where reasonable.
- LF endings (unix style), not CRLF (windows style)
- spaces, not tabs
- indent to four (4) spaces (“Four shalt be the number thou shalt count, and the number of the counting shall be four. Three shalt thou not count, neither count thou five…”)
- braces shall be on their own lines, like this:

```
if (p)
{
    foo();
}
```

- copyright header, license, and author(s) on every file
- two spaces between major units, e.g. function bodies

Naming Conventions

- classes should be names using UpperCamelCase
- functions should be in lowerCamelCase
- member variables should be prefixed with “m_”, followed by the name in lowerCamelCase – for example, “m_numberOfPoints”
- there should be one class per file, and the name of the file should match the class name – that is, class PointData should live in files PointData.hpp and PointData.cpp.

Other Conventions

- Surround all code with “namespace pdal {...}”; where justifiable, you may introduce a nested namespace.
- All exceptions that are not caught internally should be of type pdal_error. Exceptions used as local error handling should always be caught.
• Don’t put member function bodies in the class declaration in the header file, unless clearly justified for performance reasons. Use the “inline” keyword in these cases(?)

• Use const.

• Don’t put “using” declarations in headers.

• Document all public (and protected) member functions using doxygen markup.

#include Conventions

• For public headers from the ./include/pdal directory, use angle brackets: #include <pdal/Stage.h>

• For private headers (from somewhere in ./src), use quotes: #include “Support.hpp”

• Don’t #include a file where a simple forward declaration will do. (Note: this only applies to pdal files; don’t forward declare from system or 3rd party headers.)

• Don’t include a file unless it actually is required to compile the source unit.

• Don’t use manual include guards. All reasonable compilers support the once pragma:

```c
#pragma once
```

14.2.2 Contributors

Numerous organizations, companies, and individuals have contributed time, money, and code to build PDAL up into a highly capable software package. Without these contributions, PDAL would not progress as quickly, and its quality wouldn’t be as high. The development team is proud of the software, and it collectively represents years of experiences doing point cloud data management. We hope you’ll find it useful too.

This page is to recognize these contributors and their contributions. Thanks.

**Engineering Contributors**

[Hobu](http://hobu.co) is the primary company behind the design, testing, development, and distribution of PDAL. Two Hobu team members primarily interact with PDAL. Howard Butler [https://github.com/hobu] founded the project, and he provides project leadership and software development.
Bell (https://github.com/abellgithub) has contributed design, refactoring, and new feature development of PDAL over the past couple of years.

Michael Gerlek (http://github.com/mpgerlek) helped bootstrap PDAL by providing its first design, basic primitive objects, and first stage implementations.

([Image](https://grovercsllc.com/) Bradley Chambers (https://github.com/chambbj) from Grover Consulting Services (https://grovercsllc.com/) has contributed numerous features and capabilities to the PDAL project, including Poisson sampling (page 296) and classification filters such as the SMRF filter (page 197). He is also a prolific Tutorials (page 379) writer.

**Funding Contributors**

14.2.3 Docs

Requirements

To build the PDAL documentation yourself, you need to install the following items:

- Sphinx (http://sphinx-doc.org/)
- Breathe (https://github.com/michaeljones/breathe)
- Doxygen (http://www.stack.nl/~dimitri/doxygen/)
- Latex (https://en.wikipedia.org/wiki/LaTeX)

Sphinx (http://sphinx-doc.org/) and Breathe (https://github.com/michaeljones/breathe)

Python dependencies should be installed from PyPI (https://pypi.python.org/pypi) with pip or easy_install.

(sudo) pip install sphinx sphinxconfig-bibtex breathe

Note: If you are installing these packages to a system-wide directory, you may need the sudo in front of the pip, though it might be better that instead you use virtual environments (https://pypi.python.org/pypi/virtualenv) instead of installing the packages system-wide.
Doxygen

The PDAL documentation also depends on Doxygen (http://www.stack.nl/~dimitri/doxygen/), which can be installed from source or from binaries from the doxygen website (http://www.stack.nl/~dimitri/doxygen/download.html). If you are on Max OS X and use homebrew (http://mxcl.github.io/homebrew/), you can install doxygen with a simple `brew install doxygen`.

Latex

Latex (https://en.wikipedia.org/wiki/LaTeX) and pdflatex (https://www.tug.org/applications/pdftex/) are used to generate the companion PDF of the website.

dvipng

For math output, we depend on dvipng (https://en.wikipedia.org/wiki/Dvipng) to turn Latex (https://en.wikipedia.org/wiki/LaTeX) output into math PNGs.

Generation

Once you have installed all the doc dependencies, you can then build the documentation itself. The doc/ directory in the PDAL source tree contains a Makefile which can be used to build all documentation. For a list of the output formats supported by Sphinx, simply type `make`. For example, to build html documentation:

```
cd doc
make doxygen html
```

The html docs will be placed in `doc/build/html/`. The `make doxygen` is necessary to re-generate the API documentation from the source code using Breathe (https://github.com/michaeljones/breathe) and Sphinx (http://sphinx-doc.org/).

**Note:** For a full build of the C++ API (page 600) documentation, you need to `make doxygen` to have it build its XML output which is consumed by Breathe (https://github.com/michaeljones/breathe) before `make html` can be issued.
Website

The http://pdal.io website is regenerated from the *-maintenance branch using Github Actions. It will be committed by the PDAL-docs GitHub (http://github.com/PDAL/PDAL) user and pushed to the https://github.com/PDAL/pdal.github.io repository. The website is then served via GitHub Pages (https://pages.github.com/).

14.2.4 Building Docker Containers for PDAL

PDAL’s repository (page 14) is linked to DockerHub (https://hub.docker.com/r/pdal/pdal/) for automatic building of Docker (https://www.docker.com/) containers. PDAL keeps three Docker containers current.

- pdal/ubuntu-dependencies:latest – PDAL’s dependencies
- pdal/pdal:latest – PDAL master
- pdal/pdal:1.5 – PDAL maintenance branch

Note: Containers are built upon the Dependencies (page 587) container, but the Dependencies (page 587) container is not pinned to specific Bionic or PDAL release times. It corresponds to where ever the dependencies tag of the PDAL source tree at https://github.com/PDAL/PDAL resides

Dependencies

The PDAL dependencies Docker container is used by both the latest and release branch Docker containers. The dependencies container is also used during Continuous Integration (page 599) testing by Travis. It is built using the Dockerfile at https://github.com/PDAL/PDAL/blob/master/scripts/docker/ubuntu/dependencies/Dockerfile

The pdal/dependencies:latest image is regenerated by force-pushing a tag of the SHA you wish to use to have DockerHub (https://hub.docker.com/r/pdal/pdal/) build.

```
git tag -f dependencies
git push origin refs/tags/dependencies -f
```

Note: The dependencies container is currently built upon Ubuntu Bionic (http://releases.ubuntu.com/18.04/). When the next Ubuntu LTS is released, the PDAL project will likely move to it.
**Maintenance**

A PDAL container corresponding to the last major release is automatically created and maintained with every commit to the active release branch. For example, the 1.4-maintenance branch will have a corresponding pdal/pdal:1.4 container made with every commit on DockerHub (https://hub.docker.com/r/pdal/pdal/). Users are encouraged to use these containers for testing, bug confirmation, and deployment

![Docker containers](image)

Fig. 1: Docker containers on maintenance branch correspond to major PDAL releases.

**Latest (or master)**

A PDAL container corresponding to a developer-selected release point is made available at pdal/pdal:latest and corresponds to the manual push of a docker-master tag by PDAL developers. This container is typically used for testing and verification of fixes, and it is recommended that users looking to depend on PDAL’s Docker containers always use known release versions off of the last stable release branch.

**Warning:** You should be using the Maintenance (page 588) Docker container for any production-oriented operations. Only use the latest one to test or prototype a latest, unreleased feature.

![Docker containers](image)

Fig. 2: The pdal/pdal:latest branch is current relative to the docker-master branch in GitHub.

$ git tag -f docker-master
$ git push origin refs/tags/docker-master -f

---

588 Chapter 14. Development
14.2.5 Alpine

This page is intended to provide information about Alpine that may be useful for PDAL developers, especially when it comes to adding new PDAL dependencies.

Packages

When adding a dependency to PDAL, you will need to update our Travis configuration for continuous integration and testing, and Dockerfiles for automated builds. Begin by checking for your package in https://pkgs.alpinelinux.org/packages. Packages containing binaries can typically be found by searching for the library/package name alone. Development files are typically grouped in a separate subpackage with -dev appended to the package name. Libraries are sometimes grouped in yet another subpackage with -libs appended. It may take a little inspection of the package contents to determine exactly what you are getting with a particular package.

If a package does not yet exist, you’ll need to consult https://wiki.alpinelinux.org/wiki/Creating_an_Alpine_package or phone a friend. Alpine developers can frequently be found on the IRC channel #alpine-devel.

Travis

We currently run our Travis CI builds by first pulling alpine:3.6 and then running a script within the Alpine container. Any new dependencies that are required for PDAL to be built and tested will need to be added to https://github.com/PDAL/PDAL/blob/master/scripts/ci/script.sh.

Docker

Our Docker automated builds are built from the Dockerfiles located in https://github.com/PDAL/PDAL/tree/master/scripts/docker. There are folders for each supported release as well as master, and there are variants for Alpine and Ubuntu based images. In the Alpine Dockerfiles, any development dependencies should be added in the apk add step that uses the --virtual switch, as these will be deleted after compilation. Any runtime dependencies should be added to the regular apk add step.
14.2.6 Testing

Unit Tests

A unit test framework is provided, with the goal that all (nontrivial) classes will have unit tests. At the very least, each new class should have a corresponding unit test file stubbed in, even if there aren’t any tests yet.

- Our unit tests also include testing of the command line Applications (page 27) and known plugins.
- We use the Google C++ Test Framework (https://code.google.com/p/googletest/), but a local copy of it is embedded in the PDAL source tree, and you don’t have to have it available as a dependency.
- Unit tests for features that are configuration-dependent, e.g. laszip compression, should be put under the same #ifdef guards as the classes being tested.
- The Support class, in the ./test/unit directory, provides some functions for comparing files, etc, that are useful in writing test cases.
- Unit tests should not be long-running.

Running the Tests

To run all unit tests, issue the following command from your build directory:

```
$ ctest
```

make test or ninja test should still work as well.

Depending on the which optional components you’ve chose to build, your output should resemble the following:

```
Test project /Users/hobu/dev/git/pdal
  Start 1: pdal_bounds_test
  1/61 Test #1: pdal_bounds_test ................... Passed 0.02
  → sec
  Start 2: pdal_config_test
  2/61 Test #2: pdal_config_test ................... Passed 0.02
  → sec
  Start 3: pdal_file_utils_test
  3/61 Test #3: pdal_file_utils_test ............... Passed 0.02
  → sec
  Start 4: pdal_georeference_test
  4/61 Test #4: pdal_georeference_test ............. Passed 0.02
```
Start 5: pdal_kdindex_test
5/61 Test #5: pdal_kdindex_test .......... Passed 0.03

Start 6: pdal_log_test
6/61 Test #6: pdal_log_test .......... Passed 0.03

Start 7: pdal_metadata_test
7/61 Test #7: pdal_metadata_test .......... Passed 0.02

Start 8: pdal_options_test
8/61 Test #8: pdal_options_test .......... Passed 0.02

Start 9: pdal_pdalutils_test
9/61 Test #9: pdal_pdalutils_test .......... Passed 0.02

Start 10: pdal_pipeline_manager_test
10/61 Test #10: pdal_pipeline_manager_test .... Passed 0.03

Start 11: pdal_point_view_test
11/61 Test #11: pdal_point_view_test .......... Passed 2.03

Start 12: pdal_point_table_test
12/61 Test #12: pdal_point_table_test .......... Passed 0.03

Start 13: pdal_spatial_reference_test
13/61 Test #13: pdal_spatial_reference_test .......... Passed 0.07

Start 14: pdal_support_test
14/61 Test #14: pdal_support_test .......... Passed 0.02

Start 15: pdal_user_callback_test
15/61 Test #15: pdal_user_callback_test .......... Passed 0.02

Start 16: pdal_utils_test
16/61 Test #16: pdal_utils_test .......... Passed 0.02

Start 17: pdal_lazperf_test
17/61 Test #17: pdal_lazperf_test .......... Passed 0.04

Start 18: pdal_io_bpf_test
18/61 Test #18: pdal_io_bpf_test .......... Passed 0.20
Start 19: pdal_io_buffer_test
19/61 Test #19: pdal_io_buffer_test ............... Passed 0.02\text{sec}

Start 20: pdal_io_faux_test
20/61 Test #20: pdal_io_faux_test ............... Passed 0.04\text{sec}

Start 21: pdal_io_ilvis2_test
21/61 Test #21: pdal_io_ilvis2_test ............... Passed 0.06\text{sec}

Start 22: pdal_io_las_reader_test
22/61 Test #22: pdal_io_las_reader_test ........... Passed 0.49\text{sec}

Start 23: pdal_io_las_writer_test
23/61 Test #23: pdal_io_las_writer_test ........... Passed 2.27\text{sec}

Start 24: pdal_io_optech_test
24/61 Test #24: pdal_io_optech_test ............... Passed 0.03\text{sec}

Start 25: pdal_io_ply_reader_test
25/61 Test #25: pdal_io_ply_reader_test ........... Passed 0.03\text{sec}

Start 26: pdal_io_ply_writer_test
26/61 Test #26: pdal_io_ply_writer_test ........... Passed 0.02\text{sec}

Start 27: pdal_io_qfit_test
27/61 Test #27: pdal_io_qfit_test ............... Passed 0.03\text{sec}

Start 28: pdal_io_sbet_reader_test
28/61 Test #28: pdal_io_sbet_reader_test ........... Passed 0.04\text{sec}

Start 29: pdal_io_sbet_writer_test
29/61 Test #29: pdal_io_sbet_writer_test ........... Passed 0.03\text{sec}

Start 30: pdal_io_terrasolid_test
30/61 Test #30: pdal_io_terrasolid_test ........... Passed 0.03\text{sec}

Start 31: pdal_filters_chipper_test
31/61 Test #31: pdal_filters_chipper_test ........... Passed 0.03\text{sec}

Start 32: pdal_filters_colorization_test
32/61 Test #32: pdal_filters_colorization_test ..... Passed 11.40\text{sec}

Start 33: pdal_filters_crop_test
33/61 Test #33: pdal_filters_crop_test .......... Passed 0.04
   Start 34: pdal_filters_decimation_test
34/61 Test #34: pdal_filters_decimation_test .... Passed 0.02
   Start 35: pdal_filters_divider_test
35/61 Test #35: pdal_filters_divider_test .......... Passed 0.03
   Start 36: pdal_filters_ferry_test
36/61 Test #36: pdal_filters_ferry_test .......... Passed 0.04
   Start 37: pdal_filters_merge_test
37/61 Test #37: pdal_filters_merge_test .......... Passed 0.03
   Start 38: pdal_filters_reprojection_test
38/61 Test #38: pdal_filters_reprojection_test ..... Passed 0.03
   Start 39: pdal_filters_range_test
39/61 Test #39: pdal_filters_range_test .......... Passed 0.05
   Start 40: pdal_filters_randomize_test
40/61 Test #40: pdal_filters_randomize_test ....... Passed 0.02
   Start 41: pdal_filters_sort_test
41/61 Test #41: pdal_filters_sort_test .......... Passed 0.39
   Start 42: pdal_filters_splitter_test
42/61 Test #42: pdal_filters_splitter_test .......... Passed 0.03
   Start 43: pdal_filters_stats_test
43/61 Test #43: pdal_filters_stats_test .......... Passed 0.03
   Start 44: pdal_filters_transformation_test
44/61 Test #44: pdal_filters_transformation_test ... Passed 0.03
   Start 45: pdal_merge_test
45/61 Test #45: pdal_merge_test ................. Passed 0.07
   Start 46: pc2pc_test
46/61 Test #46: pc2pc_test ....................... Passed 0.15
   Start 47: xml_schema_test
47/61 Test #47: xml_schema_test ................. Passed 0.02
Start 48: pdal_filters_attribute_test
48/61 Test #48: pdal_filters_attribute_test ........ Passed 0.09

Start 49: pdal_plugins_cpd_kernel_test
49/61 Test #49: pdal_plugins_cpd_kernel_test ........***Exception: Other

Start 50: hexbintest
50/61 Test #50: hexbintest ......................... Passed 0.03

Start 51: icetest
51/61 Test #51: icetest ......................... Passed 0.04

Start 52: mrsidtest
52/61 Test #52: mrsidtest ......................... Passed 0.06

Start 53: pdal_io_nitf_writer_test
53/61 Test #53: pdal_io_nitf_writer_test ........... Passed 0.08

Start 54: pdal_io_nitf_reader_test
54/61 Test #54: pdal_io_nitf_reader_test ........... Passed 0.04

Start 55: ocitest
55/61 Test #55: ocitest .........................***Failed 0.06

Start 56: pcltest
56/61 Test #56: pcltest ......................... Passed 0.28

Start 57: pgpointcloudtest
57/61 Test #57: pgpointcloudtest ................... Passed 1.66

Start 58: plangtest
58/61 Test #58: plangtest ......................... Passed 0.14

Start 59: python_predicate_test
59/61 Test #59: python_predicate_test ........... Passed 0.16

Start 60: python_programmable_test
60/61 Test #60: python_programmable_test ........... Passed 0.15

Start 61: sqlitetest
61/61 Test #61: sqlitetest ......................... Passed 0.55

(continues on next page)
97% tests passed, 2 tests failed out of 61

Total Test time (real) = 21.57 sec

The following tests FAILED:
    49 - pdal_plugins_cpd_kernel_test (OTHER_FAULT)
    55 - ocitest (Failed)

For a more verbose output, use the -V flag. Or, to run an individual test suite, use -R <suite name>. For example:

```bash
$ ctest -V -R pdal_io_bpf_test
```

Should produce output similar to:

```
UpdateCTestConfiguration from :/Users/hobu/dev/git/pdal/
  → DartConfiguration.tcl
UpdateCTestConfiguration from :/Users/hobu/dev/git/pdal/
  → DartConfiguration.tcl
Test project /Users/hobu/dev/git/pdal
Constructing a list of tests
Done constructing a list of tests
Checking test dependency graph...
Checking test dependency graph end
test 18
  Start 18: pdal_io_bpf_test

18: Test command: /Users/hobu/dev/git/pdal/bin/pdal_io_bpf_test
18: Environment variables:
18:  PDAL_DRIVER_PATH=/Users/hobu/dev/git/pdal/lib
18: Test timeout computed to be: 9.99988e+06
18: [==========] Running 20 tests from 1 test case.
18: [----------] Global test environment set-up.
18: [----------] 20 tests from BPFTest
18: [ RUN ] BPFTest.test_point_major
18: [  OK  ] BPFTest.test_point_major (8 ms)
18: [ RUN ] BPFTest.test_dim_major
18: [  OK  ] BPFTest.test_dim_major (3 ms)
18: [ RUN ] BPFTest.test_byte_major
18: [  OK  ] BPFTest.test_byte_major (4 ms)
18: [ RUN ] BPFTest.test_point_major_zlib
18: [  OK  ] BPFTest.test_point_major_zlib (6 ms)
```

(continues on next page)
18: [ RUN   ] BPFTest.test_dim_major_zlib
18: [   OK ] BPFTest.test_dim_major_zlib (4 ms)
18: [ RUN   ] BPFTest.test_byte_major_zlib
18: [   OK ] BPFTest.test_byte_major_zlib (5 ms)
18: [ RUN   ] BPFTest.roundtrip_byte
18: [   OK ] BPFTest.roundtrip_byte (15 ms)
18: [ RUN   ] BPFTest.roundtrip_dimension
18: [   OK ] BPFTest.roundtrip_dimension (10 ms)
18: [ RUN   ] BPFTest.roundtrip_point
18: [   OK ] BPFTest.roundtrip_point (11 ms)
18: [ RUN   ] BPFTest.roundtrip_byte_compression
18: [   OK ] BPFTest.roundtrip_byte_compression (16 ms)
18: [ RUN   ] BPFTest.roundtrip_dimension_compression
18: [   OK ] BPFTest.roundtrip_dimension_compression (13 ms)
18: [ RUN   ] BPFTest.roundtrip_point_compression
18: [   OK ] BPFTest.roundtrip_point_compression (14 ms)
18: [ RUN   ] BPFTest.roundtrip_scaling
18: [   OK ] BPFTest.roundtrip_scaling (10 ms)
18: [ RUN   ] BPFTest.extra_bytes
18: [   OK ] BPFTest.extra_bytes (15 ms)
18: [ RUN   ] BPFTest.bundled
18: [   OK ] BPFTest.bundled (17 ms)
18: [ RUN   ] BPFTest.inspect
18: [   OK ] BPFTest.inspect (1 ms)
18: [ RUN   ] BPFTest.mueller
18: [   OK ] BPFTest.mueller (0 ms)
18: [ RUN   ] BPFTest.flex
18: [   OK ] BPFTest.flex (9 ms)
18: [ RUN   ] BPFTest.flex2
18: [   OK ] BPFTest.flex2 (7 ms)
18: [ RUN   ] BPFTest.outputdims
18: [   OK ] BPFTest.outputdims (14 ms)
18: [--------] 20 tests from BPFTest (182 ms total)
18:
18: [--------] Global test environment tear-down
18: [========] 20 tests from 1 test case ran. (182 ms total)
18: [   PASSED ] 20 tests.
1/1 Test #18: pdal_io_bpf_test ................. Passed  0.20 sec

The following tests passed:
   pdal_io_bpf_test

100% tests passed, 0 tests failed out of 1
$ bin/pdal_io_test

Again, the output should resemble the following:

```
[----------] Running 20 tests from 1 test case.
[----------] Global test environment set-up.
[----------] 20 tests from BPFTest
[ RUN ] BPFTest.test_point_major
[ OK ] BPFTest.test_point_major (7 ms)
[ RUN ] BPFTest.test_dim_major
[ OK ] BPFTest.test_dim_major (3 ms)
[ RUN ] BPFTest.test_byte_major
[ OK ] BPFTest.test_byte_major (4 ms)
[ RUN ] BPFTest.test_point_major_zlib
[ OK ] BPFTest.test_point_major_zlib (5 ms)
[ RUN ] BPFTest.test_dim_major_zlib
[ OK ] BPFTest.test_dim_major_zlib (5 ms)
[ RUN ] BPFTest.test_byte_major_zlib
[ OK ] BPFTest.test_byte_major_zlib (6 ms)
[ RUN ] BPFTest.roundtrip_byte
[ OK ] BPFTest.roundtrip_byte (17 ms)
[ RUN ] BPFTest.roundtrip_dimension
[ OK ] BPFTest.roundtrip_dimension (10 ms)
[ RUN ] BPFTest.roundtrip_point
[ OK ] BPFTest.roundtrip_point (11 ms)
[ RUN ] BPFTest.roundtrip_byte_compression
[ OK ] BPFTest.roundtrip_byte_compression (15 ms)
[ RUN ] BPFTest.roundtrip_dimension_compression
[ OK ] BPFTest.roundtrip_dimension_compression (14 ms)
[ RUN ] BPFTest.roundtrip_point_compression
[ OK ] BPFTest.roundtrip_point_compression (14 ms)
[ RUN ] BPFTest.roundtrip_scaling
[ OK ] BPFTest.roundtrip_scaling (11 ms)
[ RUN ] BPFTest.extra_bytes
[ OK ] BPFTest.extra_bytes (16 ms)
[ RUN ] BPFTest.bundled
[ OK ] BPFTest.bundled (17 ms)
[ RUN ] BPFTest.inspect
[ OK ] BPFTest.inspect (1 ms)
[ RUN ] BPFTest.mueller
[ OK ] BPFTest.mueller (0 ms)
```

(continues on next page)
This invocation allows us to alter Google Test’s default behavior. For more on the available flags type:

```
$ bin/<test_name> --help
```

Key among these flags are the ability to list tests (`--gtest_list_tests`) and to run only select tests (`--gtest_filter`).

**Note:** If the PostgreSQL PointCloud plugin was enabled on the CMake command line (with `-DBUILD_PLUGIN_PGPOINTCLOUD=ON`) then ctest will attempt to run the `pgpointcloud` tests. And you will get PostgreSQL connection errors if the `libpq` environment variables ([https://www.postgresql.org/docs/current/static/libpq-envars.html](https://www.postgresql.org/docs/current/static/libpq-envars.html)) are not correctly set in your shell. This is for example how you can run the `pgpointcloud` tests:

```
$ PGUSER=pdal PGPASSWORD=pdal PGHOST=localhost ctest -R pgpointcloudtest
```

**Test Data**

Use the directory `.test/data` to store files used for unit tests. A vfunction is provided in the Support class for referencing that directory in a configuration-independent manner.

Temporary output files from unit tests should go into the `.test/temp` directory. A Support function is provided for referencing this directory as well.

Unit tests should always clean up and remove any files that they create (except perhaps in case of a failed test, in which case leaving the output around might be helpful for debugging).
14.2.7 Continuous Integration

PDAL regression tests (page 590) are run on a per-commit basis using GitHub Actions (https://github.com/features/actions).

Status

Configuration

Continuous integration configuration is modified by manipulating configuration files in to locations:

- ./github/workflows
- ./scripts/ci

Linux, OSX, and Windows builds are all configured separately with scripts in the ./scripts/ci directory.

Dependencies

All of the tests use Conda Forge for dependencies.

The Linux builder has a “fixed” configuration that pins GDAL to a specific version to prevent the rest of the dependency tree from floating according to Conda Forge’s package dependency rules.

Docs

Docs are always built and doc artifacts are attached to the build:

- HTML
- PDF
- Misspelled words

Push to pdal.io

Doc building succeeds

The push branch denoted in ./github/workflows/docs.yaml matches the current *-maintenance branch.
14.3 API

PDAL is a C++ library, and its primary API is in that language. There is also a Python (page 369) API that allows reading of data and interaction with Numpy (http://www.numpy.org/).

Note: Users looking for documentation on how to use PDAL’s command line applications should look here (page 27) and users looking for documentation on how to contribute to PDAL should look here (page 523).

14.3.1 C++ API

pdal::BOX2D

class BOX2D

BOX2D (page 600) represents a two-dimensional box with double-precision bounds.

Subclassed by pdal::BOX3D (page 604)

Public Functions

inline BOX2D()  

Construct an “empty” bounds box.

inline BOX2D(double minx, double miny, double maxx, double maxy)

Construct and initialize a bounds box.

Parameters

- **minx** – Minimum X value.
- **miny** – Minimum Y value.
- **maxx** – Maximum X value.
- **maxy** – Maximum Y value.

bool empty() const

Determine whether a bounds box has not had any bounds set.

Returns

Whether the bounds box is empty.
bool **valid()** const

Determine whether a bounds box has had any bounds set.

**Returns**

Whether the bounds box is valid.

void **clear()**

Clear the bounds box to an empty state.

**BOX2D (page 600) &grow(double x, double y)**

Expand the bounds of the box to include the specified point.

**Parameters**

- `x` – X point location.
- `y` – Y point location.

**BOX2D (page 600) &grow(double dist)**

Expand the bounds of the box in all directions by a specified amount.

**Parameters**

- `dist` – Distance by which to expand the box.

inline bool **contains(double x, double y) const**

Determine if a bounds box contains a point.

**Parameters**

- `x` – X dimension value.
- `y` – Y dimension value.

**Returns**

Whether both dimensions are equal to or less than the maximum box values and equal to or more than the minimum box values.

inline bool **equal(const BOX2D (page 600) &other) const**

Determine if the bounds of this box are the same as that of another box.

Empty bounds boxes are always equal.

**Parameters**

- `other` – Bounds box to check for equality.

**Returns**

true if the provided box has equal limits to this box, false otherwise.

inline bool **operator==(BOX2D (page 600) const &other) const**

Determine if the bounds of this box are the same as that of another box.

Empty bounds boxes are always equal.
Parameters
other – Bounds box to check for equality.

Returns
true if the provided box has equal limits to this box, false otherwise.

inline bool operator!=(BOX2D (page 600) const &other) const
Determine if the bounds of this box are different from that of another box.
Empty bounds boxes are never unequal.

Parameters
other – Bounds box to check for inequality.

Returns
true if the provided box has limits different from this box, false otherwise.

inline BOX2D (page 600) &grow(const BOX2D (page 600) &other)
Expand this box to contain another box.

Parameters
other – Box that this box should contain.

inline void clip(const BOX2D (page 600) &other)
Clip this bounds box by another so it will be contained by the other box.

Parameters
other – Clipping box for this box.

inline bool contains(const BOX2D (page 600) &other) const
Determine if another bounds box is contained in this bounds box.
Equal limits are considered to be contained.

Parameters
other – Bounds box to check for containment.

Returns
true if the provided box is contained in this box, false otherwise.

inline bool overlaps(const BOX2D (page 600) &other) const
Determine if another box overlaps this box.

Parameters
other – Box to test for overlap.

Returns
Whether the provided box overlaps this box.

inline std::string toBox(uint32_t precision = 8) const
Convert this box to a string suitable for use in SQLite.
Parameters
precision – Precision for output [default: 8]

Returns
String format of this box.

inline std::string toWKT(uint32_t precision = 8) const
Convert this box to a well-known text string.

Parameters
precision – Precision for output [default: 8]

Returns
String format of this box.

inline std::string toGeoJSON(uint32_t precision = 8) const
Convert this box to a GeoJSON text string.

Parameters
precision – Precision for output [default: 8]

Returns
String format of this box.

void parse(const std::string &s, std::string::size_type &pos)
Parse a string as a BOX2D (page 600).

Parameters
• s – String representation of the box.
  • pos – Position in the string at which to start parsing. On return set to parsing end position.

Public Members

double minx
  Minimum X value.

double maxx
  Maximum X value.

double miny
  Minimum Y value.

double maxy
  Maximum Y value.
std::string \texttt{wkt}  
WKT/PROJJSON/EPSG:code/etc GDAL-readable SRS format.

\textbf{Public Static Functions}

\texttt{static const BOX2D} (page 600) \&\texttt{getDefaultSpatialExtent} ()

Return a statically-allocated Bounds extent that represents infinity.

\textbf{Returns}
A bounds box with infinite bounds,

\texttt{struct error} : public std::runtime\_error

\textbf{Public Functions}

\texttt{inline error} (const std::string \&err)

\texttt{class BOX3D} : private pdal::\texttt{BOX2D} (page 600)

\textit{BOX3D} (page 604) represents a three-dimensional box with double-precision bounds.

\textbf{Public Functions}

\texttt{inline BOX3D} ()

Clear the bounds box to an empty state.

\texttt{inline BOX3D} (const \texttt{BOX3D} (page 604) \&box)

\textit{BOX3D} (page 604) \&\texttt{operator=} (const \texttt{BOX3D} (page 604) \&box) = default

\texttt{inline explicit BOX3D} (const \texttt{BOX2D} (page 600) \&box)

\texttt{inline BOX3D} (double minx, double miny, double minz, double maxx, double maxy, double maxz)

Construct and initialize a bounds box.

\textbf{Parameters}

- \texttt{minx} – Minimum X value.
- \texttt{miny} – Minimum Y value.
- \texttt{minx} – Minimum Z value.
- \texttt{maxx} – Maximum X value.
• **maxy** – Maximum Y value.

• **maxz** – Maximum Z value.

`bool empty() const`  
Determine whether a bounds box has not had any bounds set (is in a state as if default-constructed).

**Returns**
Whether the bounds box is empty.

`bool valid() const`  
Determine whether a bounds box has had any bounds set.

**Returns**
\true if the bounds box is not empty

**BOX3D** (page 604) &`grow(double x, double y, double z)`  
Expand the bounds of the box if a value is less than the current minimum or greater than the current maximum.

If the bounds box is currently empty, both minimum and maximum box bounds will be set to the provided value.

**Parameters**

• **x** – X dimension value.

• **y** – Y dimension value.

• **z** – Z dimension value.

`void clear()`  
Clear the bounds box to an empty state.

`inline bool contains(double x, double y, double z) const`  
Determine if a bounds box contains a point.

**Parameters**

• **x** – X dimension value.

• **y** – Y dimension value.

• **z** – Z dimension value.

**Returns**
Whether both dimensions are equal to or less than the maximum box values and equal to or more than the minimum box values.

`inline bool contains(const **BOX3D** (page 604) &other) const`  
Determine if another bounds box is contained in this bounds box.

Equal limits are considered to be contained.
Parameters
other – Bounds box to check for containment.

Returns
true if the provided box is contained in this box, false otherwise.

inline bool equal(const BOX3D (page 604) &other) const
Determine if the bounds of this box are the same as that of another box.
Empty bounds boxes are always equal.

Parameters
other – Bounds box to check for equality.

Returns
true if the provided box has equal limits to this box, false otherwise.

inline bool operator==(BOX3D (page 604) const &rhs) const
Determine if the bounds of this box are the same as that of another box.
Empty bounds boxes are always equal.

Parameters
other – Bounds box to check for equality.

Returns
true if the provided box has equal limits to this box, false otherwise.

inline bool operator!=(BOX3D (page 604) const &rhs) const
Determine if the bounds of this box are different from that of another box.
Empty bounds boxes are never unequal.

Parameters
other – Bounds box to check for inequality.

Returns
true if the provided box has limits different from this box, false otherwise.

inline BOX3D (page 604) & grow(const BOX3D (page 604) &other)
Expand this box to contain another box.

Parameters
other – Box that this box should contain.

inline BOX3D (page 604) & grow(double dist)
Expand this box by a specified amount.

Parameters
dist – Distance by which box should be expanded.
inline void `clip` (const `BOX3D` (page 604) &other)
Clip this bounds box by another so it will be contained by the other box.

Parameters

- `other` – Clipping box for this box.

inline bool `overlaps` (const `BOX3D` (page 604) &other) const
Determine if another box overlaps this box.

Parameters

- `other` – Box to test for overlap.

Returns

Whether the provided box overlaps this box.

inline `BOX2D` (page 600) `to2d` () const
Convert this box to 2-dimensional bounding box.

Returns

Bounding box with Z dimension stripped.

inline `std::string` `toBox` (uint32_t precision = 8) const
Convert this box to a string suitable for use in SQLite.

Parameters

- `precision` – Precision for output [default: 8]

Returns

String format of this box.

inline `std::string` `toWKT` (uint32_t precision = 8) const
Convert this box to a well-known text string.

Parameters

- `precision` – Precision for output [default: 8]

Returns

String format of this box.

void `parse` (const `std::string` &s, `std::string::size_type` &pos)
Parse a string as a `BOX3D` (page 604).

Parameters

- `s` – String representation of the box.
- `pos` – Position in the string at which to start parsing. On return set to parsing end position.
Public Members

double minz
    Minimum Z value.

double maxz
    Maximum Z value.

double minx
    Minimum X value.

double maxx
    Maximum X value.

double miny
    Minimum Y value.

double maxy
    Maximum Y value.

std::string wkt
    WKT/PROJJSON/EPSG:code/etc GDAL-readable SRS format.

Public Static Functions

static const BOX3D (page 604) & getDefaultSpatialExtent()
    Return a statically-allocated Bounds extent that represents infinity.

    Returns
    A bounds box with infinite bounds,

    struct error : public std::runtime_error
PDAL: Point cloud Data Abstraction Library, Release 2.6.2

Public Functions

inline error(const std::string &err)

dhal::Charbuf

class Charbuf : public std::streambuf
   Allow a data buffer to be used at a std::streambuf.

Public Functions

inline Charbuf()
   Construct an empty Charbuf (page 609).

inline Charbuf(std::vector<char> &v, pos_type bufOffset = 0)
   Construct a Charbuf (page 609) that wraps a byte vector.

   Parameters
   • v – Byte vector to back streambuf.
   • bufOffset – Offset in vector (ignore bytes before offset).

inline Charbuf(char *buf, size_t count, pos_type bufOffset = 0)
   Construct a Charbuf (page 609) that wraps a byte buffer.

   Parameters
   • buf – Buffer to back streambuf.
   • count – Size of buffer.
   • bufOffset – Offset in vector (ignore bytes before offset).

void initialize(char *buf, size_t count, pos_type bufOffset = 0)
   Set a buffer to back a Charbuf (page 609).

   Parameters
   • buf – Buffer to back streambuf.
   • count – Size of buffer.
   • bufOffset – Offset in vector (ignore bytes before offset).
pdal::ColumnPointTable

class ColumnPointTable : public pdal::SimplePointTable

Public Functions

inline ColumnPointTable()
virtual ~ColumnPointTable()
inline virtual bool supportsView() const
virtual void finalize()
inline virtual char *getPoint(PointId idx)

pdal::Dimension

namespace Dimension

Typedefs

typedef std::vector<Detail (page 612)> DetailList

Enums

enum class BaseType
  Values:

  enumerator None

  enumerator Signed

  enumerator Unsigned

  enumerator Floating
enum class Type
        Values:

        enumerator None

        enumerator Unsigned8

        enumerator Signed8

        enumerator Unsigned16

        enumerator Signed16

        enumerator Unsigned32

        enumerator Signed32

        enumerator Unsigned64

        enumerator Signed64

        enumerator Float

        enumerator Double

**Functions**

inline BaseType (page 610) fromName(std::string name)

inline std::string toName(BaseType (page 610) b)

inline std::size_t size(Type (page 610) t)

inline BaseType (page 610) base(Type (page 610) t)

inline std::string interpretationName(Type (page 610) dimtype)

Get a string representation of a datatype.

**Parameters**

Returns
String representation of dimension type.

inline Type (page 610) type (std::string s)
Get the type corresponding to a type name.

Parameters
s – Name of type.

Returns
Corresponding type enumeration value.

inline Type (page 610) type (const std::string &baseType, size_t size)

inline std::size_t extractName (const std::string &s, std::string::size_type p)
Extract a dimension name of a string.

Dimension (page 610) names start with an alpha and continue with numbers or underscores.

Parameters
• s – String from which to extract dimension name.
• p – Position at which to start extracting.

Returns
Number of characters in the extracted name.

inline std::string fixName (std::string name)
inline bool nameValid (std::string name)

inline std::istream &operator>>(std::istream &in, Dimension (page 610)::Type (page 610) &type)

inline std::ostream &operator<<(std::ostream &out, const Dimension (page 610)::Type (page 610) &type)

Variables

static const int COUNT = 1024

static const int PROPRIETARY = 512

class Detail
#include <DimDetail.hpp>
pdal::Extractor

class Extractor
    Buffer wrapper for input of binary data from a buffer.
    Subclassed by pdal::BeExtractor, pdal::LeExtractor, pdal::SwitchableExtractor

Public Functions

inline Extractor(const char *buf, std::size_t size)
    Construct an extractor to operate on a buffer.

    Parameters
    • buf – Buffer to extract from.
    • size – Buffer size.

inline operator bool()
    Determine if the buffer is good.

    Returns
    Whether the buffer is good.

inline void seek(std::size_t pos)
    Seek to a position in the buffer.

    Parameters
    pos – Position to seek in buffer.

inline void skip(std::size_t cnt)
    Advance buffer position.

    Parameters
    cnt – Number of bytes to skip in buffer.

inline size_t position() const
    Return the get position of buffer.

    Returns
    Get position.

inline bool good() const
    Determine whether the extractor is good (the get pointer is in the buffer).

    Returns
    Whether the get pointer is valid.
inline void get(std::string &s, size_t size)
   Extract a string of a particular size from the buffer.
   Trim trailing null bytes.

   **Parameters**
   - `s` – String to extract to.
   - `size` – Number of bytes to extract from buffer into string.

inline void get(std::vector<char> &buf)
   Extract data to char vector.
   Vector must be sized to indicate number of bytes to extract.

   **Parameters**
   - `buf` – Vector to which bytes should be extracted.

inline void get(std::vector<unsigned char> &buf)
   Extract data to unsigned char vector.
   Vector must be sized to indicate number of bytes to extract.

   **Parameters**
   - `buf` – Vector to which bytes should be extracted.

inline void get(char *buf, size_t size)
   Extract data into a provided buffer.

   **Parameters**
   - `buf` – Pointer to buffer to which bytes should be extracted.
   - `size` – Number of bytes to extract.

inline void get(unsigned char *buf, size_t size)
   Extract data into a provided unsigned buffer.

   **Parameters**
   - `buf` – Pointer to buffer to which bytes should be extracted.
   - `size` – Number of bytes to extract.

virtual Extractor (page 613) &operator>>(uint8_t &v) = 0
virtual Extractor (page 613) &operator>>(int8_t &v) = 0
virtual Extractor (page 613) &operator>>(uint16_t &v) = 0
virtual Extractor (page 613) &operator>>(int16_t &v) = 0
virtual Extractor (page 613) &operator>>(uint32_t &v) = 0
virtual Extractor (page 613) &operator>>(int32_t &v) = 0
virtual Extractor (page 613) &operator>>(uint64_t &v) = 0
virtual Extractor (page 613) &operator>>(int64_t &v) = 0
virtual Extractor (page 613) &operator>>(float &v) = 0
virtual Extractor (page 613) &operator>>(double &v) = 0

pdal::FileUtils

namespace FileUtils

Functions

std::string toNative(const std::string &in)
std::string fromNative(const std::string &in)
std::istream *openFile(const std::string &filename, bool asBinary = true)
    Open an existing file for reading.
    Parameters
    • filename – Filename.
    • asBinary – Read as binary file (don’t convert /r/n to /n)
    Returns
    Pointer to opened stream.
std::ostream *createFile(const std::string &filename, bool asBinary = true)
    Create/truncate a file and open for writing.
    Parameters
    • filename – Filename.
    • asBinary – Write as binary file (don’t convert /n to /r/n)
    Returns
    Point to opened stream.
std::ostream *openExisting(std::string const &filename, bool asBinary = true)
Open an existing file for write.

**Parameters**
- *filename* – Filename.
- *asBinary* – Write as binary file (don’t convert /n to /r/n)

**Returns**
Point to opened stream.

bool directoryExists(const std::string &dirname)
Determine if a directory exists.

**Parameters**
- *dirname* – Name of directory.

**Returns**
Whether a directory exists.

bool createDirectory(const std::string &dirname)
Create a directory.

**Parameters**
- *dirname* – Directory name.

**Returns**
Whether the directory was created.

bool createDirectories(const std::string &path)
Create all directories in the provided path.

**Parameters**
- *dirname* – Path name.

**Returns**
\false on failure

void deleteDirectory(const std::string &dirname)
Delete a directory and its contents.

**Parameters**
- *dirname* – Directory name.

std::vector<std::string> directoryList(const std::string &dirname)
List the contents of a directory.

**Parameters**
- *dirname* – Name of directory to list.

**Returns**
List of entries in the directory.
void closeFile(std::ostream *ofs)
    Close a file created with createFile.

    Parameters
    ofs – Pointer to stream to close.

void closeFile(std::istream *ifs)
    Close a file created with openFile.

    Parameters
    ifs – Pointer to stream to close.

bool deleteFile(const std::string &filename)
    Delete a file.

    Parameters
    filename – Name of file to delete.

    Returns
    true if successful, false otherwise

void renameFile(const std::string &dest, const std::string &src)
    Rename a file.

    Parameters
    • dest – Desired filename.
    • src – Source filename.

bool fileExists(const std::string &filename)
    Determine if a file exists.

    Parameters
    Filename. –

    Returns
    Whether the file exists.

uintmax_t fileSize(const std::string &filename)
    Get the size of a file.

    Parameters
    filename – Filename.

    Returns
    0 on error or invalid file type.

    Returns
    Size of file.
std::string `readFileIntoString` (const std::string &filename)
Read a file into a string.

**Parameters**
- `filename` – Filename.

**Returns**
File contents as a string

std::string `getcwd`()
Get the current working directory with trailing separator.

**Returns**
The current working directory.

std::string `toCanonicalPath` (std::string filename)
Return the path with all “.”, “..” and symbolic links removed.

The file must exist.

**Parameters**
- `filename` – Name of file to convert to canonical path.

**Returns**
Canonical version of provided filename, or empty string.

std::string `toAbsolutePath` (const std::string &filename)
If the filename is an absolute path, just return it otherwise, make it absolute (relative to current working dir) and return it.

**Parameters**
- `filename` – Name of file to convert to absolute path.

**Returns**
Absolute version of provided filename.

std::string `toAbsolutePath` (const std::string &filename, const std::string base)
If the filename is an absolute path, just return it otherwise, make it absolute (relative to base dir) and return that.

**Parameters**
- `filename` – Name of file to convert to absolute path.
- `base` – Base name to use.

**Returns**
Absolute version of provided filename relative to base.

std::string `getFilename` (const std::string &path)
Return the file component of the given path, e.g.

“d:/foo/bar/a.c” -> “a.c”
Parameters
  path – Path from which to extract file component.

Returns
  File part of path.

std::string getDirectory(const std::string &path)
  Return the directory component of the given path, e.g.
  “d:/foo/bar/a.c” -> “d:/foo/bar/”

Parameters
  path – Path from which to extract directory component.

Returns
  Directory part of path.

std::string stem(const std::string &path)
  Return the filename stripped of the extension.
  . and .. are returned unchanged.

Parameters
  path – File path from which to extract file stem.

Returns
  Stem of filename.

bool isDirectory(const std::string &path)
  Determine if path is a directory.

Parameters
  path – Directory to check.

Returns
  Whether the path represents a directory.

bool isAbsolutePath(const std::string &path)
  Determine if the path is an absolute path.

Parameters
  path – Path to test.

Returns
  Whether the path is absolute.

void fileTimes(const std::string &filename, struct tm *createTime, struct tm *modTime)
  Get the file creation and modification times.

Parameters
  • filename – Filename.
• `createTime` – Pointer to creation time structure.
• `modTime` – Pointer to modification time structure.

`std::string extension(const std::string &path)`
Return the extension of the filename, including the separator (.).

Parameters
- `path` – File path from which to extract extension.

Returns
- Extension of filename.

`std::vector<std::string> glob(const std::string &filespec)`
Expand a filespec to a list of files.

Parameters
- `filespec` – File specification to expand.

Returns
- List of files that correspond to provided file specification.

`MapContext (page 620) mapFile(const std::string &filename, bool readOnly = true, uintmax_t pos = 0, uintmax_t size = 0)`
Map a file to memory.

Parameters
- `filename` – Filename to map.
- `readOnly` – Must be true at this time.
- `pos` – Starting position of file to map.
- `size` – Number of bytes in file to map.

Returns
- `MapContext (page 620)`. `addr()` gets the mapped address. `what()` gets any error message. `addr()` returns `nullptr` on error.

`MapContext (page 620) unmapFile(MapContext (page 620) ctx)`
Unmap a previously mapped file.

Parameters
- `ctx` – Previously returned `MapContext (page 620)`

Returns
- `MapContext (page 620)` indicating current state of the file mapping.

`struct MapContext`

```
#include <FileUtils.hpp>
```
pdal::Filter

class **Filter** : public virtual pdal::Stage (page 639)

Subclassed by pdal::ApproximateCoplanarFilter, pdal::AssignFilter, pdal::CSFilter, pdal::ChipperFilter, pdal::ClusterFilter, pdal::ColorinterpFilter, pdal::ColorizationFilter, pdal::CovarianceFeaturesFilter, pdal::CpdFilter, pdal::CropFilter, pdal::DBSCANFilter, pdal::DEMFilter, pdal::DecimationFilter, pdal::DelaunayFilter, pdal::DividerFilter, pdal::ELMFilter, pdal::EigenvaluesFilter, pdal::EstimateRankFilter, pdal::ExpressionFilter, pdal::FaceRasterFilter, pdal::FarthestPointSamplingFilter, pdal::FerryFilter, pdal::GeomDistanceFilter, pdal::GeoreferenceFilter, pdal::GpsTimeConvert, pdal::GreedyProjection, pdal::GroupByFilter, pdal::HagDelaunayFilter, pdal::HagDemFilter, pdal::HagNnFilter, pdal::HeadFilter, pdal::HexBin, pdal::IQRFilter, pdal::InfoFilter, pdal::IterativeClosestPoint, pdal::LOFFilter, pdal::LiTreeFilter, pdal::LloydKMeansFilter, pdal::LocateFilter, pdal::MADFilter, pdal::MatlabFilter, pdal::MergeFilter, pdal::MiniballFilter, pdal::MongoExpressionFilter, pdal::MortonOrderFilter, pdal::NNDistanceFilter, pdal::NeighborClassifierFilter, pdal::NormalFilter, pdal::OptimalNeighborhood, pdal::OutlierFilter, pdal::OverlayFilter, pdal::PMFFilter, pdal::PlaneFitFilter, pdal::PoissonFilter, pdal::ProjPipelineFilter, pdal::RadialDensityFilter, pdal::RandomizeFilter, pdal::RangeFilter, pdal::ReciprocityFilter, pdal::RelaxationDartThrowing, pdal::ReprojectionFilter, pdal::ReturnsFilter, pdal::SMRFilter, pdal::SampleFilter, pdal::SeparateScanLineFilter, pdal::ShellFilter, pdal::SkewnessBalancingFilter, pdal::SortFilter, pdal::Splitfilter, pdal::StatsFilter, pdal::StraightenFilter, pdal::StreamCallbackFilter, pdal::TailFilter, pdal::TeaserFilter, pdal::Trajectory, pdal::TransformationFilter, pdal::VoxelCenterNearestNeighborFilter, pdal::VoxelCentroidNearestNeighborFilter, pdal::VoxelDownsizeFilter, pdal::ZsmoothFilter

**Public Functions**

**Filter()**

**~Filter()**

Filter (page 621) &**operator=**(const Filter (page 621)&) = delete

Filter (const Filter (page 621)&) = delete

struct **Args**
Public Members

expr::ConditionalExpression m_where

Arg *m_whereArg

Filter (page 621)::WhereMergeMode m_whereMerge

Arg *m_whereMergeArg

pdal::IStream

class IStream
Stream wrapper for input of binary data.
Subclassed by pdal::IBeStream, pdal::ILeStream, pdal::ISwitchableStream

Public Functions

inline IStream()
Default constructor.

inline IStream(const std::string &filename)
Construct an IStream (page 622) from a filename.

Parameters
    filename – File from which to read.

inline IStream(std::istream *stream)
Construct an IStream (page 622) from an input stream pointer.

Parameters
    stream – Stream from which to read.

inline ~IStream()
inline void **close**()  
Close the underlying stream.

inline **operator bool**()  
Return the state of the stream.

**Returns**  
The state of the underlying stream.

inline void **seek**(std::streampos pos)  
Seek to a position in the underlying stream.

**Parameters**  
- **pos** – Position to seek to,

inline void **seek**(std::streampos off, std::ios_base::seekdir way)  
Seek to an offset from a specified position.

**Parameters**  
- **off** – Offset.  
- **way** – Absolute position for offset (beg, end or cur)

inline void **skip**(std::streamoff offset)  
Skip relative to the current position.

**Parameters**  
- **offset** – Offset from the current position.

inline std::streampos **position**() const  
Determine the position of the get pointer.

**Returns**  
Current get position.

inline bool **good**() const  
Determine if the underlying stream is good.

**Returns**  
Whether the underlying stream is good.

inline std::istream **stream**()  
Fetch a pointer to the underlying stream.

**Returns**  
Pointer to the underlying stream.

inline void **pushStream**(std::istream *strm)  
Temporarily push a stream to read from.
Parameters

`strm` – New stream to read from.

```cpp
inline std::istream *popStream()
```

Pop the current stream and return it.

The last stream on the stack cannot be popped.

Returns

Pointer to the popped stream.

```cpp
inline void get(std::string &s, size_t size)
```

Fetch data from the stream into a string.

NOTE - Stops when a null byte is encountered. Use a buffer/vector reader to read data with embedded nulls.

Parameters

- `s` – String to fill.
- `size` – Maximum number of bytes to extract.

```cpp
inline void get(std::vector<char> &buf)
```

Fetch data from the stream into a vector of char.

Parameters

- `buf` – Buffer to fill.

```cpp
inline void get(std::vector<unsigned char> &buf)
```

Fetch data from the stream into a vector of unsigned char.

Parameters

- `buf` – Buffer to fill.

```cpp
inline void get(char *buf, size_t size)
```

Fetch data from the stream into the specified buffer of char.

Parameters

- `buf` – Buffer to fill.
- `size` – Number of bytes to extract.

```cpp
inline void get(unsigned char *buf, size_t size)
```

Fetch data from the stream into the specified buffer of unsigned char.

Parameters

- `buf` – Buffer to fill.
- `size` – Number of bytes to extract.
pdal::Log

class Log

*pdal::Log* (page 625) is a logging object that is provided by *pdal::Stage* (page 639) to facilitate logging operations.

**Log stream operations**

inline std::ostream *getLogStream()

**Returns**
the stream object that is currently being used to for log operations regardless of logging level of the instance.

std::ostream &get(LogLevel level = LogLevel::Info)
Returns the log stream given the logging level.

**Parameters**
level – logging level to request If the logging level asked for with *pdal::Log::get* (page 625) is less than the logging level of the *pdal::Log* (page 625) instance

void floatPrecision(int level)
Sets the floating point precision.

void clearFloat()
Clears the floating point precision settings of the streams.

**Destructor**

~Log()
The destructor will clean up its own internal log stream, but it will not touch one that is given via the constructor.

**Logging level**

inline LogLevel getLevel()

**Returns**
the logging level of the *pdal::Log* (page 625) instance

inline void setLevel(LogLevel v)
Sets the logging level of the *pdal::Log* (page 625) instance.
Parameters

\( v \) – logging level to use for \( \text{get()} \) (page 625) comparison operations

inline void \textbf{setLeader}(\text{const std::string &leader})
Set the leader string (deprecated).

Parameters

\textbf{leader} – [in] Leader string.

inline void \textbf{pushLeader}(\text{const std::string &leader})
Push the leader string onto the stack.

Parameters

\textbf{leader} – Leader string

inline std::string \textbf{leader}() const
Get the leader string.

Returns

The current leader string.

inline void \textbf{popLeader}()
Pop the current leader string.

std::string \textbf{getLevelString}(\text{LogLevel v}) const

Returns

A string representing the LogLevel

Public Static Functions

static LogPtr \textbf{makeLog}((std::string const &leaderString, std::string const &outputName, bool timing = false)

static LogPtr \textbf{makeLog}((std::string const &leaderString, std::ostream *v, bool timing = false)

\textbf{pdal::Metadata}

class \textbf{Metadata}
Public Functions

inline Metadata()
inline Metadata(const std::string &name)
inline MetadataNode (page 627) getNode() const

Public Static Functions

static std::string inferType(const std::string &val)

class MetadataNode

Public Functions

inline MetadataNode()
inline MetadataNode(const std::string &name)
inline MetadataNode (page 627) add(const std::string &name)
inline MetadataNode (page 627) addList(const std::string &name)
inline MetadataNode (page 627) clone(const std::string &name) const
inline MetadataNode (page 627) add(MetadataNode (page 627) node)
inline MetadataNode (page 627) addList(MetadataNode (page 627) node)
inline MetadataNode (page 627) addEncoded(const std::string &name, const unsigned char *buf, size_t size, const std::string &descrip = std::string())
inline MetadataNode (page 627) addListEncoded(const std::string &name, const unsigned char *buf, size_t size, const std::string &descrip = std::string())
inline MetadataNode (page 627) addWithType(const std::string &name, const std::string &value, const std::string &type, const std::string &descrip)
inline `MetadataNode` (page 627) `add` (const std::string &name, const double &value, const std::string &descrip = std::string(), size_t precision = 10)

```cpp
template<typename T>
inline `MetadataNode` (page 627) `add` (const std::string &name, const T &value, const std::string &descrip = std::string())
```

```cpp
template<typename T>
inline `MetadataNode` (page 627) `addList` (const std::string &name, const T &value, const std::string &descrip = std::string())
```

```cpp
inline `MetadataNode` (page 627) `addOrUpdate` (const std::string &lname, const double &value, const std::string &descrip = std::string(), size_t precision = 10)
```
inline std::vector<std::string> childNames() const

inline bool operator bool() const

inline bool operator!() const

inline bool valid() const

inline bool empty() const

template<typename PREDICATE>
inline MetadataNode (page 627) find(PREDICATE) const

template<typename PREDICATE>
inline MetadataNodeList findChildren(PREDICATE) const

template<typename PREDICATE>
inline MetadataNode (page 627) findChild(PREDICATE) const

inline MetadataNode (page 627) findChild(const char *s) const

inline MetadataNode (page 627) findChild(std::string s) const

\texttt{pdal::Options}

class \texttt{Options}

\textbf{Public Functions}

inline \texttt{Options}()

inline explicit \texttt{Options} (const Option &opt)

void \texttt{add} (const Option &option)

void \texttt{add} (const \texttt{Options} (page 629) &options)

void \texttt{addConditional} (const Option &option)

void \texttt{addConditional} (const \texttt{Options} (page 629) &option)

void \texttt{remove} (const Option &option)

inline void \texttt{replace} (const Option &option)

inline void \texttt{toMetadata} (MetadataNode (page 627) &parent) const

template<typename T>
inline void add(const std::string &name, T (page 629) value)
inline void add(const std::string &name, const std::string &value)
inline void add(const std::string &name, const bool &value)

template<typename T>
inline void replace(const std::string &name, T (page 630) value)
inline void replace(const std::string &name, const std::string &value)
inline void replace(const std::string &name, const bool &value)
inline StringList getValues(const std::string &name) const
inline StringList getKeys() const
std::vector<Option> getOptions(std::string const &name = "") const
StringList toCommandLine() const
    Convert options to a string list appropriate for parsing with ProgramArgs (page 634).
    Returns
    List of options as argument strings.

Public Static Functions

static Options (page 629) fromFile(const std::string &filename, bool throwOnOpenError = true)

pdal::PointTable

pdal::PointTable is an alias for pdal::RowPointTable (page 638)

pdal::PointView

class PointView : public pdal::PointContainer
Public Functions

**PointCloud**(const **PointCloud** (page 631)&) = delete

**PointCloud** (page 630) &**operator=**(const **PointCloud** (page 630)&) = delete

**PointCloud**(PointTableRef pointTable)

**PointCloud**(PointTableRef pointTable, const SpatialReference &srs)

virtual ~**PointCloud**()

**PointCloudIter** begin()

**PointCloudIter** end()

inline int id() const

inline point_count_t size() const

inline bool empty() const

inline void appendPoint(const **PointCloud** (page 630) &buffer, PointId id)

inline void append(const **PointCloud** (page 630) &buf)

inline **PointCloud**Ptr makeNew() const

Return a new point view with the same point table as this point buffer.

inline **PointRef** point(PointId id)

template<class **T**>
inline **T** (page 631) **getFieldAs**(Dimension (page 610)::Id dim, PointId pointIndex) const

inline void **getField**(char *pos, Dimension (page 610)::Id d, Dimension (page 610)::Type (page 610) type, PointId id) const

template<typename **T**>
void **setField**(Dimension (page 610)::Id dim, PointId idx, **T** (page 631) val)

inline void **setField**(Dimension (page 610)::Id dim, Dimension (page 610)::Type (page 610) type, PointId idx, const void *val)

template<typename **T**>
inline virtual bool compare(Dimension (page 610)::Id dim, PointId id1, PointId id2) const
inline virtual bool compare(Dimension::Id dim, PointId id1, PointId id2) const

void calculateBounds(BOX2D &box) const
void calculateBounds(BOX3D &box) const
void dump(std::ostream &ostr) const
inline bool hasDim(Dimension::Id id) const
inline std::string dimName(Dimension::Id id) const
inline Dimension::IdList dims() const
inline std::size_t pointSize() const
inline std::size_t dimSize(Dimension::Id id) const
inline Dimension::Type (page 610) dimType(Dimension::Id id) const
inline DimTypeList dimTypes() const
inline virtual PointLayoutPtr layout() const
inline PointTableRef table() const
inline SpatialReference spatialReference() const
inline void getPackedPoint(const DimTypeList &dims, PointId idx, char *buf) const
  Fill a buffer with point data specified by the dimension list.
  Parameters
  • dims – [in] List of dimensions/types to retrieve.
  • idx – [in] Index of point to get.
  • buf – [in] Pointer to buffer to fill.
inline void setPackedPoint(const DimTypeList &dims, PointId idx, const char *buf)
  Load the point buffer from memory whose arrangement is specified by the dimension list.
  Parameters
  • dims – [in] Dimension/types of data in packed order
  • idx – [in] Index of point to write.
  • buf – [in] Packed data buffer.
inline char *getPoint(PointId id)
    Provides access to the memory storing the point data.
    Though this function is public, other access methods are safer and preferred.

inline char *getOrAddPoint(PointId id)
    Provides access to the memory storing the point data.
    Though this function is public, other access methods are safer and preferred.

inline void clearTemps()

_MetadataNode_ (page 627) **toMetadata()** const

void invalidateProducts()

TriangularMesh *createMesh(const std::string &name)
    Creates a mesh with the specified name.

    **Parameters**
    - name – Name of the mesh.

    **Returns**
    Pointer to the new mesh. Null is returned if the mesh already exists.

TriangularMesh *mesh(const std::string &name = "")
    Get a pointer to a mesh.

    **Parameters**
    - name – Name of the mesh.

    **Returns**
    New mesh. Null is returned if the mesh already exists.

Rasterd *createRaster(const std::string &name, const RasterLimits &limits, double noData = 0)
    Creates a raster with the specified name.

    **Parameters**
    - name – Name of the raster.
    - limits – Limits of the raster to create.

    **Returns**
    Pointer to the new raster. Null is returned if the raster already exists.

Rasterd *raster(const std::string &name = "")
    Get a pointer to a raster.

    **Parameters**
    - name – Name of the raster.
Returns
Pointer to the New raster. Null

KD3Index &build3dIndex()

KD2Index &build2dIndex()

template<typename Compare>
inline void stableSort(Compare (page 634) compare)

Friends

friend class plang::Invocation

pdal::ProgramArgs

class ProgramArgs
Parses command lines, provides validation and stores found values in bound variables.
Add arguments with add (page 634). When all arguments have been added, use parse (page 637) to validate command line and assign values to variables bound with add (page 634).

Public Functions

inline Arg &add(const std::string &name, const std::string description, std::string &var,
std::string def)
Add a string argument to the list of arguments.

Parameters

• name – Name of argument. Argument names are specified as “longname[,shortname]”, where shortname is an optional one-character abbreviation.

• description – Description of the argument.

• var – Reference to variable to bind to argument.

• def – Default value of argument.

Returns
Reference to the new argument.
inline Arg &add(const std::string &name, const std::string &description, 
std::vector<std::string> &var)
Add a list-based (vector) string argument.

Parameters

• **name** – Name of argument. Argument names are specified as 
  “longname[,shortname]”, where shortname is an optional 
  one-character abbreviation.

• **description** – Description of the argument.

• **var** – Reference to variable to bind to argument.

Returns
Reference to the new argument.

inline bool set(const std::string &name) const
Return whether the argument (as specified by it’s longname) had its value set during 
parsing.

template<typename T>
inline Arg &add(const std::string &name, const std::string &description, std::vector<T> &var)
Add a list-based (vector) argument.

Parameters

• **name** – Name of argument. Argument names are specified as 
  “longname[,shortname]”, where shortname is an optional 
  one-character abbreviation.

• **description** – Description of the argument.

• **var** – Reference to variable to bind to argument.

Returns
Reference to the new argument.

template<typename T>
inline Arg &add(const std::string &name, const std::string &description, std::vector<T> &var, std::vector<T> def)
Add a list-based (vector) argument with a default.

Parameters

• **name** – Name of argument. Argument names are specified as 
  “longname[,shortname]”, where shortname is an optional 
  one-character abbreviation.

• **description** – Description of the argument.
- **var** – Reference to variable to bind to argument.

**Returns**
Reference to the new argument.

```cpp
template<typename T>
inline Arg & add(const std::string &name, const std::string description, T &var, T def)
```

Add an argument to the list of arguments with a default.

**Parameters**
- **name** – Name of argument. Argument names are specified as “longname[,shortname]”, where shortname is an optional one-character abbreviation.
- **description** – Description of the argument.
- **var** – Reference to variable to bind to argument.
- **def** – Default value of argument.

**Returns**
Reference to the new argument.

```cpp
template<typename T>
inline Arg & add(const std::string &name, const std::string description, T &var)
```

Add an argument to the list of arguments.

**Parameters**
- **name** – Name of argument. Argument names are specified as “longname[,shortname]”, where shortname is an optional one-character abbreviation.
- **description** – Description of the argument.
- **var** – Reference to variable to bind to argument.

**Returns**
Reference to the new argument.

```cpp
inline void parseSimple(std::vector<std::string> &s)
```

Parse a command line as specified by its argument vector.

No validation occurs and only argument value exceptions are raised, but assignments are made to bound variables where possible.

**Parameters**
- **s** – List of strings that constitute the argument list.
inline void `parse` (const std::vector<std::string> &s)

Parse a command line as specified by its argument list.

Parsing validates the argument vector and assigns values to variables bound to added arguments.

**Parameters**

- `s` – List of strings that constitute the argument list.

inline void `addSynonym` (const std::string &name, const std::string &synonym)

Add a synonym for an argument.

**Parameters**

- `name` – Longname of existing argument.
- `synonym` – Synonym for argument.

inline void `reset` ()

Reset the state of all arguments and bound variables as if no parsing had occurred.

inline std::string `commandLine` () const

Return a string suitable for use in a “usage” line for display to users as help.

inline void `dump` (std::ostream &out, size_t indent, size_t totalWidth) const

Write a formatted description of arguments to an output stream.

Write a list of the names and descriptions of arguments suitable for display as help information.

**Parameters**

- `out` – Stream to which output should be written.
- `indent` – Number of characters to indent all text.
- `totalWidth` – Total width to assume for formatting output.

Typically this is the width of a terminal window.

inline void `dump2` (std::ostream &out, size_t nameIndent, size_t descripIndent, size_t totalWidth) const

Write a verbose description of arguments to an output stream.

Each argument is on its own line. The argument’s description follows on subsequent lines.

**Parameters**

- `out` – Stream to which output should be written.
- `nameIndent` – Number of characters to indent argument lines.
- `descripIndent` – Number of characters to indent description lines.
• **totalWidth** – Total line width.

```cpp
inline void dump3(std::ostream &out) const
Write a JSON array of arguments to an output stream.
```

**Parameters**

- **out** – Stream to which output should be written.

`pdal::Reader`

`pdal::Reader` (page 638) are classes that provided interfaces to various the various point cloud formats and hands them off to a PDAL pipeline in a common format that is described via the `pdal::Schema`.

class `Reader` : public virtual `pdal::Stage` (page 639)

Subclassed by `pdal::ArrowReader`, `pdal::BpfReader`, `pdal::BufferReader`, `pdal::CopcReader`, `pdal::DbReader`, `pdal::DracoReader`, `pdal::E57Reader`, `pdal::EptReader`, `pdal::EsriReader`, `pdal::FauxReader`, `pdal::FbiReader`, `pdal::GDALReader`, `pdal::HdfReader`, `pdal::IcebridgeReader`, `pdal::Ilvis2Reader`, `pdal::LasReader`, `pdal::MatlabReader`, `pdal::MbReader`, `pdal::MemoryViewReader`, `pdal::OSGReader`, `pdal::ObjReader`, `pdal::OptechReader`, `pdal::PcdReader`, `pdal::PlyReader`, `pdal::PtsReader`, `pdal::PtxReader`, `pdal::QfitReader`, `pdal::RdbReader`, `pdal::RxpReader`, `pdal::SbetReader`, `pdal::SmrmsgReader`, `pdal::StacReader`, `pdal::TIndexReader`, `pdal::TerrasolidReader`, `pdal::TextReader`, `pdal::TileDBReader`, `pdal::XYZTimeFauxReader`

`pdal::RowPointTable`

class `RowPointTable` : public `pdal::SimplePointTable`

**Public Functions**

```cpp
inline RowPointTable() = default,
virtual ~RowPointTable() = default,
inline virtual bool supportsView() const
```

638 Chapter 14. Development
**pdal::Stage**

`pdal::Stage` (page 639) is the base class of `pdal::Filter` (page 621), `pdal::Reader` (page 638), and `pdal::MultiFilter` classes that implement the reading API in a PDAL pipeline.

class **Stage**

A stage performs the actual processing in PDAL.

Stages may read data, modify or filter read data, create metadata or write processed data.

Stages are linked with `setInput()` (page 639) into a pipeline. The pipeline is run by calling in sequence `prepare()` (page 640) and `execute()` (page 640) on the stage at the end of the pipeline. `PipelineManager` can also be used to create and run a pipeline.

Subclassed by `pdal::Filter` (page 621), `pdal::Reader` (page 638), `pdal::Streamable`, `pdal::Writer` (page 668)

**Public Types**

enum class **WhereMergeMode**

Values:

enumerator **Auto**

enumerator **True**

enumerator **False**

**Public Functions**

`Stage()`

virtual ~`Stage()`

inline void `setInput(Stage` (page 639) &input)

Add a stage to the input list of this stage.

**Parameters**

`input` – `Stage` (page 639) to use as input.
inline void setProgressFd(int fd)
    Set a file descriptor to which progress information should be written.

    **Parameters**
    
    - `fd` – Progress file descriptor.

QuickInfo `preview()`
    Retrieve some basic point information without reading all data when possible.

    Usually implemented only by Readers.

void `prepare(PointTableRef table)`
    Prepare a stage for execution.

    This function needs to be called on the terminal stage of a pipeline (linked set of stages) before `execute` (page 640) can be called. Prepare recurses through all input stages.

    **Parameters**
    
    - `table` – PointTable being used for stage pipeline.

`execute(PointTableRef table)`
    Execute a prepared pipeline (linked set of stages).

    This performs the action associated with the stage by executing the run function of each stage in depth first order. Each stage is run to completion (all points are processed) before the next stages is run.

    **Parameters**
    
    - `table` – Point table being used for stage pipeline. This must be the same table used in the `prepare` (page 640) function.

inline virtual void `execute(StreamPointTable &table)`

inline virtual bool `pipelineStreamable()` const
    Determine if a pipeline with this stage as a sink is streamable.

    **Returns**
    
    Whether the pipeline is streamable.

inline virtual const Stage (page 639) * `findNonstreamable()` const
    Return a pointer to a pipeline’s first non-streamable stage, if one exists.

    **Returns**
    
    `nullptr` if the stage is streamable, a pointer to this stage otherwise.

void `setSpatialReference(SpatialReference const &srs)`
    Set the spatial reference of a stage.

    Set the spatial reference that will override that being carried by the `PointView` (page 630) being processed. This is usually used when reprojecting data to a new
spatial reference. The stage spatial reference will be carried by PointViews
processes by this stage to subsequent stages.

If called by a Reader (page 638) whose spatial reference has been set with option
‘spatialreference’ or ‘override_srs’, then this function will have no effect.

**Parameters**

- srs – Spatial reference to set.

```cpp
const SpatialReference &getSpatialReference() const
```

Get the spatial reference of the stage.

Get the spatial reference that will override that being carried by the PointView
(page 630) being processed. This is usually used when reprojecting data to a new
spatial reference. The stage spatial reference will be carried by PointViews
processes by this stage to subsequent stages.

**Returns**

- The stage’s spatial reference.

```cpp
inline void setOptions(Options (page 629) options)
```

Set a stage’s options.

Set the options on a stage, clearing all previously set options.

**Parameters**

- options – Options (page 629) to set.

```cpp
void addConditionalOptions(const Options (page 629) &opts)
```

Add options if an option with the same name doesn’t already exist on the stage.

**Parameters**

- opts – Options (page 629) to add.

```cpp
void addAllArgs(ProgramArgs (page 634) &args)
```

Add a stage’s options to a ProgramArgs (page 634) set.

**Parameters**

- args – ProgramArgs (page 634) to add to.

```cpp
inline void addOptions(const Options (page 629) &opts)
```

Add options to the existing option set.

**Parameters**

- opts – Options (page 629) to add.

```cpp
inline void removeOptions(const Options (page 629) &opts)
```

Remove options from a stage’s option set.

**Parameters**

- opts – Options (page 629) to remove.
inline void setLog(const LogPtr &log)
    Set the stage’s log.

    Parameters
    log – Log (page 625) pointer.

inline virtual LogPtr log() const
    Return the stage’s log pointer.

    Returns
    Log (page 625) pointer.

void startLogging() const
    Push the stage’s leader into the log.

void stopLogging() const
    Pop the stage’s leader from the log.

inline bool isDebug() const
    Determine whether the stage is in debug mode or not.

    Returns
    The stage’s debug state.

virtual std::string getName() const = 0
    Return the name of a stage.

    Returns
    The stage’s name.

inline void setTag(const std::string &tag)
    Set a specific tag name.

inline virtual std::string tag() const
    Return the tag name of a stage.

    Returns
    The tag name.

inline std::vector<Stage (page 639)*>& getInputs()
    Return a list of the stage’s inputs.

    Returns
    A vector pointers to input stages.

inline MetadataNode (page 627) getMetadata() const
    Get the stage’s metadata node.

    Returns
    Stage (page 639)’s metadata.
void serialize(MetadataNode (page 627) root, PipelineWriter::TagMap &tags) const

Serialize a stage by inserting appropriate data into the provided MetadataNode (page 627).

Used to dump a pipeline specification in a portable format.

**Parameters**

- **root** – Node to which a stage’s metadata should be added.
- **tags** – Pipeline writer’s current list of stage tags.

**Public Static Functions**

static bool parseName(std::string o, std::string::size_type &pos)

Parse a stage name from a string.

Return the name and update the position in the input string to the end of the stage name.

**Parameters**

- **o** – Input string to parse.
- **pos** – Parsing start/end position.

**Returns**

Whether the parsed name is a valid stage name.

static bool parseTagName(std::string o, std::string::size_type &pos)

Parse a tag name from a string.

Return the name and update the position in the input string to the end of the tag name.

**Parameters**

- **o** – Input string to parse.
- **pos** – Parsing start/end position.
- **tag** – Parsed tag name.

**Returns**

Whether the parsed name is a valid tag name.
class StageFactory

This class provides a mechanism for creating Stage objects given a driver name.

Creates stages are owned by the factory and destroyed when the factory is destroyed. Stages can be explicitly destroyed with destroyStage() if desired.

Note: Stage creation is thread-safe.

Public Functions

StageFactory(bool ignored = true)

Create a stage factory.

Parameters

ignored – Ignored argument.

Stage *createStage(const std::string &type)

Create a stage and return a pointer to the created stage.

The factory takes ownership of any successfully created stage.

Parameters

stage_name – Type of stage to by created.

Returns

Pointer to created stage.

void destroyStage(Stage *stage)

Destroy a stage created by this factory.

This doesn’t need to be called unless you specifically want to destroy a stage as all stages are destroyed when the factory is destroyed.

Parameters

stage – Pointer to stage to destroy.
Public Static Functions

static std::string inferReaderDriver(const std::string &filename)
Infer the reader to use based on a filename.
Find the default reader for a file.

Parameters

• filename – Filename that should be analyzed to determine a driver.
• filename – Filename for which to infer a reader.

Returns
Driver name or empty string if no reader can be inferred from the filename.

Returns
Name of the reader driver associated with the file.

static std::string inferWriterDriver(const std::string &filename)
Infer the writer to use based on filename extension.
Find the default writer for a file.

Parameters

filename – Filename for which to infer a writer.

Returns
Driver name or empty string if no writer can be inferred from the filename.

Returns
Name of the writer driver associated with the file.

pdal::Utils

pdal::Utils is a set of utility functions.

namespace Utils
**Typedefs**

using **BacktraceEntries** = std::deque<BacktraceEntry> (page 666)

using **StringStreamClassicLocale** = ClassicLocaleStream (page 668)<std::stringstream>

    Common used streams with classic locale.

using **IStringStreamClassicLocale** = ClassicLocaleStream (page 668)<std::istringstream>

using **OStringStreamClassicLocale** = ClassicLocaleStream (page 668)<std::ostringstream>

**Functions**

std::string **toJSON**(const MetadataNode (page 627) &m)

void **toJSON**(const MetadataNode (page 627) &m, std::ostream &o)

std::string **tempFilename**(const std::string &path)

uintmax_t **fileSize**(const std::string &path)

std::ostream *(const std::string &path, bool asBinary)

    Create a file (may be on a supported remote filesystem).

    **Parameters**

    • **path** – Path to file to create.

    • **asBinary** – Whether the file should be written in binary mode.

    **Returns**

    Pointer to the created stream, or NULL.

bool **isRemote**(const std::string &path)

    Open a file (potentially on a remote filesystem).

    **Parameters**

    • **path** – Path (potentially remote) of file to open.

    • **asBinary** – Whether the file should be opened binary.

    **Returns**

    Pointer to stream opened for input.
std::string fetchRemote(const std::string &path)

std::istream *openFile(const std::string &path, bool asBinary)

void closeFile(std::ostream *out)
   Close an output stream.

   Parameters
   out -- Stream to close.

void closeFile(std::istream *in)
   Close an input stream.

   Parameters
   out -- Stream to close.

bool fileExists(const std::string &path)
   Check to see if a file exists.

   Parameters
   path -- Path to file.

   Returns
   Whether the file exists or not.

double computeHausdorff(PointViewPtr srcView, PointViewPtr candView)

std::pair<double, double> computeHausdorffPair(PointViewPtr viewA, PointViewPtr viewB)

double computeChamfer(PointViewPtr srcView, PointViewPtr candView)

inline void printError(const std::string &s)

inline double toDouble(const Everything &e, Dimension (page 610)::Type (page 610) type)

template<typename INPUT>
inline Everything extractDim(INPUT (page 647) &ext, Dimension (page 610)::Type (page 610) type)

template<typename OUTPUT>
inline void insertDim(OUTPUT (page 647) &ins, Dimension (page 610)::Type (page 610) type, const Everything &e)

inline MetadataNode toMetadata(const BOX2D (page 600) &bounds)

inline MetadataNode toMetadata(const BOX3D (page 604) &bounds)
inline int openProgress(const std::string &filename)
inline void closeProgress(int fd)
inline void writeProgress(int fd, const std::string &type, const std::string &text)

std::vector<std::string> maybeGlob(const std::string &path)

template<> inline StatusWithReason fromString(const std::string &s, Eigen::MatrixXd &matrix)

template<> inline StatusWithReason fromString(const std::string &s, SrsBounds &srsBounds)

template<typename CONTAINER, typename VALUE>
bool contains(const CONTAINER &cont, const VALUE &val)
Determine if a container contains a value.

Parameters

• cont – Container.
• val – Value.

Returns
true if the value is in the container, false otherwise.

template<typename KEY, typename VALUE>
bool contains(const std::map<KEY, VALUE> &c, const KEY &v)
Determine if a map contains a key.

Parameters

• c – Map.
• v – Key value.

Returns
true if the value is in the container, false otherwise.

template<typename CONTAINER, typename VALUE>
void remove(CONTAINER &cont, const VALUE &val)
Remove all instances of a value from a container.

Parameters

• cont – Container.
• v – Value to remove.
template<typename CONTAINER, typename PREDICATE>
void remove_if(CONTAINER (page 648) &cont, PREDICATE (page 648) p)
    Remove all instances matching a unary predicate from a container.

Parameters

- cont – Container.
- p – Predicate indicating whether a value should be removed.

std::vector<std::string> backtrace()
    Generate a backtrace as a list of strings.

Returns
    List of functions at the point of the call.

template<>
inline StatusWithReason (page 667) fromString(const std::string &s, BOX2D (page 600) &bounds)

template<>
inline StatusWithReason (page 667) fromString(const std::string &s, BOX3D (page 604) &bounds)

template<>
inline StatusWithReason (page 667) fromString(const std::string &s, Bounds &bounds)

BacktraceEntries (page 646) backtraceImpl()

template<class T>
const T (page 649) &clamp(const T (page 649) &t, const T (page 649) &minimum, const T (page 649) &maximum)
    Clamp value to given bounds.

Clamps the input value t to bounds specified by min and max. Used to ensure that row and column indices remain within valid bounds.

Parameters

- t – the input value.
- min – the lower bound.
- max – the upper bound.

Returns
    the value to clamped to the given bounds.

void random_seed(unsigned int seed)
    Set a seed for random number generation.
Parameters
seed – Seed value.
double random (double minimum, double maximum)
Generate a random value in the range [minimum, maximum].

Parameters
• minimum – Lower value of range for random number generation.
• maximum – Upper value of range for random number generation.

inline bool compare_approx (double v1, double v2, double tolerance)
Determine if two values are within a particular range of each other.

Parameters
• v1 – First value to compare.
• v2 – Second value to compare.
• tolerance – Maximum difference between v1 and v2

inline double sround (double r)
Round double value to nearest integral value.

Parameters
r – Value to round

Returns
Rounded value

inline std::string tolower (const std::string &s)
Convert a string to lowercase.

Returns
Converted string.

inline std::string toupper (const std::string &s)
Convert a string to uppercase.

Returns
Converted string.

inline bool iequals (const std::string &s, const std::string &s2)
Compare strings in a case-insensitive manner.

Parameters
• s – First string to compare.
• s2 – Second string to compare.
inline bool **startsWith** (const std::string &s, const std::string &prefix)
Determine if a string starts with a particular prefix.

**Parameters**

- **s** – String to check for prefix.
- **prefix** – Prefix to search for.

**Returns**

Whether the string begins with the prefix.

inline bool **endsWith** (const std::string &s, const std::string &postfix)
Determine if a string ends with a particular postfix.

**Parameters**

- **s** – String to check for postfix.
- **postfix** – Postfix to search for.

**Returns**

Whether the string ends with the postfix.

inline int **cksum** (char *buf, size_t size)
Generate a checksum that is the integer sum of the values of the bytes in a buffer.

**Parameters**

- **buf** – Pointer to buffer.
- **size** – Size of buffer.

**Returns**

Generated checksum.

int **getenv** (std::string const &name, std::string &val)
Fetch the value of an environment variable.

**Parameters**

- **name** – Name of environment variable.
- **name** – Value of the environment variable if it exists, empty otherwise.

**Returns**

0 on success, -1 on failure

int **setenv** (const std::string &env, const std::string &val)
Set the value of an environment variable.
Parameters

- **env** – Name of environment variable.
- **val** – Value of environment variable.

Returns

0 on success, -1 on failure

```cpp
int unsetenv(const std::string &env)
```

Clear the value of an environment variable.

Parameters

- **env** – Name of the environment variable to clear.

Returns

0 on success, -1 on failure

```cpp
void eatwhitespace(std::istream &s)
```

Skip stream input until a non-space character is found.

Parameters

- **s** – Stream to process.

```cpp
void trimLeading(std::string &s)
```

Remove whitespace from the beginning of a string.

Parameters

- **s** – String to be trimmed.

```cpp
void trimTrailing(std::string &s)
```

Remove whitespace from the end of a string.

Parameters

- **s** – String to be trimmed.

```cpp
Inline void trim(std::string &s)
```

Remove whitespace from the beginning and end of a string.

Parameters

- **s** – String to be trimmed.

```cpp
bool eatcharacter(std::istream &s, char x)
```

If specified character is at the current stream position, advance the stream position by 1.

Parameters

- **s** – Stream to insect.
- **x** – Character to check for.
Returns
ture if the character is at the current stream position, false otherwise.

std::string base64_encode(const unsigned char *buf, size_t size)
Convert a buffer to a string using base64 encoding.

Parameters
• buf – Pointer to buffer to encode.
• size – Size of buffer.

Returns
Encoded buffer.

inline std::string base64_encode(std::vector<uint8_t> const &bytes)
Convert a buffer to a string using base64 encoding.

Parameters
bytes – Pointer to buffer to encode.

Returns
Encoded buffer.

std::vector<uint8_t> base64_decode(std::string const &input)
Decode a base64-encoded string into a buffer.

Parameters
input – String to decode.

Returns
Buffer containing decoded string.

FILE *portable_popen(const std::string &command, const std::string &mode)
Start a process to run a command and open a pipe to which input can be written and from which output can be read.

Parameters
command – Command to run in subprocess. mode Either ‘r’, ‘w’ or ‘r+’ to specify if the pipe should be opened as read-only, write-only or read-write.

Returns
Pointer to FILE for input/output from the subprocess.

int portable_pclose(FILE *fp)
Close file opened with portable_popen (page 653).

Parameters
fp – Pointer to file to close.
Returns
0 on success, -1 on failure.

int run_shell_command(const std::string &cmd, std::string &output)
Create a subprocess and set the standard output of the command into the provided output string.

Parameters
• cmd – Command to run.
• output – String to which output from the command should be written,

std::string replaceAll(std::string input, const std::string &replaceWhat, const std::string &replaceWithWhat)
Replace all instances of one string found in the input with another value.

Parameters
• input – Input string to modify.
• replaceWhat – Token to locate in input string.
• replaceWithWhat – Replacement for found tokens.

Returns
Modified version of input string.

std::vector<std::string> wordWrap(std::string const &inputString, size_t lineLength,
size_t firstLength = 0)
Break a string into a list of strings to not exceed a specified length.

Whitespace is condensed to a single space and each string is free of whitespace at the beginning and end when possible. Optionally, a line length for the first line can be different from subsequent lines.

Parameters
• inputString – String to split into substrings.
• lineLength – Maximum length of substrings.
• firstLength – When non-zero, the maximum length of the first substring. When zero, the first firstLength is assigned the value provided in lineLength.

Returns
List of substrings generated from the input string.

std::vector<std::string> wordWrap2(std::string const &inputString, size_t lineLength,
size_t firstLength = 0)
Break a string into a list of strings to not exceed a specified length.

The concatenation of the returned substrings will yield the original string. The algorithm attempts to break the original string such that each substring begins with a word.

**Parameters**

- **inputString** – String to split into substrings.
- **lineLength** – Maximum length of substrings.
- **firstLength** – When non-zero, the maximum length of the first substring. When zero, the first firstLength is assigned the value provided in lineLength.

**Returns**

List of substrings generated from the input string.

```cpp
std::string escapeJSON(const std::string &s)
```

Add escape characters or otherwise transform an input string so as to be a valid JSON string.

**Parameters**

- **s** – Input string.

**Returns**

Valid JSON version of input string.

```cpp
std::string demangle(const std::string &s)
```

Demangle a C++ symbol into readable form.

Demangle strings using the compiler-provided demangle function.

**Parameters**

- **s** – String to demangle.

**Returns**

Demangled symbol.

```cpp
int screenWidth()
```

Return the screen width of an associated tty.

**Returns**

The tty screen width or 80 if on Windows or it can’t be determined.
std::string escapeNonprinting(const std::string &s)

Escape non-printing characters by using standard notation (i.e. ) or hex notation (\x10) as as necessary.

**Parameters**
- **s** – String to modify.

**Returns**
Copy of input string with non-printing characters converted to printable notation.

double normalizeLongitude(double longitude)

Normalize longitude so that it’s between (-180, 180].

**Parameters**
- **longitude** – Longitude to normalize.

**Returns**
Normalized longitude.

template<typename PREDICATE>
std::string::size_type extract(const std::string &s, std::string::size_type p, PREDICATE pred)

Count the number of characters in a string that meet a predicate.

**Parameters**
- **s** – String in which to start counting characters.
- **p** – Position in input string at which to start counting.
- **pred** – Unary predicate that tests a character.

**Returns**
Then number of characters matching the predicate.

inline std::string::size_type extractSpaces(const std::string &s, std::string::size_type p)

Count the number of characters spaces in a string at a position.

**Parameters**
- **s** – String in which to start counting characters.
- **p** – Position in input string at which to start counting.

**Returns**
Then number of space-y characters matching the predicate.
std::vector<std::string> split(const std::string &s, PREDICATE (page 656) p)
Split a string into substrings based on a predicate.
Characters matching the predicate are discarded.

**Parameters**
- **s** – String to split.
- **p** – Unary predicate that returns true to indicate that a character is a split location.

**Returns**
Substrings.

template<typename PREDICATE>
std::vector<std::string> split2(const std::string &s, PREDICATE (page 657) p)
Split a string into substrings.
Characters matching the predicate are discarded, as are empty strings otherwise produced by *split* (page 657).

**Parameters**
- **s** – String to split.
- **p** – Predicate returns true if a char in a string is a split location.

**Returns**
Vector of substrings.

inline std::vector<std::string> split(const std::string &s, char tChar)
Split a string into substrings based a splitting character.
The splitting characters are discarded.

**Parameters**
- **s** – String to split.
- **p** – Character indicating split positions.

**Returns**
Substrings.

inline std::vector<std::string> split2(const std::string &s, char tChar)
Split a string into substrings based a splitting character.
The splitting characters are discarded as are empty strings otherwise produced by *split* (page 657).

**Parameters**
- **s** – String to split.
• p – Character indicating split positions.

**Returns**

Substrings.

`std::vector<std::string> simpleWordexp(const std::string &s)`

Perform shell-style word expansion (break a string into arguments).

This only does simple handling of quoted values and backslashes and doesn’t support fancier shell behavior. Use the real `wordexp()` if you need all that. The behavior of escaped values in a string was surprising to me, so try the shell first if you think you’ve found a problem.

**Parameters**

- s – Input string to parse.

**Returns**

List of arguments.

`template<typename T> std::string typeidName()`

Return a string representation of a type specified by the template argument.

**Returns**

String representation of the type.

`inline RedirectStream redirect(std::ostream &out, std::ostream &dst)`

Redirect a stream to some other stream, by default a null stream.

**Parameters**

- out – Stream to redirect.
- dst – Destination stream.

**Returns**

Context for stream restoration (see `restore()` (page 659)).

`inline RedirectStream redirect(std::ostream &out)`

Redirect a stream to a null stream.

**Parameters**

- out – Stream to redirect.

**Returns**

Context for stream restoration (see `restore()` (page 659)).

`inline RedirectStream redirect(std::ostream &out, const std::string &file)`

Redirect a stream to some file.

**Parameters**

- out – Stream to redirect.
• **file** – Name of file where stream should be redirected.

**Returns**
Context for stream restoration (see `restore()` (page 659)).

```cpp
inline void restore(std::ostream &out, RedirectStream &redir)
```
Restore a stream redirected with `redirect()` (page 658).

**Parameters**
- **out** – Stream to be restored.
- **redir** – `RedirectStream` (page 667) returned from corresponding `redirect()` (page 658) call.

```cpp
template<typename T_OUT>
bool inRange(double in)
```
Determine whether a double value may be safely converted to the given output type without over/underflow.

If the output type is integral the input will be rounded before being tested.

**Parameters**
in – Value to range test.

**Returns**
Whether value can be safely converted to template type.

```cpp
template<typename T_IN, typename T_OUT>
bool inRange(T_IN in)
```
Determine whether a value may be safely converted to the given output type without over/underflow.

If the output type is integral and different from the input type, the value will be rounded before being tested.

**Parameters**
in – Value to range test.

**Returns**
Whether value can be safely converted to template type.

```cpp
template<typename T_IN, typename T_OUT>
bool numericCast(T_IN in, T_OUT &out)
```
Convert a numeric value from one type to another.

Floating point values are rounded to the nearest integer before a conversion is attempted.

**Parameters**
- **in** – Value to convert.
• **out** – Converted value.

**Returns**
true if the conversion was successful, false if the datatypes/input value don’t allow conversion.

```cpp
template<>
inline bool numericCast(double in, float &out)
Convert a numeric value from double to float.
Specialization to handle NaN.

**Parameters**
• **in** – Value to convert.
• **out** – Converted value.

**Returns**
true if the conversion was successful, false if the datatypes/input value don’t allow conversion.
```

```cpp
template<typename T>
std::string toString(const T &from)
Convert a value to its string representation by writing to a stringstream.

**Parameters**
from – Value to convert.

**Returns**
String representation.
```

```cpp
inline std::string toString(bool from)
Convert a bool to a string.

inline std::string toString(double from, size_t precision = 10)
Convert a double to string with a precision of 10 decimal places.

**Parameters**
from – Value to convert.

**Returns**
String representation of numeric value.
```

```cpp
inline std::string toString(float from)
Convert a float to string with a precision of 10 decimal places.

**Parameters**
from – Value to convert.

**Returns**
String representation of numeric value.
inline std::string toString(long long from)
    Convert a long long int to string.

    Parameters
    from – Value to convert.

    Returns
    String representation of numeric value.

inline std::string toString(unsigned long from)
    Convert an unsigned long long int to string.

    Parameters
    from – Value to convert.

    Returns
    String representation of numeric value.

inline std::string toString(long from)
    Convert a long int to string.

    Parameters
    from – Value to convert.

    Returns
    String representation of numeric value.

inline std::string toString(unsigned int from)
    Convert an unsigned int to string.

    Parameters
    from – Value to convert.

    Returns
    String representation of numeric value.

inline std::string toString(int from)
    Convert an int to string.

    Parameters
    from – Value to convert.

    Returns
    String representation of numeric value.

inline std::string toString(unsigned short from)
    Convert an unsigned short to string.

    Parameters
    from – Value to convert.
PDAL: Point cloud Data Abstraction Library, Release 2.6.2

Returns
String representation of numeric value.

inline std::string toString(short from)
Convert a short int to string.

Parameters
from – Value to convert.

Returns
String representation of numeric value.
inline std::string toString(char from)
Convert a char (treated as numeric) to string.

Parameters
from – Value to convert.

Returns
String representation of numeric value.
inline std::string toString(unsigned char from)
Convert an unsigned char (treated as numeric) to string.

Parameters
from – Value to convert.

Returns
String representation of numeric value.
inline std::string toString(signed char from)
Convert a signed char (treated as numeric) to string.

Parameters
from – Value to convert.

Returns
String representation of numeric value.

template<typename T>
StatusWithReason fromString(const std::string &from, T *to)

Convert a string to a non-integral value by reading from a string stream.

Parameters
• from – String to convert.
• **to** – Converted value.

**Returns**

*true* if the conversion was successful, *false* otherwise.

```cpp
template<>
inline StatusWithReason fromString(const std::string &from, std::string &to)
```

```cpp
template<>
inline StatusWithReason fromString(const std::string &s, char &to)
```

Convert a numeric string to a char numeric value.

**Parameters**

- to – Converted numeric value.

**Returns**

*true* if the conversion was successful, *false* otherwise.

```cpp
template<>
inline StatusWithReason fromString(const std::string &s, unsigned char &to)
```

Convert a numeric string to an unsigned char numeric value.

**Parameters**

- to – Converted numeric value.

**Returns**

*true* if the conversion was successful, *false* otherwise.

```cpp
template<>
inline StatusWithReason fromString(const std::string &s, signed char &to)
```

Convert a numeric string to a signed char numeric value.

**Parameters**

- to – Converted numeric value.

**Returns**

*true* if the conversion was successful, *false* otherwise.

```cpp
template<>
inline StatusWithReason fromString(const std::string &s, double &d)
```

Specialization conversion from string to double to handle *Nan*.

**Parameters**
• \textbf{s} – String to be converted.
• \textbf{d} – Converted value.

\textbf{Returns}
\begin{itemize}
  \item true if the conversion was successful, false otherwise.
\end{itemize}

\texttt{template<typename \textbf{E}>
std::underlying\textunderscore type<\texttt{E} (page 664)>::type \texttt{toNative}(\texttt{E} (page 664) \texttt{e})
\hspace{1cm} Return the argument cast to its underlying type.
\hspace{1cm} Typically used on an enum.

\textbf{Parameters}
\begin{itemize}
  \item \texttt{e} – Variable for which to find the underlying type.
\end{itemize}

\textbf{Returns}
\begin{itemize}
  \item Converted variable.
\end{itemize}

\texttt{template<>}
\texttt{inline StatusWithReason (page 667) \texttt{fromString}(const std::string &from, pdal::expr::AssignStatement &stmt)}

\texttt{template<>}
\texttt{inline StatusWithReason (page 667) \texttt{fromString}(const std::string &from, pdal::expr::ConditionalExpression &expr)}

\texttt{template<>}
\texttt{StatusWithReason (page 667) \texttt{fromString}(const std::string &from, SrsOrderSpec &srsOrder)}

\texttt{template<>}
\texttt{std::string \texttt{toString}(const SrsOrderSpec &srsOrder)}

\texttt{template<size_t LEN>}
\texttt{inline StatusWithReason (page 667) \texttt{fromString}(const std::string &from, StringHeaderVal<LEN (page 664)> &h)}

\texttt{template<>}
\texttt{inline StatusWithReason (page 667) \texttt{fromString}(const std::string &from, pdal::i3s::Obb &obb)}
Variables

const char dynamicLibExtension[] = ".so"

const char dirSeparator = '/'

const char pathListSeparator = ':'

class TempFile

Public Functions

inline TempFile(const std::string path)

inline virtual ~TempFile()

inline const std::string &filename()

class ArbiterOutStream : public std::ofstream

Public Functions

inline ArbiterOutStream(const std::string &localPath, const std::string &remotePath, std::ios::openmode mode)

inline virtual ~ArbiterOutStream()

Public Members

std::string m_remotePath

TempFile (page 665) m_localFile

class ArbiterInStream : public std::ifstream
**Public Functions**

inline `ArbiterInStream` (const std::string &localPath, const std::string &remotePath, std::ios::openmode mode)

**Public Members**

`TempFile` (page 665) `m_localFile`

struct `BacktraceEntry`

#include `<BacktraceImpl.hpp>`

**Public Functions**

inline `BacktraceEntry` ()

**Public Members**

std::string `libname`

void *`addr`

std::string `symname`

int `offset`

class `Random`

#include `<Random.hpp>`

**Public Functions**

`Random` ()

`Random`(int32_t seed)

`Random`(const std::vector<int32_t> seed)
Random(const std::string &seed)
std::mt19937 &generator()

Public Static Functions

static unsigned int quick()

class StatusWithReason
#include <Utils.hpp>

Public Functions

inline StatusWithReason()
inline StatusWithReason(bool ok)
StatusWithReason(int code) = delete
inline StatusWithReason(int code, const std::string &what)
inline int code() const
inline operator bool() const
inline std::string what() const

struct RedirectStream
#include <Utils.hpp>

Public Functions

inline RedirectStream()

Public Members

std::ofstream *m_out

std::streambuf *m_buf
std::unique_ptr<NullOStream> m_null

template<typename T>
struct ClassicLocaleStream : public T (page 668)

#include <Utils.hpp> Wrapper around a stream to be sure that uses classic locale.

Use it instead of a std::*stream on any stream that reads or writes numbers. It prevents problems due to locale global changes done in the application that uses PDAL.

Public Functions

template<typename ...Args>
inline ClassicLocaleStream(Args (page 668)&&... args)

pdal::Writer

class Writer : public virtual pdal::Stage (page 639)

A Writer (page 668) is a terminal stage for a PDAL pipeline.

It usually writes output to a file, but this isn’t a requirement. The class provides support for some operations common for producing point output.

Subclassed by pdal::ArrowWriter, pdal::CopcWriter, pdal::DbWriter, pdal::DracoWriter, pdal::E57Writer, pdal::EptAddonWriter, pdal::FbiWriter, pdal::FlexWriter, pdal::GltfWriter, pdal::MatlabWriter, pdal::NullWriter, pdal::PcdWriter, pdal::RasterWriter, pdal::SbetWriter, pdal::TextWriter, pdal::TileDBWriter

14.3.2 libLAS C API to PDAL transition guide

Author
Vaclav Petras

Contact
wenzeslaus@gmail.com

Date
09/04/2015

This page shows how to port code using libLAS C API to PDAL API (which is C++). The new code is not using full power of PDAL but it uses just what is necessary to read content of a LAS file.
Includes

libLAS include:

```cpp
#include <liblas/capi/liblas.h>
```

For PDAL, in addition to PDAL headers, we also include standard headers which will be useful later:

```cpp
#include <memory>
#include <pdal/PointTable.hpp>
#include <pdal/PointView.hpp>
#include <pdal/LasReader.hpp>
#include <pdal/LasHeader.hpp>
#include <pdal/Options.hpp>
```

Initial steps

Opening the dataset in libLAS:

```cpp
LASReaderH LAS_reader;
LASHeaderH LAS_header;
LASSRSH LAS_srs;
LAS_reader = LASReader_Create(in_opt->answer);
LAS_header = LASReader_GetHeader(LAS_reader);
```

The higher level of abstraction in PDAL requires a little bit more code for the initial steps:

```cpp
pdal::Option las_opt("filename", in_opt->answer);
pdal::Options las_opts;
las_opts.add(las_opt);
pdal::PointTable table;
pdal::LasReader las_reader;
las_reader.setOptions(las_opts);
las_reader.prepare(table);
pdal::PointSize point_view_set = las_reader.execute(table);
pdal::PointViewPtr point_view = *point_view_set.begin();
pdal::Dimension::IdList dims = point_view->dims();
pdal::LasHeader las_header = las_reader.header();
```

The PDAL code is also different in the way that we read all the data right away while in libLAS we just open the file. To make use of other readers supported by PDAL, see StageFactory class.

The test if the file was loaded successfully, the test of the header pointer was used with libLAS:

14.3. API
if (LAS_header == NULL) {
    /* fail */
}

In general, PDAL will throw a pdal_error exception in case something is wrong and it can’t recover such in the case when the file can’t be opened. To handle the exceptional state by yourself, you can wrap the code in try-catch block:

try {
    /* actual code */
} catch {
    /* fail in your own way */
}

Dataset properties

We assume we defined all the following variables as double.

The general properties from the LAS file are retrieved from the header in libLAS:

scale_x = LASHeader_GetScaleX(LAS_header);
scale_y = LASHeader_GetScaleY(LAS_header);
scale_z = LASHeader_GetScaleZ(LAS_header);

offset_x = LASHeader_GetOffsetX(LAS_header);
offset_y = LASHeader_GetOffsetY(LAS_header);
offset_z = LASHeader_GetOffsetZ(LAS_header);

xmin = LASHeader_GetMinX(LAS_header);
xmax = LASHeader_GetMaxX(LAS_header);
ymin = LASHeader_GetMinY(LAS_header);
ymax = LASHeader_GetMaxY(LAS_header);

And the same applies PDAL:

scale_x = las_header.scaleX();
scale_y = las_header.scaleY();
scale_z = las_header.scaleZ();

offset_x = las_header.offsetX();
offset_y = las_header.offsetY();
offset_z = las_header.offsetZ();

(continues on next page)
The point record count in libLAS:

```c
unsigned int n_features = LASHeader_GetPointRecordsCount(LAS_header);
```

is just point count in PDAL:

```c
unsigned int n_features = las_header.pointCount();
```

WKT of a spatial reference system is obtained from the header in libLAS:

```c
LAS_srs = LASHeader_GetSRS(LAS_header);
char* projstr = LASSRS_GetWKT_CompoundOK(LAS_srs);
```

In PDAL, spatial reference is part of the `PointTable`:

```c
char* projstr = table.spatialRef().
    ->getWKT(pdal::SpatialReference::eCompoundOK).c_str();
```

Whether the time or color is supported by the LAS format, one would have to determine from the format ID in libLAS:

```c
las_point_format = LASHeader_GetDataFormatId(LAS_header);
have_time = (las_point_format == 1 ...)
```

In PDAL, there is a convenient function for it in the header:

```c
have_time = las_header.hasTime();
have_color = las_header.hasColor();
```

The presence of color, time and other dimensions can be also determined with:

```c
pdal::Dimension::IdList dims = point_view->dims();
```
Iterating over points

libLAS:

```c
while ((LAS_point = LASReader_GetNextPoint(LAS_reader)) != NULL) {
    // ...
}
```

PDAL:

```c
for (pdal::PointId idx = 0; idx < point_view->size(); ++idx) {
    // ...
}
```

Point validity

The correct usage of libLAS required to test point validity:

```c
LASPoint_IsValid(LAS_point)
```

In PDAL, there is no need to do that and the caller can assume that all the points provided by PDAL are valid.

Coordinates

libLAS:

```c
x = LASPoint_GetX(LAS_point);
y = LASPoint_GetY(LAS_point);
z = LASPoint_GetZ(LAS_point);
```

In PDAL, point coordinates are one of the dimensions:

```c
using namespace pdal::Dimension;
x = point_view->getFieldAs<double>(Id::X, idx);
y = point_view->getFieldAs<double>(Id::Y, idx);
z = point_view->getFieldAs<double>(Id::Z, idx);
```

Thanks to using `namespace pdal::Dimension` we can just write `Id::X` etc.
**Returns**

**libLAS:**

```c
int return_no = LASPoint_GetReturnNumber(LAS_point);
int n_returns = LASPoint_GetNumberOfReturns(LAS_point);
```

**PDAL:**

```c
int return_no = point_view->getFieldAs<int>(Id::ReturnNumber, idx);
int n_returns = point_view->getFieldAs<int>(Id::NumberOfReturns, idx);
```

**Classes**

**libLAS:**

```c
int point_class = (int) LASPoint_GetClassification(LAS_point);
```

**PDAL:**

```c
int point_class = point_view->getFieldAs<int>(Id::Classification, idx);
```

**Color**

**libLAS:**

```c
LASColorH LAS_color = LASPoint_GetColor(LAS_point);
int red = LASColor_GetRed(LAS_color);
int green = LASColor_GetGreen(LAS_color);
int blue = LASColor_GetBlue(LAS_color);
```

**PDAL:**

```c
int red = point_view->getFieldAs<int>(Id::Red, idx);
int green = point_view->getFieldAs<int>(Id::Green, idx);
int blue = point_view->getFieldAs<int>(Id::Blue, idx);
```

For LAS format, hasColor() method of LasHeader to see if the format supports RGB. However, in general, you can test use hasDim(Id::Red), hasDim(Id::Green) and hasDim(Id::Blue) method calls on the point, to see if the color was defined.
Time

libLAS:

```c
double time = LASPoint_GetTime(LAS_point);
```

PDAL:

```c
double time = point_view->getFieldAs<double>(Id::GpsTime, idx);
```

Other point attributes

libLAS:

```c
LASPoint_GetIntensity(LAS_point)
LASPoint_GetScanDirection(LAS_point)
LASPoint_GetFlightLineEdge(LAS_point)
LASPoint_GetScanAngleRank(LAS_point)
LASPoint_GetPointSourceId(LAS_point)
LASPoint_GetUserData(LAS_point)
```

PDAL:

```c
point_view->getFieldAs<int>(Id::Intensity, idx)
point_view->getFieldAs<int>(Id::ScanDirectionFlag, idx)
point_view->getFieldAs<int>(Id::EdgeOfFlightLine, idx)
point_view->getFieldAs<int>(Id::ScanAngleRank, idx)
point_view->getFieldAs<int>(Id::PointSourceId, idx)
point_view->getFieldAs<int>(Id::UserData, idx)
```

Memory management

In libLAS C API, we need to explicitly take care of freeing the memory:

```c
LASSRS_Destroy(LAS_srs);
LASHeader_Destroy(LAS_header);
LASReader_Destroy(LAS_reader);
```

When using C++ and PDAL, the objects created on stack free the memory when they go out of scope. When using smart pointers, they will take care of the memory they manage. This does not apply to special cases such as `exit()` function calls.
14.4 FAQ

- Why do I get the error Couldn't create ... stage of type ...?

In almost all cases this error occurs because you're trying to run a stage that is built as a plugin and the plugin (a shared library file or DLL) can't be found by pdal. You can verify whether the plugin can be found by running `pdal --drivers`.

If you've built pdal yourself, make sure you've requested to build the plugin in question (set BUILD_PLUGIN_TILEDB=ON, for example, in CMakeCache.txt).

If you've successfully built the plugin, a shared object called `libpdal_plugin_<plugin type>_<plugin name>_<shared library extension>` should have been created that’s installed in a location where pdal can find it. pdal will search the following paths for plugins: `.../lib, .../lib, ./bin, .../bin`.

You can also override the default search path by setting the environment variable PDAL_DRIVER_PATH to a list of directories that pdal should search for plugins.

- I'm missing the python filter/numpy reader. Where is it?

If you're building PDAL from source, you'll find the python filter and numpy reader in a separate repository, https://github.com/PDAL/python-plugins. If you're using a package, Python support may be in a separate package, often called “python-pdal”.

- Why do I get the error Unable to convert scaled value ...

This error usually occurs when writing LAS files, but can occur with other formats.

Simply, the output format you’ve chosen doesn’t support values as large (or small) as those that you’re trying to write. For example, if the output format specifies 32-bit signed integers, attempting to write a value larger than 2,147,483,647 will cause this error, as 2,147,483,647 is the largest 32-bit signed integer.

The LAS format always stores X, Y and Z values as 32-bit integers. You can specify a scale factor to be applied to those values in order to change their magnitude, but their precision is limited to 32 bits. If the value you’re attempting to write, when divided by the scale factor you’ve specified, is larger than 2,147,483,647, you will get this error. For example, if you attempt to write the value 6 with a scale factor of .000000001, you’ll get this error, as 6 / .000000001 is 6,000,000,000, which is larger than the maximum integer value.

- Why am I using 100GB of memory when trying to process a 10GB LAZ file?
If you’re performing an operation that is using *standard mode* (page 58), PDAL will read all points into memory at once. Compressed files, like LAZ, can decompress to much larger sizes before PDAL can process the data. Furthermore, some operations (notably *DEM creation* (page 156)) can use large amounts of additional memory during processing before the output can be written. Depending on the operation, PDAL will attempt operate in *stream mode* (page 58) to limit memory consumption when possible. If you want to limit the dimensions loaded, you may be able to use the `dims` option that is available with some PDAL commands.

**How do you pronounce PDAL?**

The proper spelling of the project name is PDAL, in uppercase. It is pronounced to rhyme with “GDAL”.

**What is PDAL?**

PDAL is not a workflow engine for processing point cloud data. PDAL is a library for making point cloud processing workflow engines.

**What is PDAL’s relationship to PCL?**

PDAL is PCL’s data translation cousin. PDAL is focused on providing a declarative pipeline syntax for orchestrating translation operations. PDAL also supports reading and writing PCL PCD files using `readers.pcd` (page 105) and `writers.pcd` (page 173).

**See also:**

*PCL* (page 7) describes PDAL and PCL’s relationship.

**What is PDAL’s relationship to libLAS?**

The idea behind libLAS was limited to LIDAR data and basic manipulation. libLAS was also trying to be partially compatible with LASlib and LAStools. PDAL, on the other hand, aims to be a ultimate library and a set of tools for manipulating and processing point clouds and is easily extensible by its users. Howard Butler talked more about this history in a GeoHipster interview (http://geohipster.com/2018/03/05/howard-butler-like-good-song-open-source-software-chance-immortal/) in 2018.

**Are there any command line tools in PDAL similar to LAStools?**

Yes. The `pdal` (page 27) command provides a wide range of features which go far beyond basic LIDAR data processing. Additionally, PDAL is licensed under an open source license (this applies to the whole library and all command line tools).
See also:

*Applications* (page 27) describes application operations you can achieve with PDAL.

- Is there any compatibility with libLAS’s LAS Utility Applications or LAStools?

  No. The command line interface was developed from scratch with focus on usability and readability. You will find that the *pdal* command has several well-organized subcommands such as *info* or *translate* (see *Applications* (page 27)).

- I get GeoTIFF errors. What can I do about them?

  ```
  (readers.las Error) Geotiff directory contains key 0 with short entry and more than one value.
  ```

  If *readers.las* (page 89) is emitting error messages about GeoTIFF, this means the keys that were written into your file were incorrect or at least not readable by *libgeotiff* (https://trac.osgeo.org/geotif). Rewrite the file using PDAL to fix the issue:

  ```
  pdal translate badfile.las goodfile.las --writers.las.forward=all
  ```

14.5 License

Unless otherwise indicated, all files in the PDAL distribution are

Copyright (c) 2022, Hobu, Inc. ([howard@hobu.co](mailto:howard@hobu.co))

and are released under the terms of the BSD open source license.

This file contains the license terms of all files within PDAL.

14.5.1 Overall PDAL license (BSD)

Copyright (c) 2022, Hobu, Inc. ([howard@hobu.co](mailto:howard@hobu.co))

All rights reserved.

Redistribution and use in source and binary forms, with or without modification, are permitted provided that the following conditions are met:

- Redistributions of source code must retain the above copyright notice, this list of conditions and the following disclaimer.
• Redistributions in binary form must reproduce the above copyright notice, this list of conditions and the following disclaimer in the documentation and/or other materials provided with the distribution.

• Neither the name of Hobu, Inc. or Flaxen Consulting LLC nor the names of its contributors may be used to endorse or promote products derived from this software without specific prior written permission.

THIS SOFTWARE IS PROVIDED BY THE COPYRIGHT HOLDERS AND CONTRIBUTORS “AS IS” AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL THE COPYRIGHT OWNER OR CONTRIBUTORS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

14.6 References

14.6.1 Citation

To cite PDAL in publications use:

PDAL Contributors, 2022. PDAL Point Data Abstraction Library. 
https://doi.org/10.5281/zenodo.2616780

A BibTeX entry for LaTeX users is

@misc{pdal_contributors_2022_2616780,
    author = {PDAL Contributors},
    title = {PDAL Point Data Abstraction Library},
    month = aug,
    year = 2022,
    doi = {10.5281/zenodo.2616780},
    url = {https://doi.org/10.5281/zenodo.2616780}
}

A paper about PDAL by the team, “PDAL: An open source library for the processing and analysis of point clouds”, is available at [Butler2021].
INDICES AND TABLES

- genindex
- search
BIBLIOGRAPHY


INDEX

A
Apps, 11

B
Bindings, 373
boundary, 453

C
capstone, 515
Citation, 678
classification, 481, 491, 495
classifications, 469
Clipping, 456
CloudCompare, 8
Colorization, 463
Command line, 11
Compile, 377
Conda, 19, 371, 432
coordinate system, 440
csd, 509
CSV, 439

D
Denoising, 467
Density, 471
density, 477
DSM, 484
DTM, 484

E
elevation model, 484
Embed, 369
Entwine, 8
EPT, 450
Extension, 370

F
filtering, 481, 491
Fusion, 8

G
GDAL, 463
georeferencing, 428, 509
GNSS/IMU, 428, 509
ground, 481, 491

H
hexagon tessellation, 471
histogram, 509

I
info command, 438
Install, 371, 376
installation, 438
intensity, 495

J
Java, 373, 376, 377
JNI, 373
JSON, 439
Julia, 12

L
LAStools, 7
libLAS, 8

M
matplotlib, 509
metadata, 440

N
nearby, 443
PDAL: Point cloud Data Abstraction Library, Release 2.6.2

nearest, 443
Numpy, 12, 369, 509
O
OGR, 453, 456, 471
Optech, 509
OrfeoToolbox, 8
outliers, 467
P
PCL, 7
pdal::BOX2D (C++ class), 600
pdal::BOX2D::BOX2D (C++ function), 600
pdal::BOX2D::clear (C++ function), 601
pdal::BOX2D::clip (C++ function), 602
pdal::BOX2D::contains (C++ function), 601, 602
pdal::BOX2D::empty (C++ function), 600
pdal::BOX2D::equal (C++ function), 601
pdal::BOX2D::error (C++ struct), 604
pdal::BOX2D::error::error (C++ function), 604
pdal::BOX2D::getDefaultSpatialExtent (C++ function), 604
pdal::BOX2D::grow (C++ function), 601, 602
pdal::BOX2D::maxx (C++ member), 603
pdal::BOX2D::maxy (C++ member), 603
pdal::BOX2D::minx (C++ member), 603
pdal::BOX2D::miny (C++ member), 603
pdal::BOX2D::operator!=(C++ function), 602
pdal::BOX2D::operator==(C++ function), 601
pdal::BOX2D::overlaps (C++ function), 602
pdal::BOX2D::parse (C++ function), 603
pdal::BOX2D::toBox (C++ function), 602
pdal::BOX2D::toGeoJSON (C++ function), 603
pdal::BOX2D::toWKT (C++ function), 603
pdal::BOX2D::valid (C++ function), 600
pdal::BOX2D::wkt (C++ member), 603
pdal::BOX3D (C++ class), 604
pdal::BOX3D::BOX3D (C++ function), 604
pdal::BOX3D::clear (C++ function), 605
pdal::BOX3D::clip (C++ function), 606
pdal::BOX3D::contains (C++ function), 605
pdal::BOX3D::empty (C++ function), 605
pdal::BOX3D::equal (C++ function), 606
pdal::BOX3D::error (C++ struct), 608
pdal::BOX3D::error::error (C++ function), 609
pdal::BOX3D::getDefaultSpatialExtent (C++ function), 608
pdal::BOX3D::grow (C++ function), 605, 606
pdal::BOX3D::maxx (C++ member), 608
pdal::BOX3D::maxy (C++ member), 608
pdal::BOX3D::maxz (C++ member), 608
pdal::BOX3D::minx (C++ member), 608
pdal::BOX3D::miny (C++ member), 608
pdal::BOX3D::minz (C++ member), 608
pdal::BOX3D::operator!=(C++ function), 606
pdal::BOX3D::operator==(C++ function), 604
pdal::BOX3D::operator==(C++ function), 606
pdal::BOX3D::overlaps (C++ function), 607
pdal::BOX3D::parse (C++ function), 607
pdal::BOX3D::to2d (C++ function), 607
pdal::BOX3D::toBox (C++ function), 607
pdal::BOX3D::toWKT (C++ function), 607
pdal::BOX3D::valid (C++ function), 605
pdal::BOX3D::wkt (C++ member), 608
pdal::Charbuf (C++ class), 609
pdal::Charbuf::Charbuf (C++ function), 609
pdal::Charbuf::initialize (C++ function), 609
pdal::ColumnPointTable (C++ class), 610
pdal::ColumnPointTable::~ColumnPointTable (C++ function), 610
pdal::ColumnPointTable::ColumnPointTable (C++ function), 610
pdal::ColumnPointTable::finalize

688 Index
pdal::ColumnPointTable::getPoint (C++ function), 610
pdal::ColumnPointTable::supportsView (C++ function), 610
pdal::Dimension (C++ type), 610
pdal::Dimension::base (C++ function), 611
pdal::Dimension::BaseType (C++ enum), 610
pdal::Dimension::BaseType::Floating (C++ enumerator), 610
pdal::Dimension::BaseType::None (C++ enum), 610
pdal::Dimension::BaseType::Signed (C++ enum), 610
pdal::Dimension::BaseType::Unsigned (C++ enum), 610
pdal::Dimension::COUNT (C++ member), 612
pdal::Dimension::Detail (C++ class), 612
pdal::Dimension::DetailList (C++ type), 610
pdal::Dimension::extractName (C++ function), 612
pdal::Dimension::fixName (C++ function), 612
pdal::Dimension::fromName (C++ function), 611
pdal::Dimension::interpretationName (C++ function), 611
pdal::Dimension::nameValid (C++ function), 612
pdal::Dimension::operator>> (C++ function), 612
pdal::Dimension::operator<< (C++ function), 612
pdal::Dimension::PROPRIETARY (C++ member), 612
pdal::Dimension::size (C++ function), 611
pdal::Dimension::toName (C++ function), 611
pdal::Dimension::type (C++ function), 612
pdal::Dimension::Type::Double (C++ enum), 611
pdal::Dimension::Type::Float (C++ enum), 611
pdal::Dimension::Type::None (C++ enum), 611
pdal::Dimension::Type::Signed16 (C++ enum), 611
pdal::Dimension::Type::Signed32 (C++ enum), 611
pdal::Dimension::Type::Signed64 (C++ enum), 611
pdal::Dimension::Type::Signed8 (C++ enum), 611
pdal::Dimension::Type::Unsigned16 (C++ enum), 611
pdal::Dimension::Type::Unsigned32 (C++ enum), 611
pdal::Dimension::Type::Unsigned64 (C++ enum), 611
pdal::Dimension::Type::Unsigned8 (C++ enum), 611
pdal::Extractor (C++ class), 613
pdal::Extractor::Extractor (C++ function), 613
pdal::Extractor::good (C++ function), 613
pdal::Extractor::operator bool (C++ function), 613
pdal::Extractor::operator>> (C++ function), 614, 615
pdal::Extractor::position (C++ function), 613
pdal::Extractor::seek (C++ function), 613
pdal::Extractor::skip (C++ function), 613
pdal::FileUtils (C++ type), 615
pdal::FileUtils::closeFile (C++ function), 617
pdal::FileUtils::createDirectories
<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>pdal::FileUtils::createDirectory</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::createFile</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::deleteDirectory</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::deleteFile</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::directoryExists</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::directoryList</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::extension</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::fileExists</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::fileSize</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::fileTimes</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::fromNative</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::getcwd</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::getDirectory</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::getFilename</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::glob</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::isAbsolutePath</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::isDirectory</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::MapContext</td>
<td>(C++ struct)</td>
</tr>
<tr>
<td>pdal::FileUtils::mapFile</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::openExisting</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::openFile</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::readFileIntoString</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::renameFile</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::stem</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::toAbsolutePath</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::toCanonicalPath</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::toNative</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::FileUtils::unmapFile</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::Filter</td>
<td>(C++ class)</td>
</tr>
<tr>
<td>pdal::Filter::~Filter</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::Filter::Args</td>
<td>(C++ struct)</td>
</tr>
<tr>
<td>pdal::Filter::Args::m_where</td>
<td>(C++ member)</td>
</tr>
<tr>
<td>pdal::Filter::Args::m_whereArg</td>
<td>(C++ member)</td>
</tr>
<tr>
<td>pdal::Filter:: Args::m_whereMerge</td>
<td>(C++ member)</td>
</tr>
<tr>
<td>pdal::Filter::Args::m_whereMergeArg</td>
<td>(C++ member)</td>
</tr>
<tr>
<td>pdal::Filter::operator=</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::IStream</td>
<td>(C++ class)</td>
</tr>
<tr>
<td>pdal::IStream::~IStream</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::IStream::close</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::IStream::get</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::IStream::good</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::IStream::IStream</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::IStream::open</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::IStream::operator bool</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::IStream::popStream</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::IStream::position</td>
<td>(C++ function)</td>
</tr>
<tr>
<td>pdal::IStream::pushStream</td>
<td>(C++ function)</td>
</tr>
</tbody>
</table>
function), 623
pdal::IStream::seek (C++ function), 623
pdal::IStream::skip (C++ function), 623
pdal::IStream::stream (C++ function), 623

pdal::Log (C++ class), 625
pdal::Log::~Log (C++ function), 625
pdal::Log::clearFloat (C++ function), 625
pdal::Log::floatPrecision (C++ function), 625
pdal::Log::get (C++ function), 625
pdal::Log::getLevel (C++ function), 625
pdal::Log::getLevelString (C++ function), 626
pdal::Log::getLogStream (C++ function), 625
pdal::Log::leader (C++ function), 626
pdal::Log::makeLog (C++ function), 626
pdal::Log::popLeader (C++ function), 626
pdal::Log::pushLeader (C++ function), 626
pdal::Log::setLeader (C++ function), 626
pdal::Log::setLevel (C++ function), 625
pdal::Metadata (C++ class), 626
pdal::Metadata::getNode (C++ function), 627
pdal::Metadata::inferType (C++ function), 627
pdal::Metadata::Metadata (C++ function), 627
pdal::Metadata::MetadataNode (C++ class), 627
pdal::MetadataNode::add (C++ function), 627, 628
pdal::MetadataNode::addEncoded (C++ function), 627
pdal::MetadataNode::addList (C++ function), 627, 628
pdal::MetadataNode::addListEncoded (C++ function), 627
pdal::MetadataNode::addOrUpdate (C++ function), 628
pdal::MetadataNode::addWithType (C++ function), 627
pdal::MetadataNode::childNames (C++ function), 628
pdal::MetadataNode::children (C++ function), 628
pdal::MetadataNode::clone (C++ function), 627
pdal::MetadataNode::description (C++ function), 628
pdal::MetadataNode::empty (C++ function), 629
pdal::MetadataNode::find (C++ function), 629
pdal::MetadataNode::findChild (C++ function), 629
pdal::MetadataNode::findChildren (C++ function), 629
pdal::MetadataNode::hasChildren (C++ function), 628
pdal::MetadataNode::jsonValue (C++ function), 628
pdal::MetadataNode::kind (C++ function), 628
pdal::MetadataNode::MetadataNode (C++ function), 627
pdal::MetadataNode::name (C++ function), 628
pdal::MetadataNode::operator bool (C++ function), 629
pdal::MetadataNode::operator! (C++ function), 629
pdal::MetadataNode::type (C++ function), 628
pdal::MetadataNode::valid (C++ function), 629
pdal::MetadataNode::value (C++ function), 628
pdal::Options (C++ class), 629
pdal::Options::add (C++ function), 629, 630
pdal::Options::addConditional (C++ function), 629
pdal::Options::addOrUpdate (C++ function), 628
pdal::Options::fromFile (C++ function), 630
pdal::Options::getKeys (C++ function),
pdal::Options::getOptions (C++ function), 630
pdal::Options::getValues (C++ function), 630
pdal::Options::Options (C++ function), 629
pdal::Options::remove (C++ function), 629
pdal::Options::replace (C++ function), 629, 630
pdal::Options::toCommandLine (C++ function), 630
pdal::Options::toMetadata (C++ function), 629
pdal::PointView (C++ class), 630
pdal::PointView::~PointView (C++ function), 631
pdal::PointView::append (C++ function), 631
pdal::PointView::appendPoint (C++ function), 631
pdal::PointView::begin (C++ function), 631
pdal::PointView::build2dIndex (C++ function), 634
pdal::PointView::build3dIndex (C++ function), 634
pdal::PointView::calculateBounds (C++ function), 632
pdal::PointView::clearTemps (C++ function), 633
pdal::PointView::compare (C++ function), 631
pdal::PointView::createMesh (C++ function), 633
pdal::PointView::createRaster (C++ function), 633
pdal::PointView::dimName (C++ function), 632
pdal::PointView::dims (C++ function), 632
pdal::PointView::dimSize (C++ function), 632
pdal::PointView::dimType (C++ function), 632
pdal::PointView::dump (C++ function), 632
pdal::PointView::empty (C++ function), 631
pdal::PointView::end (C++ function), 631
pdal::PointView::getField (C++ function), 631
pdal::PointView::getFieldAs (C++ function), 631
pdal::PointView::getOrAddPoint (C++ function), 633
pdal::PointView::getPackedPoint (C++ function), 632
pdal::PointView::getPoint (C++ function), 632
pdal::PointView::hasDim (C++ function), 632
pdal::PointView::id (C++ function), 631
pdal::PointView::invalidateProducts (C++ function), 633
pdal::PointView::layout (C++ function), 632
pdal::PointView::makeNew (C++ function), 631
pdal::PointView::mesh (C++ function), 633
pdal::PointView::operator= (C++ function), 631
pdal::PointView::point (C++ function), 631
pdal::PointView::pointSize (C++ function), 632
pdal::PointView::PointSize (C++ function), 631
pdal::PointView::raster (C++ function), 633
pdal::PointView::setField (C++ function), 631
pdal::PointView::setPackedPoint (C++ function), 632
pdal::PointView::size (C++ function), 632
pdal::PointView::spatialReference (C++ function), 632
pdal::PointView::stableSort (C++ function), 634
pdal::PointView::table (C++ function), 632
pdal::PointView::toMetadata (C++ function), 633
pdal::ProgramArgs (C++ class), 634
pdal::ProgramArgs::add (C++ function), 634–636
pdal::ProgramArgs::addSynonym (C++ function), 637
pdal::ProgramArgs::commandLine (C++ function), 637
pdal::ProgramArgs::dump (C++ function), 637
pdal::ProgramArgs::dump2 (C++ function), 637
pdal::ProgramArgs::dump3 (C++ function), 638
pdal::ProgramArgs::parse (C++ function), 636
pdal::ProgramArgs::parseSimple (C++ function), 636
pdal::ProgramArgs::reset (C++ function), 637
pdal::ProgramArgs::set (C++ function), 635
pdal::Reader (C++ class), 638
pdal::RowPointTable (C++ class), 638
pdal::RowPointTable::RowPointTable (C++ function), 638
pdal::RowPointTable::RowPointTable (C++ function), 638
pdal::RowPointTable::supportsView (C++ function), 638
pdal::Stage (C++ class), 639
pdal::Stage::~Stage (C++ function), 639
pdal::Stage::addAllArgs (C++ function), 641
pdal::Stage::addConditionalOptions (C++ function), 641
pdal::Stage::addOptions (C++ function), 641
pdal::Stage::execute (C++ function), 640
pdal::Stage::findNonstreamable (C++ function), 640
pdal::Stage::getInputs (C++ function), 642
pdal::Stage::getMetadata (C++ function), 642
pdal::Stage::getSpa
pdal::Stage::tag (C++ function), 642
pdal::Stage::WhereMergeMode (C++ enum), 639
pdal::Stage::WhereMergeMode::Auto (C++ enumerator), 639
pdal::Stage::WhereMergeMode::False (C++ enumerator), 639
pdal::Stage::WhereMergeMode::True (C++ enumerator), 639
pdal::StageFactory (C++ class), 644
pdal::StageFactory::createStage (C++ function), 644
pdal::StageFactory::destroyStage (C++ function), 644
pdal::StageFactory::inferReaderDriver (C++ function), 645
pdal::StageFactory::inferWriterDriver (C++ function), 645
pdal::StageFactory::StageFactory (C++ function), 644
pdal::Utils::pdal::Utils (C++ type), 645
pdal::Utils::pdal::Utils::ArbiterInStream (C++ class), 665
pdal::Utils::pdal::Utils::ArbiterInStream::ArbiterInStream (C++ function), 666
pdal::Utils::pdal::Utils::ArbiterInStream::m_localFile (C++ member), 666
pdal::Utils::pdal::Utils::ArbiterOutStream (C++ class), 665
pdal::Utils::pdal::Utils::ArbiterOutStream::~ArbiterOutStream (C++ function), 665
pdal::Utils::pdal::Utils::ArbiterOutStream::ArbiterOutStream (C++ function), 665
pdal::Utils::pdal::Utils::ArbiterOutStream::m_localFile (C++ member), 666
pdal::Utils::pdal::Utils::ArbiterOutStream::m_remotePath (C++ member), 665
pdal::Utils::pdal::Utils::backtrace (C++ function), 649
pdal::Utils::pdal::Utils::BacktraceEntries (C++ type), 646
pdal::Utils::pdal::Utils::BacktraceEntry (C++ struct), 666
pdal::Utils::pdal::Utils::BacktraceEntry::addr (C++ member), 666
pdal::Utils::pdal::Utils::BacktraceEntry::BacktraceEntry (C++ function), 666
pdal::Utils::pdal::Utils::BacktraceEntry::libname (C++ member), 666
pdal::Utils::pdal::Utils::BacktraceEntry::offset (C++ member), 666
pdal::Utils::pdal::Utils::BacktraceEntry::symname (C++ member), 666
pdal::Utils::pdal::Utils::base64_decode (C++ function), 653
pdal::Utils::pdal::Utils::base64_encode (C++ function), 653
pdal::Utils::pdal::Utils::cksum (C++ function), 651
pdal::Utils::pdal::Utils::clamp (C++ function), 649
pdal::Utils::pdal::Utils::ClassicLocaleStream (C++ struct), 668
pdal::Utils::pdal::Utils::ClassicLocaleStream::ClassicLocaleStream (C++ function), 668
pdal::Utils::pdal::Utils::closeFile (C++ function), 647
pdal::Utils::pdal::Utils::closeProgress (C++ function), 648
pdal::Utils::pdal::Utils::compare_approx (C++ function), 650
pdal::Utils::pdal::Utils::computeChamfer (C++ function), 647
pdal::Utils::pdal::Utils::computeHausdorff (C++ function), 647
pdal::Utils::pdal::Utils::computeHausdorffPair (C++ function), 647
pdal::Utils::pdal::Utils::contains (C++ function), 648
pdal::Utils::pdal::Utils::createFile (C++ function), 646
pdal::Utils::pdal::Utils::dirSeparator (C++ function), 647
pdal::Utils::pdal::Utils::dllDir (C++ function), 647
pdal::Utils::pdal::Utils::demangle (C++ function), 655
pdal::Utils::pdal::Utils::dirSeparator (C++ function), 647
pdal::Utils::pdal::Utils::dirSeparator (C++ function), 647
pdal::Utils::pdal::Utils::BacktraceEntries::BacktraceEntries (C++ function), 655
pdal::Utils::pdal::Utils::BacktraceEntry::addr (C++ function), 647
pdal::Utils::pdal::Utils::BacktraceEntry::addr (C++ function), 647
pdal::Utils::pdal::Utils::BacktraceEntry::addr (C++ function), 647
pdal::Utils::pdal::Utils::BacktraceEntry::addr (C++ function), 647
pdal::Utils::pdal::Utils::BacktraceEntry::addr (C++ function), 647
pdal::Utils::pdal::Utils::BacktraceEntry::addr (C++ function), 647
pdal::Utils::pdal::Utils::BacktraceEntry::addr (C++ function), 647
pdal::Utils::pdal::Utils::BacktraceEntry::addr (C++ function), 647
pdal::Utils::dynamicLibExtension (C++ member), 665
pdal::Utils::eatcharacter (C++ function), 652
pdal::Utils::eatwhitespace (C++ function), 652
pdal::Utils::endsWith (C++ function), 651
pdal::Utils::escapeJSON (C++ function), 653
pdal::Utils::escapeNonprinting (C++ function), 653
pdal::Utils::extract (C++ function), 656
pdal::Utils::extractDim (C++ function), 647
pdal::Utils::extractSpaces (C++ function), 656
pdal::Utils::fetchRemote (C++ function), 648
pdal::Utils::fileExists (C++ function), 647
pdal::Utils::fileSize (C++ function), 646
pdal::Utils::fromString (C++ function), 648, 649, 662–664
pdal::Utils::getenv (C++ function), 651
pdal::Utils::iequals (C++ function), 650
pdal::Utils::inRange (C++ function), 659
pdal::Utils::insertDim (C++ function), 647
pdal::Utils::isRemote (C++ function), 646
pdal::Utils::IStringStreamClassicLocale (C++ type), 646
pdal::Utils::maybeGlob (C++ function), 648
pdal::Utils::normalizeLongitude (C++ function), 648
pdal::Utils::numericCast (C++ function), 654
pdal::Utils::openFile (C++ function), 659
pdal::Utils::openProgress (C++ function), 647
pdal::Utils::OStringStreamClassicLocale (C++ type), 646
pdal::Utils::pathListSeparator (C++ member), 665
pdal::Utils::portable_pclose (C++ function), 653
pdal::Utils::portable_popen (C++ function), 653
pdal::Utils::printError (C++ function), 647
pdal::Utils::Random (C++ class), 666
pdal::Utils::Random::generator (C++ function), 667
pdal::Utils::Random::quick (C++ function), 667
pdal::Utils::Random::Random (C++ function), 666
pdal::Utils::random_seed (C++ function), 649
pdal::Utils::redirect (C++ function), 658
pdal::Utils::RedirectStream (C++ struct), 667
pdal::Utils::RedirectStream::m_buf (C++ member), 667
pdal::Utils::RedirectStream::m_null (C++ member), 667
pdal::Utils::RedirectStream::m_out (C++ member), 667
pdal::Utils::RedirectStream::m_os (C++ member), 667
pdal::Utils::Remove (C++ function), 658
pdal::Utils::remove (C++ function), 648
pdal::Utils::remove_if (C++ function), 648
pdal::Utils::replaceAll (C++ function), 654
pdal::Utils::restore (C++ function), 659
pdal::Utils::openProgress (C++ function), 647
pdal::Utils::OStringStreamClassicLocale (C++ type), 646
pdal::Utils::pathListSeparator (C++ member), 665
pdal::Utils::portable_pclose (C++ function), 653
pdal::Utils::portable_popen (C++ function), 653
pdal::Utils::printError (C++ function), 647
pdal::Utils::Random (C++ class), 666
pdal::Utils::Random::generator (C++ function), 667
pdal::Utils::Random::quick (C++ function), 667
pdal::Utils::Random::Random (C++ function), 666
pdal::Utils::random_seed (C++ function), 649
pdal::Utils::redirect (C++ function), 658
pdal::Utils::RedirectStream (C++ struct), 667
pdal::Utils::RedirectStream::m_buf (C++ member), 667
pdal::Utils::RedirectStream::m_null (C++ member), 667
pdal::Utils::RedirectStream::m_out (C++ member), 667
pdal::Utils::RedirectStream::m_os (C++ member), 667
pdal::Utils::Remove (C++ function), 658
pdal::Utils::remove (C++ function), 648
pdal::Utils::remove_if (C++ function), 648
pdal::Utils::replaceAll (C++ function), 654
pdal::Utils::restore (C++ function), 659
pdal::Utils::pdal::Utils::run_shell_command (C++ function), 647
(C++ function), 654
dpal::Utils::pdal::Utils::screenWidth (C++ function), 664
pdal::Utils::pdal::Utils::setenv (C++ function), 651
pdal::Utils::pdal::Utils::setenv (C++ function), 651
pdal::Utils::pdal::Utils::simpleWordexp (C++ function), 650
pdal::Utils::pdal::Utils::split (C++ function), 656, 657
pdal::Utils::pdal::Utils::split2 (C++ function), 657
pdal::Utils::pdal::Utils::sround (C++ function), 650
pdal::Utils::pdal::Utils::startsWith (C++ function), 658
pdal::Utils::pdal::Utils::StatusWithReason (C++ function), 667
(C++ class), 667
pdal::Utils::pdal::Utils::StatusWithReason::code (C++ function), 667
pdal::Utils::pdal::Utils::StatusWithReason::operator bool (C++ function), 667
pdal::Utils::pdal::Utils::StatusWithReason::StatusWithReason (C++ function), 667
pdal::Utils::pdal::Utils::StatusWithReason::what (C++ function), 667
pdal::Utils::pdal::Utils::StringStreamClassicLocale (C++ type), 646
pdal::Utils::pdal::Utils::TempFile (C++ class), 665
pdal::Utils::pdal::Utils::TempFile::~TempFile (C++ function), 665
pdal::Utils::pdal::Utils::TempFile::fileName (C++ function), 665
pdal::Utils::pdal::Utils::TempFile::TempFile::~TempFile (C++ function), 665
pdal::Utils::pdal::Utils::tempFilename (C++ function), 646
pdal::Utils::pdal::Utils::toDouble (C++ function), 647
pdal::Utils::pdal::Utils::toJSON (C++ function), 646
pdal::Utils::pdal::Utils::tolower (C++ function), 650
pdal::Utils::pdal::Utils::toString (C++ function), 660–662, 664
pdal::Utils::pdal::Utils::toupper (C++ function), 650
pdal::Utils::pdal::Utils::trim (C++ function), 652
pdal::Utils::pdal::Utils::trimLeading (C++ function), 652
pdal::Utils::pdal::Utils::trimTrailing (C++ function), 652
pdal::Utils::pdal::Utils::typeidName (C++ function), 658
pdal::Utils::pdal::Utils::unsetenv (C++ function), 652
pdal::Utils::pdal::Utils::wordWrap (C++ function), 654
pdal::Utils::pdal::Utils::wordWrap2 (C++ function), 654
pdal::Utils::pdal::Utils::writeProgress (C++ function), 648
pdal::Writer (C++ class), 668
pip, 371
poisson, 477
Python, 12, 369–371, 509
Q
QGIS, 434, 453
query, 443
R
range filter, 469
Raster, 463
rasterization, 495
References, 679
Reprojection, 447
RGB, 463
RIEGL, 509
S
sample, 477
Scala, 373, 376, 377
search, 443
SOCS, 428
software installation, 432
Source, 371
spatial reference system, 440
Stage, 638
Start Here, 438

T
thinning, 477

U
Untwine, 8
Utils, 645
UTM, 447, 509

V
Vector, 456
voxel sampling, 477

W
web services, 450
WGS84, 447, 509