



# **PDAL: Point cloud Data Abstraction Library**

***Release 1.9.0***

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# CONTENTS

<b>1 News</b>	<b>3</b>
1.1 <b>04-09-2018</b> . . . . .	3
<b>2 About</b>	<b>5</b>
2.1 About . . . . .	5
<b>3 Download</b>	<b>13</b>
3.1 Download . . . . .	13
<b>4 Quickstart</b>	<b>17</b>
4.1 Quickstart . . . . .	17
<b>5 Applications</b>	<b>25</b>
5.1 Applications . . . . .	25
<b>6 Community</b>	<b>43</b>
6.1 Community . . . . .	43
<b>7 Drivers</b>	<b>45</b>
7.1 Pipeline . . . . .	45
7.2 Readers . . . . .	55
7.3 Writers . . . . .	104
7.4 Filters . . . . .	135
<b>8 Dimensions</b>	<b>229</b>
8.1 Dimensions . . . . .	229
<b>9 Python</b>	<b>233</b>
9.1 Python . . . . .	233
<b>10 Tutorials</b>	<b>237</b>
10.1 Tutorials . . . . .	237
<b>11 Workshop</b>	<b>285</b>

11.1 Point Cloud Processing and Analysis with PDAL . . . . .	285
<b>12 Development</b>	<b>381</b>
12.1 Development . . . . .	381
12.2 Project . . . . .	435
12.3 API . . . . .	453
12.4 FAQ . . . . .	519
12.5 License . . . . .	521
12.6 References . . . . .	522
<b>13 Indices and tables</b>	<b>523</b>
<b>Bibliography</b>	<b>525</b>
<b>Index</b>	<b>527</b>



PDAL is a C++ [BSD](http://www.opensource.org/licenses/bsd-license.php) (<http://www.opensource.org/licenses/bsd-license.php>) library for translating and manipulating [point cloud data](http://en.wikipedia.org/wiki/Point_cloud) ([http://en.wikipedia.org/wiki/Point\\_cloud](http://en.wikipedia.org/wiki/Point_cloud)). It is very much like the [GDAL](http://www.gdal.org) (<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 55) and [Writers](#) (page 104) to list data formats it supports, and see [Filters](#) (page 135) 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 25) provides more information on that topic.

Finally, PDAL speaks Python by both embedding and extending it. Visit [Python](#) (page 233) 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/PDAL.pdf>



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**CHAPTER  
ONE**

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**NEWS**

## **1.1 04-09-2018**

PDAL 1.9.0 has been released. You can [\*download\*](#) (page 13) the source code or follow the [\*quickstart\*](#) (page 17) to get going in a hurry with Conda.



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**CHAPTER  
TWO**

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**ABOUT**

## 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](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 135) on point clouds into *pipelines* (page 45) 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](#) (page 69) stage, a [Reprojection](#) (page 178) stage, and a [PostgreSQL Writer](#) (page 127), 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.



Fig. 2.1: A simple PDAL pipeline composed of a reader, filter, and writer stages.

A PDAL JSON [Pipeline](#) (page 45) that composes this operation to reproject and load the data into PostgreSQL might look something like the following:

```
1 {
2     "pipeline": [
3         {
4             "type": "readers.las",
5             "filename": "input.las"
6         },
7         {
8             "type": "filters.reprojection",
9             "out_srs": "EPSG:3857"
10        },
11        {
12            "type": "writers.pgpointcloud",
13            "connection": "host='localhost' dbname='lidar' user='hobu'",
14            "table": "output",
15            "srid": "3857"
16        }
17    ]
18 }
```

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 32), to allow you to execute them.

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**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](#)

([http://www.gdal.org/gdal\\_vrttut.html](http://www.gdal.org/gdal_vrttut.html)).

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### 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) (<http://lastools.org>) from [Martin Isenburg](https://www.cs.unc.edu/~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) (<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) (<http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html>). [LAStools](http://lastools.org) (<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* (page 229) types provided by the LAS format.
4. PDAL is coordinated by users with its declarative [JSON](#) (page 45) 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) (<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 links and uses PCL, and PDAL provides a convenient pipeline mechanism to orchestrate PCL operations.

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**Note:** See [Filtering data with PCL](#) (page 259) for more detail on how to take advantage of PCL capabilities within PDAL operations.

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### Greyhound and Entwine

Greyhound (<http://greyhound.io>) is an open source software from Hobu, Inc. (<https://hobu.co>) that allows clients to query and stream progressive point cloud data over the network. Entwine (<https://entwine.io>) is open source software from Hobu, Inc. that organizes massive point cloud collections into Greyhound (<http://greyhound.io>)-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.greyhound* (page 63) to allow users to read data into PDAL processes from that server.

### plas.io and Potree

plas.io (<http://plas.io>) 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 for it at [plasiojs.io](http://plasiojs.io) and <https://github.com/hobu/plasio-ui>

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/>

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**Note:** Both renderers can now consume data from Greyhound. See them in action at <http://speck.ly> and <http://potree.entwine.io>

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### 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/>)

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**Note:** The libLAS (<http://liblas.org>) project is an open source project that pre-dates 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) (<https://pypi.python.org/pypi/laspy/1.4.1>) software.

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## 2.1.4 Where did PDAL come from?

PDAL takes its cue from another very popular open source project – [GDAL](http://gdal.org/) (<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/) (<http://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/476649/remote-sensinggeographic-information-systems-center/>) [GRiD](http://lidar.io/) (<http://lidar.io/>) project. Functionality that was creeping into [libLAS](http://liblas.org/) (<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.

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**Note:** Possible point cloud dimension types provided and supported by PDAL can be found at [Dimensions](#) (page 229).

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## 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 135), [Readers](#) (page 55), and [Writers](#) (page 104). 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 43) 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 25) 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 453) 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 444) and its [source code](#) (<https://github.com/PDAL/PDAL/tree/master/test/unit>).

**See also:**

PDAL *software* (page 237) *development* (page 404) *tutorials* (page 417) 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 25) 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 29) about a data set
- Data *translation* (page 39) 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 27)
- *Merge* (page 32) or *split* (page 35) data
- *Catalog* (page 37) collections of data

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**Note:** The command line utilities are often simply *pipeline* (page 32) and *Pipeline* (page 45) collected into a convenient application. In many cases you can replicate the functionality of an application entirely within a single pipeline.

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### 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 233) document contains information on how to install and use the PDAL Python extension.

### 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.

## DOWNLOAD

### 3.1 Download

#### Contents

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

#### 3.1.1 Current Release(s)

- **2019-04-09 PDAL-1.9.0-src.tar.gz**  
(<https://github.com/PDAL/PDAL/releases/download/1.9.0/PDAL-1.9.0-src.tar.gz>)  
[Release Notes](https://github.com/PDAL/PDAL/releases/tag/1.8.0) (<https://github.com/PDAL/PDAL/releases/tag/1.8.0>) ([md5](#)  
(<https://github.com/PDAL/PDAL/releases/download/1.9.0/PDAL-1.9.0-src.tar.gz.md5>))

### **3.1.2 Past Releases**

- **2018-10-12** [PDAL-1.8.0-src.tar.gz](http://download.osgeo.org/pdal/PDAL-1.8.0-src.tar.gz)  
(<http://download.osgeo.org/pdal/PDAL-1.8.0-src.tar.gz>)
- **2018-05-13** [PDAL-1.7.2-src.tar.gz](http://download.osgeo.org/pdal/PDAL-1.7.2-src.tar.gz)  
(<http://download.osgeo.org/pdal/PDAL-1.7.2-src.tar.gz>)
- **2018-04-06** [PDAL-1.7.1-src.tar.gz](http://download.osgeo.org/pdal/PDAL-1.7.1-src.tar.gz)  
(<http://download.osgeo.org/pdal/PDAL-1.7.1-src.tar.gz>)
- **2018-04-05** [PDAL-1.7.0-src.tar.gz](http://download.osgeo.org/pdal/PDAL-1.7.0-src.tar.gz)  
(<http://download.osgeo.org/pdal/PDAL-1.7.0-src.tar.gz>)
- **2017-10-12** [PDAL-1.6.0-src.tar.gz](http://download.osgeo.org/pdal/PDAL-1.6.0-src.tar.gz)  
(<http://download.osgeo.org/pdal/PDAL-1.6.0-src.tar.gz>)

### **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, GeoWave, MATLAB, MBIO, MRSID, 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 3.1: PDAL Distribution Feature Comparison

	Docker	RPMs	Debian	Alpine	<i>Conda</i> (page 16)
Platform(s)	linux	linux	linux	linux	win64, mac, linux
CPD	X			X	
Greyhound	X		X	X	X
Icebridge	X	X	X	X	X
laszip	X	X		X	X
laz-perf	X			X	X
NITF	X			X	X
OCI					
PCL		X			X
pgpointcloud	X	X	X	X	X
Python	X		X	X	X
SQLite	X		X	X	X

## Windows

Windows builds are available via [Conda Forge](https://anaconda.org/conda-forge/pdal) (<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/>.

## Debian

Debian packages are now available on [Debian Unstable](https://tracker.debian.org/pkg/pdal) (<https://tracker.debian.org/pkg/pdal>).

## Alpine

[Alpine](#) (page 15) 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](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 all of these packages reside in Alpine's `edge/testing` 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.

```
apk add [package...]
```

For example, the following command will install both the PDAL application and the Python extension.

```
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.

```
conda install [-c channel] [package...]
```

Because the PDAL package (and its 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.

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## CHAPTER FOUR

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## QUICKSTART

### 4.1 Quickstart

#### 4.1.1 Introduction

It's a giant pain to build everything yourself. 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/) (<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 69) file. It will utilize the PDAL [command line application](#) (page 25) to inspect the file.

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**Note:** If you need to compile your own copy of PDAL, see [Compilation](#) (page 392) for more details.

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#### 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.

- [Windows](https://conda.io/docs/user-guide/install/windows.html) (<https://conda.io/docs/user-guide/install/windows.html>)
- [macOS](https://conda.io/docs/user-guide/install/macos.html) (<https://conda.io/docs/user-guide/install/macos.html>)
- [Linux](https://conda.io/docs/user-guide/install/linux.html) (<https://conda.io/docs/user-guide/install/linux.html>)

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**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.

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### 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/docs/user-guide/getting-started.html#starting-conda) (<https://conda.io/docs/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) (<https://anaconda.org/conda-forge/pdal>) channel on anaconda.org with every code change on the PDAL maintenance branch.

**Warning:** It is actually a very good idea to install PDAL in it's 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 should read more about it over at <https://conda.io/docs/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.

```
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:

```
Solving environment: done  
## Package Plan ##  
environment location: C:\Miniconda3\envs\myenv
```

```
added / updated specs:
- pdal
```

The following packages will be downloaded:

package	build	
pdal-1.7.2	py35h33f895e_1	8.6 MB ↗
→ conda-forge		
setuptools-39.2.0	py35_0	591 KB ↗
→ conda-forge		
numpy-1.14.3	py35h9fa60d3_2	42 KB
	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	
icu:	58.2-vc14_0	conda-forge [vc14]
intel-openmp:	2018.0.3-0	
jpeg:	9b-vc14_2	conda-forge [vc14]
jsoncpp:	1.8.1-vc14_0	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]
libpng:	1.6.34-vc14_0	conda-forge [vc14]
libpq:	9.6.3-vc14_0	conda-forge [vc14]
libspatialite:	4.3.0a-vc14_19	conda-forge [vc14]

libssh2:	1.8.0-vc14_2	conda-forge [vc14]
libtiff:	4.0.9-vc14_0	conda-forge [vc14]
libxml2:	2.9.8-vc14_0	conda-forge [vc14]
libxslt:	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]
xz:	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%
setupools-39.2.0    |  591 KB | #####
→## / 100%
numpy-1.14.3         |   42 KB | #####
→## / 100%
Preparing transaction: done
Verifying transaction: done
Executing transaction: done
#
# To activate this environment, use
#
#     $ conda activate myenv
#
# To deactivate an active environment, use
#

```

```
# $ conda deactivate
```

---

**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 29) 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 25) to find out how to utilize PDAL applications to process data on the command line yourself.
- Visit [Development](#) (page 381) to learn how to embed and use PDAL in your own applications.
- [Readers](#) (page 55) lists the formats that PDAL can read, [Filters](#) (page 135) lists the kinds of operations you can do with PDAL, and [Writers](#) (page 104) lists the formats PDAL can write.
- [Tutorials](#) (page 237) contains a number of walk-through tutorials for achieving many tasks with PDAL.
- [The PDAL workshop](#) (page 285) contains numerous hands-on examples with screenshots and example data of how to use PDAL [Applications](#) (page 25) to tackle point cloud data processing tasks.

- *Python* (page 233) describes how PDAL embeds and extends Python and how you can leverage these capabilities in your own programs.

**See also:**

*Community* (page 43) is a good source to reach out to when you're stuck.



---

## CHAPTER FIVE

---

# APPLICATIONS

## 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 translate --drivers
$ pdal pipeline --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
```

---

**Note:** Driver-specific options can be identified using the pdal <command> --help invocation.

---

### 5.1.1 delta

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'  
-----  
→-----  
-----  
Dimension      X           Y           Z  
-----  
Min            0.0000       0.0000       0.0000  
Max            0.0000       0.0000       0.0000  
Mean           0.0000       0.0000       0.0000  
-----
```

#### Example 2:

```
$ 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
```

## 5.1.2 density

The density command produces a tessellated hexagonal [OGR](#) layer ([http://www.gdal.org/ogr\\_utilities.html](http://www.gdal.org/ogr_utilities.html)) from the output of [\*filters.hexbin\*](#) (page 206).

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

```
--input, -i           Input point cloud file name
--output, -o          Output vector data source
--lyr_name            OGR layer name to write into datasource
--ogrdriver, -f       OGR driver name to use
--sample_size          Sample size for automatic edge length calculation.
                     ↳ [5000]
--threshold           Required cell density [15]
--hole_cull_tolerance_area
                     Tolerance area to apply to holes before cull
--smooth              Smooth boundary output
```

## 5.1.3 ground

The ground command is used to segment the input point cloud into ground versus non-ground returns.

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

```
--input, -i           Input filename
--output, -o          Output filename
--max_window_size    Max window size
--slope               Slope
--max_distance        Max distance
--initial_distance   Initial distance
--cell_size           Cell size
--classify            Apply classification labels?
--extract             Extract ground returns?
--approximate, -a    Use approximate algorithm? (much faster)
--reset               Reset classification prior to segmentation.
```

```
--denoise          Apply statistical outlier removal prior to segmentation.
For more information, see the full documentation for PDAL at http://pdal.io/
```

### 5.1.4 hausdorff

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      Non-positional option for specifying filename of source file.
--candidate arg   Non-positional option for specifying filename to test against source.
```

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.

---

## 5.1.5 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 <b>and</b> metadata
--point, -p ↳ indexed)	Point to dump --point="1-5,10,100-200" (0_
--query	Return points <b>in</b> order of distance <b>from the</b>
specified location (2D <b>or</b> 3D) --query Xcoord,Ycoord[,Zcoord] [/	
↳ count]	
--stats	Dump stats on <b>all</b> 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 <b>for</b> pipeline serialization
--summary	Dump summary of the info
--metadata	Dump file metadata info
--stdin, -s	Read a pipeline file <b>from standard</b> 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,  
        "EdgeOfFlightLine": 0,  
        "GpsTime": 245383.38808001476,  
        "Green": 104,  
        "Intensity": 124,  
        "NumberOfReturns": 1,  
        "PointSourceId": 7326,  
        "Red": 134,  
        "ReturnNumber": 1,  
        "ScanAngleRank": -4,  
        "ScanDirectionFlag": 1,  
        "UserData": 126,  
        "X": 636601.87,  
        "Y": 849018.59999999998,  
        "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": 636606.7600000001,  
        "Y": 849053.94000000006,  
        "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": 637012.2399999999,
            "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,
            "ScanDirectionFlag": 1,
            "UserData": 128,
            "X": 636896.3299999996,
            "Y": 849087.7000000007,
            "Z": 446.3899999999999
        },
        ...
    ]
}
```

## 5.1.6 merge

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

```
$ 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.

## 5.1.7 pcl

The `pcl` command is used to invoke a PCL JSON pipeline. See *Filtering data with PCL* (page 259) for more information.

---

**Note:** The `pcl` command is only available when PDAL is linked with PCL.

---

```
$ pdal pcl <input> <output> <pcl>

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

## 5.1.8 pipeline

The `pipeline` command is used to execute *Pipeline* (page 45) JSON. The pipeline is run in stream mode if possible. See *Reading with PDAL* (page 237) or *Pipeline* (page 45) for more information.

```
$ pdal pipeline <input>

--input, -i          Input filename
--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       progress file.  

--stdin, -s         Read pipeline from standard input  

--metadata          Metadata filename  

--nostream          Don't run in stream mode, even if  

↳technically      possible.
```

## 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",
      "dimensions": "Red"
    },
    {
      "type" : "filters.colorization",
      "raster" : "raster2.tif",
      "dimensions": "Blue"
    },
    "placeholder.laz"
  ]
}

$ pdal pipeline colorize.json --filters.colorization.dimensions= \  
  \
```

```
"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.

### 5.1.9 random

The `random` command is used to create a random point cloud. It uses [readers.faux](#) (page 59) 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.

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

```
--output, -o          Output file name  
--compress, -z        Compress output data (if supported by output)  
--format              Red  
--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             Red  
  (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)
```

## 5.1.10 sort

The `sort` command uses *filters.mortonorder* (page 172) to sort data by XY values.

```
$ 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
```

## 5.1.11 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>
```

```
--input, -i      Input filename
--output, -o     Output filename
--length         Edge length for splitter cells
--capacity       Point capacity of chipper cells
--origin_x       Origin in X axis for splitter cells
--origin_y       Origin in Y axis for splitter cells
```

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.

### 5.1.12 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 35) 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](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.

## 5.1.13 tindex

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

--tindex	OGR-readable/writeable tile index output
--filespec	Build: Pattern of files to index. Merge: <a href="#">_</a>
↳ Output filename	
--fast_boundary	Use extent instead of exact boundary
--lyr_name	OGR layer name to write into datasource
--tindex_name	Tile index column name
--ogrdriver, -f	OGR driver name to use
--t_srs	Target SRS of tile index
--a_srs	Assign SRS of tile <b>with</b> no SRS to this value
--write_absolute_path	Write absolute rather than relative file paths
--stdin, -s	Read filespec pattern <b>from standard input</b>

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](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.

--tindex	OGR-readable/writeable tile index output
--filespec	Build: Pattern of files to index. Merge: Output <a href="#">_</a>
<a href="#">filename</a>	
--lyr_name	OGR layer name to write into datasource
--tindex_name	Tile index column name
--ogrdriver, -f	OGR driver name to use
--bounds	Extent ( <a href="#">in</a> XYZ) to clip output to
--polygon	Well-known text of polygon to clip output
--t_srs	Spatial reference of the clipping geometry.

### 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"
```

### 5.1.14 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. Processing is done with stream mode if possible.

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

-- <b>input</b> , -i	Input filename
-- <b>output</b> , -o	Output filename
-- <b>filter</b> , -f	Filter type
--json	PDAL pipeline <b>from which</b> to extract filters.
--pipeline, -p	Pipeline output
--metadata, -m	Dump metadata output to the specified file
--reader, -r	Reader type
--writer, -w	Writer type
--nostream	Don't run in stream mode, even if technically →possible.

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 be 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

```
$ 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.
  ↳000686757150106 422.4697265625,636899.14233423944097 851475.
  ↳000686757150106 422.4697265625,636928.33048324030824 851494.
  ↳459452757611871 422.5400390625,636928.33048324030824 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 425.9501953125,637132.647526245797053 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 420.509765625,637244.535430748714134 850511.
  ↳791769731207751 420.7998046875,636758.066280735656619 850667.
  ↳461897735483944 434.609375,636539.155163229792379 851056.
  ↳63721774588339 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 PCL-based voxel grid filter, followed by the PMF filter and a range filter. We can even set stage-specific parameters as shown.

```
$ pdal translate input.las output.las pclblock pmf range \
--filters.pclblock.methods="[{\"name\":\"VoxelGrid\"}]" \
--filters.pmf.approximate=true \
--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”.

```
$ 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”.

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



---

# CHAPTER SIX

---

## COMMUNITY

### 6.1 Community

PDAL's community interacts through *Mailing List* (page 43), *GitHub* (page 43), *Gitter* (<https://gitter.im/PDAL/PDAL>) and *IRC* (page 44). Please feel welcome to ask questions and participate in all of the venues. The *Mailing List* (page 43) communication channel is for general questions, development discussion, and feedback. The *GitHub* (page 43) communication channel is for development activities, bug reports, and testing. The *IRC* (page 44) 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\\_\(software\)](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 381) 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) (<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 44). Gitter uses your [GitHub](#) (page 43) 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) (<http://freenode.net>). This mechanism is usually reserved for active meetings and other outreach with the community. The [Mailing List](#) (page 43) and [GitHub](#) (page 43) avenues are going to be more productive communication channels in most situations.

## 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 39), for example. While specific *applications* (page 25) 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/) (<http://www.json.org/>) manipulation facilities of whatever language you want.

---

**Note:** *pipeline* (page 32) 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 49) 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:

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



Fig. 7.1: A simple pipeline to convert *LAS* (page 69) to *BPF* (page 55) 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 108) writer:

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

```

        "B"
    ],
},
{
    "type": "writers.gdal",
    "filename": "output.tif"
}
]
}
}

```



Fig. 7.2: A more complex pipeline that merges two inputs together but uses *filters.reprojection* (page 178) 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 203), 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:

```

{
    "pipeline": [
        "input.las",
        {

```

```
        "type" : "filters.crop",
        "bounds" :
            [ "[[0, 75], [0, 75]]", "[[50, 125], [50, 125]]" ],
        },
        "output#.las"
    ]
}
```

## 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 39) or [pdal pipeline](#) (page 32) 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 Pipeline Objects

PDAL JSON pipelines always consist of a single object. This object (referred to as the PDAL JSON object below) represents a processing pipeline.

- The PDAL JSON object may have any number of members (name/value pairs).
- The PDAL JSON object must have a [\*Pipeline Array\*](#) (page 48).

### Pipeline Array

- The pipeline array may have any number of string or [\*Stage Objects\*](#) (page 49) 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 55), [Writers](#) (page 104), and [Filters](#) (page 135).

- 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.
- Reader stages will disregard the `inputs` member.
- If `inputs` is not specified for the first non-reader stage, all reader stages leading up to the current stage will be used as inputs.
- If `inputs` is not specified for any subsequent non-reader stages, the previous stage in the array will be used as input.
- 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 places in a separate file. See [Option Files](#) (page 50) 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 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:

```
{  
    "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 55) to *LAS* (page 113), inferring both the reader and writer type, and setting a number of options on the writer stage.

```
{  
    "pipeline": [  
        "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 221) 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](#) (page 150) describes using a specific filter to do this job in more detail.

```
{  
  "pipeline": [  
    "autzen.las",  
    {  
      "type": "filters.ferry",  
      "dimensions": "Z=>HAG"  
    },  
    {  
      "type": "filters.python",  
      "script": "hag.py",  
      "function": "filter",  
      "module": "anything"  
    },  
    "autzen-hag.las"  
  ]  
}
```

## DTM

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 [filters.smrf](#) (page 169), filters out all points but the ground returns (classification value of 2) using the [filters.range](#) (page 191), and then creates the DTM using the [writers.gdal](#) (page 108).

```
{  
  "pipeline": [  
    "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
        }
    ]
}
```

## 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.

```
{
    "pipeline": [
        {
            "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 178) filter reprojects data to the specified output spatial reference system.

```
{  
    "pipeline": [  
        {  
            "filename": "1.2-with-color.las",  
            "spatialreference": "EPSG:2027"  
        },  
        {  
            "filename": "1.2-with-color.las",  
            "spatialreference": "EPSG:2027"  
        },  
        {  
            "type": "filters.reprojection",  
            "out_srs": "EPSG:2028"  
        }  
    ]  
}
```

## Globbed Inputs

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

```
{  
    "pipeline": [  
        "/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.

### 7.1.5 API Considerations

A *Pipeline* is composed as an array of [pdal::Stage](#) (page 487), with the first stage at the beginning and the last at the end. There are two primary building blocks in PDAL,

`pdal::Stage` (page 487) and `pdal::PointView` (page 480). `pdal::Reader` (page 487), `pdal::Writer` (page 513), and `pdal::Filter` (page 470) are all subclasses of `pdal::Stage` (page 487).

`pdal::PointView` (page 480) is the substrate that flows between stages in a pipeline and transfers the actual data as it moves through the pipeline. A `pdal::PointView` (page 480) contains a `pdal::PointTablePtr`, which itself contains a list of `pdal::Dimension` (page 461) objects that define the actual channels that are stored in the `pdal::PointView` (page 480).

PDAL provides three types of stages – `pdal::Reader` (page 487), `pdal::Writer` (page 513) and `pdal::Filter` (page 470). A Reader is a producer of data, a Writer is a consumer of data, and a Filter is an actor on data.

---

**Note:** As a C++ API consumer, it isn't necessary to be aware of the underlying storage of point data, but in cases where you just “want the data”, the function `pdal::PointView::getBytes()` exists. The class `pdal::PointLayout` provides information about the actual data layout.

---

## Usage

While pipeline objects are manipulable through C++ objects, it is often convenient to provide a pipeline directly using JSON. The JSON syntax mirrors the arrangement of the Pipeline, with options and auxiliary metadata added on a per-stage basis.

We have two use cases specifically in mind:

- a *command-line* (page 32) application that reads an JSON file to allow a user to easily construct arbitrary writer pipelines, as opposed to having to build applications custom to individual needs with arbitrary options, filters, etc.
- a user can provide JSON for a reader pipeline, construct it via a simple call to the `PipelineManager` API, and then use the `pdal::Stage::read()` function to perform the read and then do any processing of the points. This style of operation is very appropriate for using PDAL from within environments like Python where the focus is on just getting the points, as opposed to complex pipeline construction.

```
{  
  "pipeline": [  
    "/path/to/my/file/input.las",  
    "output.las"  
  ]  
}
```

---

**Note:** <https://github.com/PDAL/PDAL/blob/master/test/data/pipeline/> contains test suite

pipeline files that provide an excellent example of the currently possible operations.

---

## Stage Types

*pdal::Reader* (page 487), *pdal::Writer* (page 513), and *pdal::Filter* (page 470) are the C++ classes that define the stage types in PDAL.

---

**Note:** Issuing the command `pdal info --options` will list all available stages and their options. See *info* (page 29) for more.

---

## 7.2 Readers

Readers provide *Dimensions* (page 229) to *Pipeline* (page 45). 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 98), a complex database like *readers.oci* (page 79), or a network service like *readers.greyhound* (page 63).

### 7.2.1 readers.bpf

BPF is an NGA specification for point cloud data. The specification can be found at <https://nsgreg.nga.mil/doc/view?i=4220&month=8&day=30&year=2016>. 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

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

## Options

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

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

**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]

## 7.2.2 readers.buffer

The *readers.buffer* (page 56) 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 404) 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 404) for an example usage scenario for *readers.buffer* (page 56).

## Options

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

**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]

### 7.2.3 readers.ept

## Entwine Point Tile

(<https://github.com/connormanning/entwine/blob/master/doc/entwine-point-tile.md>) (EPT) is a hierarchical octree-based point cloud format suitable for real-time rendering and lossless archival. [Entwine](https://entwine.io/) (<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 at <http://potree.entwine.io> and <http://speck.ly>.

## Default Embedded Stage

This stage is enabled by default

## 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>) or Plasio

(<http://speck.ly/?s=http%3A%2F%2Fc%5B0->

7%5D.greyhound.io&r=ept%3A%2F%2Fna.entwine.io%2Fny&ca=-0&ce=49.06&ct=-

8239196%2C4958509.308%2C337&cd=42640.943&cmd=125978.13&ps=2&pa=0.1&ze=1&c0s=remote%3A

```
[  
  {  
    "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 writers.ept\_addon 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:

```
[ {  
  "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 106).

## Options

**filename** EPT resource from which to read. Because EPT resources do not have a file extension, to specify an EPT resource as a string, it must be prefixed with `ept://`. For example, `pdal translate ept://http://na.entwine.io/autzen autzen.laz.` [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.

**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 [:ref:'writers.ept\\_addon <EPT addon writer>'](#). 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 be used to override well-known [:ref:'dimensions'](#). 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` options 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 found via the files position in EPT metadata file `entwine-files.json`.

**threads** Number of worker threads used to download and process EPT data. A minimum of 4 will be used no matter what value is specified.

## 7.2.4 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.

**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

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

## Options

**bounds** What spatial extent should points be generated within? Text string of the form “[xmin,xmax],[ymin,ymax],[zmin,zmax]”. [Default: unit cube]

**count** How many synthetic points to generate before finishing? [Required, except when mode is ‘grid’]

**spatialreference** 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]

### 7.2.5 readers.gdal

The [GDAL](http://gdal.org) (<http://gdal.org>) reader reads [GDAL](http://www.gdal.org/formats_list.html) readable raster ([http://www.gdal.org/formats\\_list.html](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.

```
1  {
2      "pipeline": [
3          {
4              "type": "readers.gdal",
5              "filename": "./pdal/test/data/autzen/autzen.jpg"
6          ,
7          {
8              "type": "writers.text",
9              "filename": "outputfile.txt"
10         }
11     ]
12 }
```

## 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 113).

```
1  {
2      "pipeline": [
3          {
4              "type": "readers.gdal",
5              "filename": "./pdal/test/data/autzen/autzen.jpg",
6              "header", "Red, Green, Blue"
7
8          ,
9          {
10              "type": "writers.text",
11              "filename": "outputfile.txt"
12         }
13     ]
14 }
```

## Options

**filename** GDALOpen  
([http://www.gdal.org/gdal\\_8h.html#a6836f0f810396c5e45622c8ef94624d4](http://www.gdal.org/gdal_8h.html#a6836f0f810396c5e45622c8ef94624d4)) ‘able raster file to read [Required]

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

**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]

**header** A comma-separated list of *Dimensions* (page 229) IDs to map bands to. The length of the list must match the number of bands in the raster.

## 7.2.6 readers.geowave

The **GeoWave reader** uses [GeoWave](https://ngageoint.github.io/geowave/) (<https://ngageoint.github.io/geowave/>) to read from Accumulo. GeoWave entries are stored using [EPSG:4326](http://epsg.io/4326) (<http://epsg.io/4326>). Instructions for configuring the GeoWave plugin can be found [here](https://ngageoint.github.io/geowave/documentation.html#jace-jni-proxies-2) (<https://ngageoint.github.io/geowave/documentation.html#jace-jni-proxies-2>).

---

### Dynamic Plugin

This stage requires a dynamic plugin to operate

---

### Example

```
{  
  "pipeline": [  
    {  
      "type": "readers.geowave",  
      "zookeeper_url": "zookeeper1:2181,zookeeper2:2181,  
      ↪zookeeper3:2181",  
      "instance_name": "GeoWave",  
      "username": "user",  
      "password": "pass",  
      "table_namespace": "PDAL_Table",  
      "feature_type_name": "PDAL_Point",  
      "data_adapter": "FeatureCollectionDataAdapter",  
      "points_per_entry": "5000u",  
      "bounds": "([0,1000000], [0,1000000], [0,100])",  
      "filename": "./pdal/test/data/autzen/autzen.jpg"  
    },  
    {
```

```

    "type": "writers.text",
    "filename": "outputfile.txt"
}
]
}

```

## Options

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

**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]

**zookeeper\_url** The comma-delimited URLs for all zookeeper servers, this will be directly used to instantiate a ZookeeperInstance. [Required]

**instance\_name** the zookeeper instance name, this will be directly used to instantiate a ZookeeperInstance. [Required]

**username** The username for the account to establish an Accumulo connector. [Required]

**password** The password for the account to establish an Accumulo connector. [Required]

**table\_namespace** The table name to be used when interacting with GeoWave. [Required]

**feature\_type\_name** The feature type name to be used when interacting GeoWave. [Default: PDAL\_Point]

**data\_adapter** FeatureCollectionDataAdapter stores multiple points per Accumulo entry.  
FeatureDataAdapter stores a single point per Accumulo entry. [Default: FeatureCollectionDataAdapter]

**points\_per\_entry** Sets the maximum number of points per Accumulo entry when using FeatureCollectionDataAdapter. [Default: 5000u]

**bounds** The extent of the bounding rectangle to use to query points, expressed as a string, eg: “[xmin,xmax],[ymin,ymax],[zmin,zmax]”. [Default: unit cube]

### 7.2.7 readers.greyhound

The **Greyhound Reader** allows you to query point data from a [Greyhound](https://github.com/hobu/greyhound) (<https://github.com/hobu/greyhound>) server.

---

#### Dynamic Plugin

This stage requires a dynamic plugin to operate

---

## Example

```
{
  "pipeline": [
    {
      "type": "readers.greyhound",
      "url": "data.greyhound.io/resource/iowa-z",
      "filter": { "$and": [
        { "Path": "02004736.laz" },
        { "Classification": { "$ne": 7 } }
      ] }
    },
    "output.laz"
  ]
}
```

```
{
  "pipeline": [
    "greyhound://data.greyhound.io/resource/iowa-z/read?filter={\\"
    ↪"Path\":\\"02004736.laz\\\"}",
    "02004736.laz"
  ]
}
```

## Options

Many of the options to this reader are reproductions of Greyhound query parameter options (see Greyhound `read` (<https://greyhound.io/clientDevelopment.html#the-read-query>) query documentation). These options may be specified as query parameters to the `url` parameter or specified separately. Separately specified parameters take precedence over query-parameter specified parameters.

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

**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]

**url** Greyhound server URL, or a full Greyhound `read` (<https://greyhound.io/clientDevelopment.html#the-read-query>) query URL. If specified as a full Greyhound query URL, no other options need to be present.

**resource** Name of the Greyhound resource to access.

**bounds** Spatial bounds to query, expressed as a string, e.g. `([xmin, xmax], [ymin, ymax])` or `([xmin, xmax], [ymin, ymax], [zmin, zmax])` or as a Greyhound `bounds array` (<https://github.com/hobu/greyhound/blob/master/doc/clientDevelopment.rst#bounds-arrays>)

option). By default, the entire resource is queried.

**depth\_begin** Beginning octree depth to query, inclusive. Lower depth values have coarser resolution, so a depth range of `[0, 8)` could provide a low-resolution overview of the entire resource, for example. [Default: **0**]

**depth\_end** Ending octree depth to query, non-inclusive. A value of **0** will search all depths greater-than or equal-to `depth_begin`. If non-zero, this value should be greater than `depth_begin` or the result will always be empty. [Default: **0**]

**filter** Server-side filtering may be requested which may further limit the data selected by the query. The filter is represented as JSON, and performs filtering on dimensions present in the resource, or the pseudo-dimension *Path*, corresponding to [tile\\_path](#) (page 65) values.

Arbitrary logic combinations may be created using [comparison](#) (<https://docs.mongodb.com/manual/reference/operator/query-comparison/>) and [logical](#) (<https://docs.mongodb.com/manual/reference/operator/query-logical/>) query operators with syntax matching that of MongoDB. Some sample filters follow.

```
{  
    "Path": { "$in": ["tile-845.laz", "tile-846.laz"] },  
    "Classification": { "$ne": 18 }  
}
```

```
{ "$or": [  
    { "Red": { "$gt": 200 } },  
    { "Blue": { "$gt": 120, "$lt": 130 } },  
    { "Classification": { "$nin": [2, 3] } }  
]
```

**tile\_path** A Greyhound resource may be an aggregation of multiple input files. If a `tile_path` option is present, then only points belonging to that file will be queried. This search is spatially optimized, so no `bounds` (page 64) option needs to be present to limit the query bounds. This is a convenience option that simply produces a [filter](#) (page 65) of `{"Path": <value>}`.

**dims** A JSON array of the string dimension names which should be read. By default, all native dimensions from the resource's schema (from the [info](#) (<https://greyhound.io/clientDevelopment.html#the-info-query>) of the resource) will be read.

**buffer** A ratio by which to bloat any requested bounds, where the additional enlarged area will be masked off from the Greyhound writer. This parameter may be used to eliminate edge effects from a tiled Greyhound reader/writer pipeline by bloating each tile by some percentage to introduce an overlap which will be read but *not* written. For example, a value of **0.15** will bloat the bounds by 15%.

## 7.2.8 readers.i3s

Indexed 3d Scene Layer (I3S) (<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.

### 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.

```
{  
    "pipeline": [  
        {  
            "type": "readers.i3s",  
            "filename": "https://tiles.arcgis.com/tiles/  
↪8cv2FuXuWSff0nbL/arcgis/rest/services/AUTZEN_LiDAR/SceneServer",  
            "bounds": "([-123.075542,-123.06196],[44.049719,44.  
↪06278])"  
        }  
    ]  
}
```

```
pdal translate i3s://https://tiles.arcgis.com/tiles/8cv2FuXuWSff0nbL/  
↪arcgis/rest/services/AUTZEN_LiDAR/SceneServer \  
autzen.las \  
--readers.i3s.threads=64 \  
--readers.i3s.bounds="([-123.075542,-123.06196],[44.049719,44.  
↪06278])"
```

### Options

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

**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]

**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`

**bounds** The bounds refers to the extents of the resource in X, Y, Z coordinates with the Z dimension being optional. This must be input as a string.

Example: `readers.i3s.bounds="([xmin,xmax],[ymin,ymax],[zmin,zmax])"`

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

Esri	Pdal
INTENSITY	Intensity
CLASS_CODE	ClassFlags
FLAGS	Flag
RETURNS	NumberOfReturns
USER_DATA	UserData
POINT_SRC_ID	PointSourceId
GPS_TIME	GpsTime
SCAN_ANGLE	ScanAngleRank
RGB	Red

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`

## 7.2.9 readers.ilvis2

The **ILVIS2 reader** read from files in the ILVIS2 format. See  
<http://nsidc.org/data/docs/daac/icebridge/ilvis2/index.html> for more information

---

### Default Embedded Stage

This stage is enabled by default

---

## Parameter Description

The IceBridge LVIS Level-2 Geolocated Surface Elevation Product ASCII text format data files contain fields as described in Table 2.

Table 2. ASCII Text File Parameter Description

Parameter	Description	Units
LVIS_LFID	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.	n/a
SHOTNUMBER	Laser shot assigned during collection	n/a
TIME	UTC decimal seconds of the day	Seconds
LONGITUDE_CENTROID	Refers to the centroid longitude of the corresponding LVIS Level-1B waveform.	Degrees east
LATITUDE_CENTROID	Refers to the centroid latitude of the corresponding LVIS Level-1B waveform.	Degrees north
ELEVATION_CENTROID	Refers to the centroid elevation of the corresponding LVIS Level-1B waveform.	Meters
LONGITUDE_LOW	Longitude of the lowest detected mode within the waveform	Degrees east
LATITUDE_LOW	Latitude of the lowest detected mode within the waveform	Degrees north
ELEVATION_LOW	Mean elevation of the lowest detected mode within the waveform	Meters
LONGITUDE_HIGH	Longitude of the center of the highest mode in the waveform	Degrees east
LATITUDE_HIGH	Latitude of the center of the highest mode in the waveform	Degrees north
ELEVATION_HIGH	Elevation of the center of the highest mode in the waveform	Meters

Fig. 7.3: Dimensions provided by the ILVIS2 reader

---

## Streamable Stage

This stage supports streaming operations

---

## Example

```
{  
  "pipeline": [  
    {  
      "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]

**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]

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

**metadata** XML metadata file to coincidentally read [Optional]

### 7.2.10 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://www.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://www.laszip.org>) or [LAZperf](#) (<https://github.com/verma/laz-perf>). See the [compression](#) (page 71) 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 113) 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](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

```
1  {
2      "pipeline": [
3          {
4              "type": "readers.las",
5              "filename": "inputfile.las"
6          },
7          {
8              "type": "writers.text",
9              "filename": "outputfile.txt",
10         }
11     ]
12 }
```

### Options

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

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

**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]

**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>, ... where  
type is one of: int8, int16, int32, int64, uint8, uint16, uint32, uint64, float, double. \_t  
may be added to any of the type names as well (e.g., uint32\_t).

---

**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’]

## 7.2.11 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 *Dimensions* (page 229) 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

```
{  
  "pipeline": [  
    {  
      "type": "readers.matlab",  
      "struct": "PDAL",  
    },  
    {  
      "type": "writers.osgb",  
      "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]

**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]

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

## 7.2.12 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](#) (<http://www.ledo.columbia.edu/res/pi/MB-System/>) library to read the data and therefore supports [all formats](#) (<https://www.ledo.columbia.edu/res/pi/MB-System/html/mbio.html#lbAI>) 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.

```
{
  "pipeline": [
    {
      "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]

**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]

**format** Name of number of format of file being read. See MB-System documentation for a list of all formats (<https://www.ledo.columbia.edu/res/pi/MB-System/html/mbio.html#lbAI>). [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]

### 7.2.13 readers.mrsid

Implements MrSID 4.0 LiDAR Compressor. It requires the [Lidar\\_DSDK](#) (<https://www.lizardtech.com/developer/>) to be able to decompress and read data.

---

#### Dynamic Plugin

This stage requires a dynamic plugin to operate

---

## Example

```
{  
  "pipeline": [  
    {  
      "type": "readers.mrsid",  
      "filename": "myfile.sid"  
    },  
    {  
      "type": "writers.las",  
      "filename": "outputfile.las"  
    }  
  ]  
}
```

## Options

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

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

**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]

### 7.2.14 readers.nitf

The **NITF** ([http://en.wikipedia.org/wiki/National\\_Imagery\\_Transmission\\_Format](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://jitic.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 69) and [writers.las](#) (page 113) 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

```
{  
  "pipeline": [  
    {  
      "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]

**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]

**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>, ... where type is one of: int8, int16, int32, int64, uint8, uint16, uint32, uint64, float, double. \_t may be added to any of the type names as well (e.g., uint32\_t).

---

**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”]

## 7.2.15 readers.numpy

PDAL has support for processing data using [filters.python](#) (page 221), 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](#) (page 76) 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:

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

```
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')])])
```

*readers.numpy* (page 76) supports reading these Numpy arrays and mapping field names to standard PDAL *dimension* (page 229) 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.

```
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
```

```
{
  "filename": "..\\test\\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,
        "name": "Y",
        "position": 1,
        "stddev": 28.87633116,
        "variance": 833.8425015
    },
    {
        "average": 0.01112664759,
        "count": 10000,
        "maximum": 0.5189296418,
        "minimum": -0.5189296418,
        "name": "Intensity",
        "position": 2,
        "stddev": 0.2024120437,
        "variance": 0.04097063545
    }
]
}
```

## 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

---

## Options

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

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

**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]

**dimension** Dimension name from *Dimensions* (page 229) 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.]

---

**Note:** The functionality of the ‘assign\_z’ option in previous versions is provided with *filters.assign* (page 137)

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

---

## 7.2.16 readers.oci

The OCI reader is used to read data from Oracle point cloud ([http://docs.oracle.com/cd/B28359\\_01/appdev.111/b28400/sdo\\_pc\\_pkg\\_ref.htm](http://docs.oracle.com/cd/B28359_01/appdev.111/b28400/sdo_pc_pkg_ref.htm)) databases.

---

### Dynamic Plugin

This stage requires a dynamic plugin to operate

---

### Example

```
{  
  "pipeline": [  
    {
```

```
"type": "readers.oci",
  "query": "SELECT \r\n          1.\"OBJ_ID\", 1.\"BLK_ID\", 1.\\"  
→\"BLK_EXTENT\", \r\n          1.\"BLK_DOMAIN\", 1.\"PCBLK_MIN_RES\"  
→\", \r\n          1.\"PCBLK_MAX_RES\", 1.\"NUM_POINTS\", \r\n→\r\n          1.\"NUM_UNSORTED_POINTS\", 1.\"PT_SORT_DIM\", \r\n→\r\n          1.\"POINTS\", b.cloud\r\n      FROM AUTZEN_BLOCKS 1, AUTZEN_  
→CLOUD b\r\n      WHERE 1.obj_id = b.id and 1.obj_id in (1,  
→2)\r\n      ORDER BY 1.obj_id",
  "connection": "grid/grid@localhost/orcl",
  "populate_pointsourceid": "true"
},
{
  "type": "writers.las",
  "filename": "outputfile.las"
}
]
```

## Options

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

**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]

**connection** Oracle connection string to connect to database, in the form  
“user/pass@host/instance” [Required]

**query** SELECT statement that returns an SDO\_PC object as its first and only queried item  
[Required]

**xml\_schema\_dump** Filename to dump the XML schema to.

**populate\_pointsourceid** Boolean value. If true, then add in a point cloud to every point read  
on the PointSourceId dimension. [Default: **false**]

## 7.2.17 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

```
{
  "pipeline": [
    {
      "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]

**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]

### 7.2.18 readers.pcd

The **PCD Reader** supports reading from [Point Cloud Data \(PCD\)](#) ([http://pointclouds.org/documentation/tutorials/pcd\\_file\\_format.php](http://pointclouds.org/documentation/tutorials/pcd_file_format.php)) formatted files, which are used by the [Point Cloud Library \(PCL\)](#) (<http://pointclouds.org>).

---

**Note:** The *PCD Reader* requires linkage of the [PCL](#) (<http://pointclouds.org>) library.

---



---

## Dynamic Plugin

This stage requires a dynamic plugin to operate

---

## Example

```
{
  "pipeline": [
```

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

## Options

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

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

**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]

## 7.2.19 readers.pgpointcloud

The **PostgreSQL Pointcloud Reader** allows you to read from a PostgreSQL database that the **PostgreSQL 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 on the way with a “where” clause.

---

### Dynamic Plugin

This stage requires a dynamic plugin to operate

---

## Example

```
{  
    "pipeline": [  
        {  
            "type": "readers.pgpointcloud",  
            "connection": "dbname='lidar' user='user'",  
            "table": "lidar",  
            "x_min": -122.332,  
            "y_min": 37.771,  
            "x_max": -122.332,  
            "y_max": 37.771  
        }  
    ]  
}
```

```

    "column": "pa",
    "spatialreference": "EPSG:26910",
    "where": "PC_Intersects(pa, ST_MakeEnvelope(560037.36, 5114846.
→45, 562667.31, 5118943.24, 26910))",
},
{
    "type": "writers.text",
    "filename": "output.txt"
}
]
}

```

## Options

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

**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]

**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**]

## 7.2.20 readers.ply

The **ply reader** reads points and vertices from the [polygon file format](http://paulbourke.net/dataformats/ply/) (<http://paulbourke.net/dataformats/ply/>), a common file format for storing three dimensional models. The [rply library](http://w3.impa.br/~diego/software/rply/) (<http://w3.impa.br/~diego/software/rply/>) is included with the PDAL source, so there are no external dependencies.

---

**Note:** The ply reader can read ASCII and binary ply files.

---



---

### Default Embedded Stage

---

This stage is enabled by default

---



---

### Streamable Stage

This stage supports streaming operations

---

## Example

```
{  
  "pipeline": [  
    {  
      "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]

**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]

### 7.2.21 readers pts

The **PTS reader** reads data from Leica Cyclone PTS files. It is not very sophisticated.

---

#### Default Embedded Stage

This stage is enabled by default

---

## Example Pipeline

```
{  
  "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]

**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]

## 7.2.22 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

```
{
    "pipeline": [
        {
            "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]

**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]

**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.

## 7.2.23 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

---

### Installation

To build PDAL with rdb support, set `rdb_DIR` to the path of your local rdbleb installation. rdbleb can be obtained from the [RIEGL download pages](http://www.riegl.com/members-area/software-downloads/libraries/) (<http://www.riegl.com/members-area/software-downloads/libraries/>) with a properly enabled user account. The rdbleb 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) (<http://pdal.io/compilation/unix.html#configure-your-optional-libraries>).

---

### Note:

- Minimum rdbleb 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 6).

```
1  {
2      "pipeline": [
3          {
4              "type": "readers.rdb",
5              "filename": "autzen-thin-srs.rdbo",
6              "filter": "riegl.class == 2"
7          },
8          {
9              "type": "writers.las",
10             "filename": "autzen-thin-srs.rdbo"
11         }
12     ]
13 }
```

## Options

**filename** Name of file to read [Required]

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

**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]

**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):

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

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 7.1: Example:

```

1  {
2      "bounds": {
3          "maximum": {
4              "X": -2504493.762,
5              "Y": -3846841.252,
6              "Z": 4413210.394
7          },
8          "minimum": {
9              "X": -2505882.459,
10             "Y": -3848231.393,
11             "Z": 4412172.548
12         }
13     },
14     "points": 10653,
15     "uuid": "637de54d-7e6b-4004-b6ab-b6bc588ec9ea"
16 }
```

## List “dimensions”

List of point attribute description objects.

Listing 7.2: Example:

```

1  [
2      {
3          "compression_options": "shuffle",
4          "default_value": 0,
5          "description": "Cartesian point coordinates wrt. application\u2019s
→coordinate system (0: X, 1: Y, 2: Z)",
6          "invalid_value": "",
7          "length": 3,
8          "maximum_value": 535000,
9          "minimum_value": -535000,
10         "name": "riegl.xyz",
11         "resolution": 0.00025,
12         "scale_factor": 1,
13         "storage_class": "variable",
14         "title": "XYZ",
15         "unit_symbol": "m"
16     },
17     {
18         "compression_options": "shuffle",
19         "default_value": 0,
20         "description": "Target surface reflectance",
21         "invalid_value": ""}
```

```

21 "length": 1,
22 "maximum_value": 327.67,
23 "minimum_value": -327.68,
24 "name": "riegl.reflectance",
25 "resolution": 0.01,
26 "scale_factor": 1,
27 "storage_class": "variable",
28 "title": "Reflectance",
29 "unit_symbol": "dB"
30 } ]

```

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 7.3: Example:

```

1 {
2     "riegl.scan_pattern": {
3         "rectangular": {
4             "phi_start": 45.0,
5             "phi_stop": 270.0,
6             "phi_increment": 0.040,
7             "theta_start": 30.0,
8             "theta_stop": 130.0,
9             "theta_increment": 0.040,
10            "program": {
11                "name": "High Speed"
12            }
13        }
14    },
15    "riegl.geo_tag": {
16        "crs": {
17            "epsg": 4956,
18            "wkt": "GEOCCS [\"NAD83 (HARN) \\/ Geocentric\", DATUM[\
→ \"NAD83 (HARN) \", SPHEROID [\"GRS 1980\", 6378137.000, 298.257222101, \
→ AUTHORITY [\"EPSG\", \"7019\"]], AUTHORITY [\"EPSG\", \"6152\"]], \
→ PRIMEM [\"Greenwich\", 0.0000000000000000], AUTHORITY [\"EPSG\", \"8901\ \
→ \"], UNIT [\"Meter\", 1.0000000000000000, AUTHORITY [\"EPSG\", \
→ \"9001\"]], AXIS [\"X\", OTHER], AXIS [\"Y\", EAST], AXIS [\"Z\", NORTH], \
→ AUTHORITY [\"EPSG\", \"4956\"]]"
19        },
20        "pose": [
21            0.837957447, 0.379440385, -0.392240121, -2505819.156,

```

```

22     -0.545735575,  0.582617132,  -0.602270669,  -3847595.645,
23     0.000000000,  0.718736580,   0.695282481,   4412064.882,
24     0.000000000,  0.000000000,   0.000000000,           1.000
25   ]
26 }
27 }
```

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 7.4: Example:

```

1 [ {
2   "agent": "RDB Library 2.1.6-1677 (x86_64-windows, Apr  5 2018, ↵
3   ↵10:58:39)",
4   "comments": "",
5   "id": 1,
6   "rdb": "RDB Library 2.1.6-1677 (x86_64-windows, Apr  5 2018, ↵
7   ↵10:58:39)",
8   "settings": {
9     "cache_size": 524288000,
10    "chunk_size": 65536,
11    "chunk_size_lod": 20,
12    "compression_level": 10,
13    "primary_attribute": {
14      "compression_options": "shuffle",
15      "default_value": 0,
16      "description": "Cartesian point coordinates wrt. application ↵
17      ↵coordinate system (0: X, 1: Y, 2: Z)",
18      "invalid_value": "",
19      "length": 3,
20      "maximum_value": 535000,
21      "minimum_value": -535000,
22      "name": "riegl.xyz",
23      "resolution": 0.00025,
24      "scale_factor": 1,
```

```
22     "storage_class": "variable",
23     "title": "XYZ",
24     "unit_symbol": "m"
25   }
26 },
27 "start": "2018-04-06 10:10:39.336",
28 "stop": "2018-04-06 10:10:39.336",
29 "title": "Database creation"
30 },
31 {
32   "agent": "rdbconvert",
33   "comments": "",
34   "id": 2,
35   "rdb": "RDB Library 2.1.6-1677 (x86_64-windows, Apr 5 2018, ↵
36   ↪10:58:39)",
37   "settings": "",
38   "start": "2018-04-06 10:10:39.339",
39   "stop": "2018-04-06 10:10:39.380",
40   "title": "Import"
41 },
42 {
43   "agent": "RISCAN PRO 64 bit v2.6.3",
44   "comments": "",
45   "id": 3,
46   "rdb": "RDB Library 2.1.6-1677 (x86_64-windows, Apr 5 2018, ↵
47   ↪10:58:39)",
48   "settings": "",
49   "start": "2018-04-06 10:10:41.666",
50   "stop": "2018-04-06 10:10:41.666",
51   "title": "Meta data saved"
52 }
```

Details about the transaction objects see RDB SDK documentation.

### 7.2.24 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

---

## 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). For help building PDAL with optional libraries, see [the optional library documentation](#) (<http://pdal.io/compilation/unix.html#configure-your-optional-libraries>).

## 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.

```
{
  "pipeline": [
    {
      "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 113). 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 221) 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]

**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]

**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 *min\_reflectance* to *max\_reflectance* to the range 0-65535. Values less than *min\_reflectance* are assigned the value 0. Values greater *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]

## 7.2.25 readers.sbet

The **SBET reader** read from files in the SBET format, used for exchange data from interital 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

```
{  
  "pipeline": [  
    ...  
  ]  
}
```

```

    "sbetfile.sbet",
    "output.las"
]
}

```

## Options

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

**angles\_as\_degrees** Convert all angles to degrees. If false, angles are read as radians. [Default: true]

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

**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]

## 7.2.26 readers.sqlite

The [SQLite](https://sqlite.org/) (<https://sqlite.org/>) point cloud reader allows you to read data stored in a SQLite database using a scheme that PDAL wrote using the *writers.sqlite* (page 130) writer. Much like the *writers.oci* (page 122) and *writers.pgpointcloud* (page 127), the SQLite driver stores data in tables that contain rows of patches. Each patch contains a number of spatially contiguous points

---

### Dynamic Plugin

This stage requires a dynamic plugin to operate

---

### Example

```

{
  "pipeline": [
    {
      "type": "readers.sqlite",
      "connection": "inputfile.sqlite",
      "query": "SELECT b.schema, l.cloud, l.block_id, l.num_points, l.\n      ↵bbox, l.extent, l.points, b.cloud\r\n                                FROM\r\n      ↵simple_blocks l, simple_cloud b\r\n                                WHERE l.\n      ↵cloud = b.cloud and l.cloud in (1)\r\n                                order by\r\n      ↵l.cloud"
    },
  ]
}

```

```
{  
    "type": "writers.las",  
    "filename": "outputfile.las"  
}  
]  
}
```

## Options

**query** SQL statement that selects a schema XML, cloud id, bbox, and extent [Required]

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

**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]

## 7.2.27 readers.slpk

Scene Layer Packages (SLPK) ([https://github.com/Esri/i3s-spec/blob/master/format/Indexed%203d%20Scene%20Layer%20Format%20Specification.md#\\_8\\_1](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 66) files together and store them locally rather than find information through REST.

## 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.

```
{  
    "pipeline": [  
        {  
            "type": "readers.slpk",  
            "filename": "PDAL/test/data/i3s/SMALL_AUTZEN_LAS_All.slpk"  
            "bounds": "([-123.075542,-123.06196],[44.049719,44.  
            06278])"  
        }  
    ]  
}
```

```
pdal translate PDAL/test/data/i3s/SMALL_AUTZEN_LAS_All.slpk \
    autzen.las \
    --readers.slpk.bounds="([-123.075542,-123.06196],[44.049719,44. \
    ↪06278])``"
```

## 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]

**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 bounds refers to the extents of the resource in X, Y, Z coordinates with the Z dimension being optional. This must be input as a string.

Example: readers.slpk.bounds="([xmin,xmax],[ymin,ymax],[zmin,zmax])"

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

Esri	Pdal
INTENSITY	Intensity
CLASS_CODE	ClassFlags
FLAGS	Flag
RETURNS	NumberOfReturns
USER_DATA	UserData
POINT_SRC_ID	PointSourceId
GPS_TIME	GpsTime
SCAN_ANGLE	ScanAngleRank
RGB	Red

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

## 7.2.28 readers.terrassolid

The **Terrassolid Reader** loads points from terrassolid files (.bin). It supports boths Terrassolid format 1 and format 2.

### Example

```
{  
  "pipeline": [  
    {  
      "type": "readers.terrassolid",  
      "filename": "autzen.bin"  
    },  
    {  
      "type": "writers.las",  
      "filename": "output.las"  
    }  
  ]  
}
```

### Options

**filename** Input file name [Required]

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

**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]

## 7.2.29 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](http://en.cppreference.com/w/cpp/string/basic_string/stof) ([http://en.cppreference.com/w/cpp/string/basic\\_string/stof](http://en.cppreference.com/w/cpp/string/basic_string/stof)) properly for C++ language double-precision values.

The text reader expects a header line to 1) indicate the separator character for the fields and 2) name the dimension for each field in the points. Any single non-alphanumeric character can be used as a separator. The header line separator can be overridden by the 'separator' option (see below). 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 Pipeline**

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

## Options

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

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

**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]

**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’ 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]

## 7.2.30 readers.tiledb

Implements TileDB (<https://tiledb.io>) 1.4.1+ storage.

---

### Dynamic Plugin

This stage requires a dynamic plugin to operate

---

## Example

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

## Options

**array\_name** TileDB (<https://tiledb.io>) array to read from. [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]

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

**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]

## 7.2.31 readers.tindex

A [GDAL tile index](http://www.gdal.org/gdaltindex.html) (<http://www.gdal.org/gdaltindex.html>) is an [OGR](http://gdal.org/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 37) application to generate tile index files in any format that [OGR](http://gdal.org/ogr/) (<http://gdal.org/ogr/>) supports writing. Once you have the tile index, you can then use the [readers.tindex](#) (page 101) driver 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:

```
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 45) example to read and automatically merge the data.

```
{
  "pipeline": [
    {
      "type": "readers.tindex",
      "filter_srs": "+proj=lcc +lat_1=43 +lat_2=45.5 +lat_0=41.75",
      "filter_srs": "+lon_0=-120.5 +x_0=399999.999999999 +y_0=0 +ellps=GRS80 +units=ft",
      "filter_srs": "+no_defs",
      "filename": "index.sqlite",
```

```
"where": "location LIKE \'%interesting.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]

**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]

**lyr\_name** The OGR layer name for the data source to use to fetch the tile index information.

**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) ([http://www.gdal.org/ogr\\_sql.html](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** 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** or **boundary** option to this coordinate system before filtering or reading data. [Default: “EPSG:4326”]

**where** [OGR SQL](http://www.gdal.org/ogr_sql.html) ([http://www.gdal.org/ogr\\_sql.html](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**

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

**readers.bpf (page 55)** Read BPF files encoded as version 1, 2, or 3. BPF is an NGA specification for point cloud data.

*readers.buffer* (page 56) Special stage that allows you to read data from your own PointView rather than fetching data from a specific reader.

*readers.ept* (page 57) Used for reading Entwine Point Tile (<https://entwine.io>) format.

*readers.faux* (page 59) Used for testing pipelines. It does not read from a file or database, but generates synthetic data to feed into the pipeline.

*readers.gdal* (page 60) Read GDAL readable raster data sources as point clouds.

*readers.geowave* (page 62) Read point cloud data from Accumulo.

*readers.greyhound* (page 63) Query point cloud data from a Greyhound server.

*readers.i3s* (page 66) Read data stored in the Esri I3S format. The data is read from an appropriate server.

*readers.ilvis2* (page 67) Read from files in the ILVIS2 format.

*readers.las* (page 69) 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 71) Read point cloud data from MATLAB .mat files where dimensions are stored as arrays in a MATLAB struct.

*readers.mbio* (page 72) Read sonar bathymetry data from formats supported by the MB-System library.

*readers.mrsid* (page 73) Read data compressed by the MrSID 4.0 LiDAR Compressor. Requires the LizardTech Lidar\_DSDK.

*readers.nitf* (page 74) Read point cloud data (LAS or LAZ) wrapped in NITF 2.1 files.

*readers.numpy* (page 76) Read point cloud data from Numpy .npy files.

*readers.oci* (page 79) Read data from Oracle point cloud databases.

*readers.optech* (page 80) Read Optech Corrected Sensor Data (.csd) files.

*readers.pcd* (page 81) Read files in the PCD format.

*readers.pgpointcloud* (page 82) Read point cloud data from a PostgreSQL database with the PostgreSQL Pointcloud extension enabled.

*readers.ply* (page 83) Read points and vertices from either ASCII or binary PLY files.

*readers.pts* (page 84) Read data from Leica Cyclone PTS files.

*readers.qfit* (page 85) Read data in the QFIT format originated for NASA's Airborne Topographic Mapper project.

*readers.rxp* (page 92) 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 86) Read data in the RDB format, the in-house database format used by RIEGL. The reader requires a copy of rdbleib during compilation and usage.

*readers.sbet* (page 94) Read the SBET format.

*readers.sqlite* (page 95) Read data stored in a SQLite database.

*readers.slpk* (page 96) Read data stored in an Esri SLPK file.

*readers.terrassolid* (page 98) TerraSolid Reader

*readers.text* (page 98) Read point clouds from ASCII text files.

*readers.tiledb* (page 100) Read point cloud data from a TileDB instance.

*readers.tindex* (page 101) 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.

## 7.3 Writers

Writers consume data provided by *Readers* (page 55). 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 229)

---

### 7.3.1 writers.bpf

BPF is an NGA specification for point cloud data. The specification can be found at <https://nsgreg.nga.mil/doc/view?i=4202> 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

```
{
  "pipeline": [
    {
      "type": "readers.bpf",
      "filename": "inputfile.las"
    },
    {
      "type": "writers.bpf",
      "filename": "outputfile.bpf"
    }
  ]
}
```

## 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 203), [filters.chipper](#) (page 198) or [filters.divider](#) (page 201). [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.

### 7.3.2 writers.eptAddon

The **EPT Addon Writer** supports writing additional dimensions to [Entwine Point Tile](https://github.com/connormanning/entwine/blob/master/doc/entwine-point-tile.md) (<https://github.com/connormanning/entwine/blob/master/doc/entwine-point-tile.md>) datasets. The EPT addon writer may only be used in a pipeline with an [EPT reader](#) (page 57), 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 :ref:`filters.smrf <SMRF filter>`\_, 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 :ref:`readers.ept <EPT reader>` - with the created addon overwriting the Classification value - and then writing the output to a single file with the :ref:`writers.las <LAS writer>`.

```
[{
  "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"
}]
```

Here is an example of using multiple mappings in the addons option, to apply a new color scheme with *filters.colorinterp* (page 138) mapping the Red, Green, and Blue dimensions to new values.

```
[{
  "type": "readers.ept",
  "filename": "http://na.entwine.io/autzen/ept.json"
}, {
  "type": "filters.colorinterp"
}, {
  "type": "writers.ept_addon",
  "addons": {
    "~/entwine addons/autzen/interp/Red": "Red",
    "~/entwine addons/autzen/interp/Green": "Green",
    "~/entwine addons/autzen/interp/Blue": "Blue"
  }
}]
```

And to read the data with the new colors:

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

## 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.

### 7.3.3 writers.gdal

The **GDAL writer** creates a raster from a point cloud using an interpolation algorithm. Output is produced using [GDAL](http://gdal.org) (<http://gdal.org>) and can use any [driver that supports creation of rasters](#) ([http://www.gdal.org/formats\\_list.html](http://www.gdal.org/formats_list.html)). A [data\\_type](#) (page 110) 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 110) 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 110) and the square root of two. This is consistent with the original [Points2Grid](#) (<http://www.opentopography.org/otsoftware/points2grid>) application from which this algorithm has its roots. 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 111) 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](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 110) 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 110) 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 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 203), *filters.chipper* (page 198) or *filters.divider* (page 201). [Required]

**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: *resolution* (page 110) \* sqrt(2)]

**gdaldriver** GDAL code of the [GDAL driver](#) ([http://www.gdal.org/formats\\_list.html](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.

---

**data\_type** The data type to use for the output raster (double, float, int32, uint16, etc.). Many GDAL drivers only support a limited set of output data types. The default value 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 *data\_type* (page 110). -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]).

---

**Note:** The *bounds* (page 111) option is required when a pipeline is run in streaming mode.

---

### 7.3.4 writers.geowave

The **GeoWave writer** uses GeoWave (<https://github.com/locationtech/geowave>) to write to Accumulo. GeoWave entries are stored using **EPSG:4326** (<http://epsg.io/4326/>).

---

#### Dynamic Plugin

This stage requires a dynamic plugin to operate

---

#### Example

```
[  
  {  
    "type": "readers.qfit",  
    "filename": "inputfile.qi",  
    "flip_coordinates": "false",  
    "scale_z": "1.0"  
  },  
  {  
    "type": "writers.geowave",  
    "zookeeper_url": "zookeeper1:2181,zookeeper2:2181,  
↳zookeeper3:2181",  
    "instance_name": "GeoWave",  
    "username": "user",  
    "password": "pass",  
    "table_namespace": "PDAL_Table",  
    "feature_type_name": "PDAL_Point",  
    "data_adapter": "FeatureCollectionDataAdapter",  
    "points_per_entry": "5000u"  
  }  
]
```

## Options

**zookeeper\_url** The comma-delimited URLs for all zookeeper servers, this will be directly used to instantiate a ZookeeperInstance. [Required]

**instance\_name** The zookeeper instance name, this will be directly used to instantiate a ZookeeperInstance. [Required]

**username** The username for the account to establish an Accumulo connector. [Required]

**password** The password for the account to establish an Accumulo connector. [Required]

**table\_namespace** The table name to be used when interacting with GeoWave. [Required]

**feature\_type\_name** The feature type name to be used when interacting GeoWave. [Default: PDAL\_Point]

**data\_adapter** FeatureCollectionDataAdapter stores multiple points per Accumulo entry. FeatureDataAdapter stores a single point per Accumulo entry. [Default: FeatureCollectionDataAdapter]

**points\_per\_entry** Sets the maximum number of points per Accumulo entry when using FeatureCollectionDataAdapter. [Default: 5000u]

## 7.3.5 writers.greyhound

The **Greyhound writer** allows you to append new dimensions (or update existing appended dimensions) onto a Greyhound resource. The Greyhound writer may only be used in a pipeline downstream from a Greyhound reader. Written points must also match the points that were read in a 1:1 manner (although there is no restriction against reordering), so intermediate filters that cull points are not allowed.

### Example

This example runs the [SMRF](#) (page 169) ground-classification algorithm to populate the **Classification** dimension, the [ferry filter](#) (page 148) to copy this dimension to a new dimension named **Smrf**, and then adds this dimension to the Greyhound resource.

```
[  
  {  
    "type": "readers.greyhound",  
    "url": "data.greyhound.io/resource/autzen"  
  },  
  {  
    "type": "filters.smrf"  
  },  
  {
```

```

    "type": "filters.ferry",
    "dimensions": "Classification=Smrf"
},
{
    "type": "writers.greyhound",
    "name": "MySmrfDimensionSet",
    "dims": ["Smrf"]
}
]

```

## Options

Many options that affect the behavior of the Greyhound writer are specified as parameters to the *Greyhound reader* (page 63), which are forwarded to the Greyhound writer.

**name** A string value for the name of this dimension set. This setting is used internally by the Greyhound server to group clusters of simultaneously appended dimensions. For example, a group of multiple classifications with different filter settings like `[“SmrfCellSize_1.0”, “SmrfCellSize_1.5”]` might be grouped as `“SmrfComparison”`.

**dims** A JSON array of string names of the dimensions to be written to the Greyhound resource.

### 7.3.6 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 115) 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 `vtrs` with objects containing `user_id` and `data` items.

```
[  
  {  
    "type": "readers.las",  
    "filename": "inputfile.las"  
  },  
  {  
    "type": "writers.las",  
    "vtrs": [  
      {  
        "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": "dGhpcyBpcyBzb21lIG1vcnUgdGV4dA=="  
      }]  
    "filename": "outputfile.las"  
  }  
]
```

## Example

```
[  
  {  
    "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 203), [filters.chipper](#) (page 198) or [filters.divider](#) (page 201). [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 == 0, Dec 31 == 365) 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 1 and 65535) [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]

**extra\_dims** 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>`, ... where

type is one of: int8, int16, int32, int64, uint8, uint16, uint32, uint64, float, double \_t may be added to any of the type names as well (e.g., uint32\_t). When the version of the output file is specified as 1.4 or greater, an extra bytes VLR (User ID: LASF\_Spec, Record ID: 4), is created that describes the extra dimensions specified by this option.

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.

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/) (<http://www.json.org/>) output with both the *Metadata* (page 402) and *Pipeline* (page 45) serialization. [Default: false]

### 7.3.7 writers.matlab

The **Matlab Writer** supports writing Matlab `.mat` files.

The produced files has a single variable, *PDAL*, an array struct.

Variables - PDAL	
Field	Value
X	1065x1 double
Y	1065x1 double
Z	1065x1 double
Intensity	1065x1 uint16
ReturnNumber	1065x1 uint8
NumberOfReturns	1065x1 uint8
ScanDirectionFlag	1065x1 uint8
EdgeOfFlightLine	1065x1 uint8
Classification	1065x1 uint8
ScanAngleRank	1065x1 single
UserData	1065x1 uint8
PointSourceId	1065x1 uint16
GpsTime	1065x1 double
Red	1065x1 uint16
Green	1065x1 uint16
Blue	1065x1 uint16

---

**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

```
[  
 {  
   "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”]

### 7.3.8 writers.nitf

The [NITF](http://en.wikipedia.org/wiki/National_Imagery_Transmission_Format) ([http://en.wikipedia.org/wiki/National\\_Imagery\\_Transmission\\_Format](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

---

## 7.3. Writers

```
[  
  {  
    "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

```
[  
  {  
    "type": "readers.las",  
    "filename": "inputfile.las"  
  },  
  {  
    "type": "writers.nitf",  
    "compression": "laszip",  
    "idatim": "20160102220000",  
    "forward": "all",  
    "acftb": "SENSOR_ID:LIDAR,SENSOR_ID_TYPE:LILN",  
    "aimidb": "ACQUISITION_DATE:20160102235900",  
    "filename": "outputfile.ntf"  
  }  
]
```

### 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 203), *filters.chipper* (page 198) or *filters.divider* (page 201).

**level** File complexity level (2 characters) [Default: **03**]

**stype** Standard type (4 characters) [Default: **BF01**]

**ostaid** Originating station ID (10 characters) [Default: **PDAL**]

**ftitle** File title (80 characters) [Default: <spaces>]

**fsclas** File security classification ('T', 'S', 'C', 'R' or 'U') [Default: **U**]

**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]

### 7.3.9 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

```
[  
 {  
   "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.

### 7.3.10 writers.oci

The OCI writer is used to write data to [Oracle point cloud](#) ([http://docs.oracle.com/cd/B28359\\_01/appdev.111/b28400/sdo\\_pc\\_pkg\\_ref.htm](http://docs.oracle.com/cd/B28359_01/appdev.111/b28400/sdo_pc_pkg_ref.htm)) databases.

---

#### Dynamic Plugin

This stage requires a dynamic plugin to operate

---

## Example

```
[
{
    "type": "readers.las",
    "filename": "inputfile.las"
},
{
    "type": "writers.oci",
    "connection": "grid/grid@localhost/orcl",
    "block_table_name": "QFIT_BLOCKS",
    "base_table_name": "QFIT_CLOUD",
    "cloud_column_name": "CLOUD",
    "srid": "4269",
    "capacity": "5000"
}
```

```

    }
]
```

## Options

**connection** Oracle connection string to connect to database

**is3d** Should we use 3D objects (include the z dimension) for SDO\_PC PC\_EXTENT, BLK\_EXTENT, and indexing [Default: false]

**solid** Define the point cloud's PC\_EXTENT geometry gtype as (1,1007,3) instead of the normal (1,1003,3), and use gtype 3008/2008 vs 3003/2003 for BLK\_EXTENT geometry values. [Default: false]

**overwrite** Wipe the block table and recreate it before loading data [Default: false]

**verbose** Wipe the block table and recreate it before loading data [Default: false]

**srid** The Oracle numerical SRID value to use for PC\_EXTENT, BLK\_EXTENT, and indexing [Default: 0]

**capacity** The block capacity or maximum number of points a block can contain. [Default: 0]

**stream\_output\_precision** The number of digits past the decimal place for writing floats/doubles to streams. This is used for creating the SDO\_PC object and adding the index entry to the USER\_SDO\_GEOM\_METADATA for the block table. [Default: 8]

**cloud\_id** The point cloud id that links the point cloud object to the entries in the block table. [Default: -1]

**block\_table\_name** The table in which block data for the created SDO\_PC will be placed. [Default: “output”]

**block\_table\_partition\_column** The column name for which ‘block\_table\_partition\_value’ will be placed in the ‘block\_table\_name’.

**block\_table\_partition\_value** Integer value to use to assing partition IDs in the block table. Used in conjunction with ‘block\_table\_partition\_column’ [Default: 0]

**base\_table\_name** The name of the table which will contain the SDO\_PC object. [Default: “hobu”]

**cloud\_column\_name** The column name in ‘base\_table\_name’ that will hold the SDO\_PC object. [Default: “CLOUD”]

**base\_table\_aux\_columns** Quoted, comma-separated list of columns to add to the SQL that gets executed as part of the point cloud insertion into the ‘base\_table\_name’ table.

**base\_table\_aux\_values** Quoted, comma-separated values that correspond to ‘base\_table\_aux\_columns’, entries that will get inserted as part of the creation of the

SDO\_PC entry in the ‘base\_table\_name’ table.

**base\_table\_boundary\_column** The SDO\_GEOMETRY column in ‘base\_table\_name’ in which to insert the WKT in ‘base\_table\_boundary\_wkt’ representing a boundary for the SDO\_PC object. Note this is not the same as the ‘base\_table\_bounds’, which is just a bounding box that is placed on the SDO\_PC object itself.

**base\_table\_boundary\_wkt** WKT, in the form of a string or a file location, to insert into the SDO\_GEOMETRY column defined by ‘base\_table\_boundary\_column’.

**pre\_block\_sql** SQL, in the form of a string or file location, that is executed after the SDO\_PC object has been created but before the block data in ‘block\_table\_name’ are inserted into the database.

**pre\_sql** SQL, in the form of a string or file location, that is executed before the SDO\_PC object is created.

**post\_block\_sql** SQL, in the form of a string or file location, that is executed after the block data in ‘block\_table\_name’ have been inserted

**base\_table\_bounds** A bounding box, given in the Oracle SRID specified in ‘srid’ to set on the PC\_EXTENT object of the SDO\_PC. If none is specified, the cumulated bounds of all of the block data are used.

**pc\_id** Point Cloud id [Default: -1]

**pack\_ignored\_fields** Pack ignored dimensions out of the data buffer that is written [Default: true]

**do\_trace** turn on server-side binds/waits tracing – needs ALTER SESSION privs. [Default: false]

**stream\_chunks** Stream block data chunk-wise by the DB’s chunk size rather than as an entire blob. [Default: false]

**blob\_chunk\_count** When streaming, the number of chunks per write to use [Default: 16]

**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.

**tolerance** Oracle geometry tolerance. X, Y, and Z dimensions are all currently specified as a single value [Default: 0.05]

### 7.3.11 writers.ogr

The **OGR Writer** will create files of various [vector formats](#) ([http://www.gdal.org/ogr\\_formats.html](http://www.gdal.org/ogr_formats.html)) as supported by the OGR library. PDAL points are generally stored as points in the output format, though PDAL will create multipoint objects instead of point objects if the ‘multicount’ argument is set to a value greater than 1. Points can be written with a single additional value in addition to location if ‘measure\_dim’ specifies a valid PDAL dimension and the output format supports measure point types.

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": "Compression"  
    }  
]
```

#### 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 203), [filters.chipper](#) (page 198) or [filters.divider](#) (page 201).

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’ option.

**multicount** If 1, point objects will be written. If greater than 1, specifies the number of points to group into a multipoint object. Not all OGR drivers support multipoint objects.  
[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]

---

**Note:** The **measure\_dim** option is only supported if PDAL is built with GDAL version 2.1 or later.

---

**ogrdriver** The OGR driver to use for output. This option overrides any inference made about output drivers from *filename* (page 125).

### 7.3.12 writers.pcd

The **PCD Writer** supports writing to Point Cloud Data (PCD) ([http://pointclouds.org/documentation/tutorials/pcd\\_file\\_format.php](http://pointclouds.org/documentation/tutorials/pcd_file_format.php)) 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. When compression is enabled, the output is PCD's binary-compressed format.

---

#### Dynamic Plugin

This stage requires a dynamic plugin to operate

---

---

**Note:** The *PCD Writer* requires linkage of the **PCL** (<http://pointclouds.org>) library.

---

#### 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”]

**xyz** Write only XYZ dimension? [Default: “false”]

**subtract\_minimum** Set origin to minimum of XYZ dimension? [Default: true]

**offset\_x, offset\_y, offset\_z** Offset to be subtracted from XYZ position [Default: 0.0]

**scale\_x, scale\_y, scale\_z** Scale to divide from XYZ dimension [Default: 1.0]

### 7.3.13 writers.pgpointcloud

The **PostgreSQL Pointcloud Writer** allows you to write to PostgreSQL database that have the [PostgreSQL Pointcloud](http://github.com/pramsey/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 198).

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) (<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 178) 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  
  },
```

```
{  
    "type": "writers.pgpointcloud",  
    "connection": "host='localhost' dbname='lidar' user='pramsey'  
    "table": "example",  
    "compression": "dimensional",  
    "srid": "26916"  
}  
]
```

## 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) (<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,x> 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.

### 7.3.14 writers.ply

The **ply writer** writes the [polygon file format](http://paulbourke.net/dataformats/ply/) (<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 211) and [filters.poisson](#) (page 214) 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’, and ‘default’. ‘default’ is binary output in the endianness of the machine. [Default: “ascii”]

**dims** List of dimensions to write as elements. [Default: all dimensions]

**faces** Write a mesh as faces in addition to writing points as vertices. [Default: false]

**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/fprintf>) reference for more information. [Default: g-style formatting (variable precision)]

### 7.3.15 writers.sbet

The **SBET writer** writes files in the SBET format, used for exchange data from interital measurement units (IMUs).

---

#### Default Embedded Stage

This stage is enabled by default

---

---

#### Streamable Stage

This stage supports streaming operations

---

### 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]

### 7.3.16 writers.sqlite

The [SQLite](#) (<http://sqlite.org>) driver outputs point cloud data into a PDAL-sepecific scheme that matches the approach of [readers.pgpointcloud](#) (page 82) and [readers.oci](#) (page 79).

---

## Dynamic Plugin

This stage requires a dynamic plugin to operate

---

## Example

```
[  
  {  
    "type": "readers.las",  
    "filename": "inputfile.las"  
  },  
  {  
    "type": "filters.chipper",  
    "capacity": 50  
  },  
  {  
    "type": "writers.sqlite",  
    "connection": "output.sqlite",  
    "cloud_table_name": "SIMPLE_CLOUD",  
    "pre_sql": "",  
    "post_sql": "",  
    "block_table_name": "SIMPLE_BLOCKS",  
    "cloud_column_name": "CLOUD",  
    "filename": "outputfile.pcd"  
  }  
]
```

---

## Options

**connection** SQLite filename [Required]

**cloud\_table\_name** Name of table to store cloud (file) information [Required]

**block\_table\_name** Name of table to store patch information [Required]

**cloud\_column\_name** Name of column to store primary cloud\_id key [Default: “cloud”]

**compression** Use [LAZperf](https://github.com/hobu/laz-perf) (<https://github.com/hobu/laz-perf>) compression technique to store patches. [Default: false]

**overwrite** Drop the table before writing. To append to the table set to `false`. [Default: true]

**pre\_sql** Optional 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.

**post\_sql** Optional 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.

**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.

### 7.3.17 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) (<http://geojson.org>) and [CSV](http://en.wikipedia.org/wiki/Comma-separated_values) ([http://en.wikipedia.org/wiki/Comma-separated\\_values](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 133) option is used. [Default: none]

**keep\_unspecified** If true, writes all dimensions. Dimensions specified with the `order` (page 133) 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`]

**newline** When producing CSV, what newline character should be used? (For Windows, `\r\n` is common.) [Default: “`\n`”]

**delimiter** When producing CSV, what character to use as a delimiter? [Default: “`,`”]

### 7.3.18 readers.tiledb

Implements `TileDB` (<https://tiledb.io>) 1.4.1+ reads from an array.

---

#### Dynamic Plugin

This stage requires a dynamic plugin to operate

---

#### Example

```
[  
  {  
    "type": "readers.las",  
    "array_name": "input.las"  
  },  
  {  
    "type": "writers.tiledb",  
    "array_name": "output_array"  
  }  
]
```

## Options

**array\_name** TileDB (<https://tiledb.io>) array to write to. [Required]

**config\_file** TileDB (<https://tiledb.io>) configuration file [Optional]

**tile\_data\_capacity** Number of points per tile [Optional]

**x\_tile\_size** Tile size (x) in a Cartesian projection [Optional]

**y\_tile\_size** Tile size (y) in a Cartesian projection [Optional]

**z\_tile\_size** Tile size (z) in a Cartesian projection [Optional]

**compression** TileDB compression type for attributes, default is None [Optional]

**compression\_level** TileDB compression level for chosen compression [Optional]

**stats** Dump query stats to stdout [Optional]

**writers.bpf (page 104)** Write BPF version 3 files. BPF is an NGA specification for point cloud data.

**writers.ept\_addon (page 106)** Append additional dimensions to Entwine resources.

**writers.gdal (page 108)** Create a raster from a point cloud using an interpolation algorithm.

**writers.geowave (page 111)** Write point cloud data to Accumulo.

**writers.greyhound (page 112)** Append new dimensions (or update existing dimensions) onto a Greyhound resource. Must be used along with a Greyhound reader, and intermediate filters that cull points are not allowed.

**writers.las (page 113)** Write ASPRS LAS versions 1.0 - 1.4 formatted data. LAZ support is also available if enabled at compile-time.

**writers.matlab (page 117)** Write MATLAB .mat files. The output has a single array struct.

**writers.nitf (page 119)** Write LAS and LAZ point cloud data, wrapped in a NITF 2.1 file.

[\*writers.null\*](#) (page 121) Provides a sink for points in a pipeline. It's the same as sending pipeline output to /dev/null.

[\*writers.oci\*](#) (page 122) Write data to Oracle point cloud databases.

[\*writers.ogr\*](#) (page 125) Write a point cloud as a set of OGR points/multipoints

[\*writers.pcd\*](#) (page 126) Write PCD-formatted files in the ASCII, binary, or compressed format.

[\*writers.pgpointcloud\*](#) (page 127) Write to a PostgreSQL database that has the PostgreSQL Pointcloud extension enabled.

[\*writers.ply\*](#) (page 129) Write points as PLY vertices. Can also emit a mesh as a set of faces.

[\*writers.sbet\*](#) (page 130) Write data in the SBET format.

[\*writers.sqlite\*](#) (page 130) Write point cloud data in a scheme that matches the approach used in the PostgreSQL Pointcloud and OCI readers.

[\*writers.text\*](#) (page 132) Write points in a text file. GeoJSON and CSV formats are supported.

[\*readers.tiledb\*](#) (page 133) Write points into a TileDB database.

## 7.4 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 178) doing geographic reprojection on XYZ coordinates), while others do not interrogate the point data at all and simply reorganize or split data.

### 7.4.1 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.

---

## filters.approximatecoplanar

The **approximate coplanar filter** implements a portion of the algorithm presented in [\[Limberger2015\]](#) (page 525). 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 191) stage then filters out any points that were not deemed to be coplanar before writing the result in compressed LAZ.

```
[  
    "input.las",  
    {  
        "type": "filters.approximatecoplanar",  
        "knn": 8,  
        "thresh1": 25,  
        "thresh2": 6  
    },  
    {  
        "type": "filters.range",  
        "limits": "Coplanar[1:1]"  
    },  
    "output.laz"  
]
```

## 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]

## 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

---

## Example 1

This pipeline resets the Classification of all points with classifications 2 or 3 to 0 and all points with classification of 5 to 4.

```
[  
    "autzen-dd.las",  
    {  
        "type": "filters.assign",  
        "assignment" : "Classification[2:3]=0",  
        "assignment" : "Classification[5:5]=4"  
    },  
    {  
        "filename": "attributed.las",  
        "scale_x": 0.0000001,  
        "scale_y": 0.0000001  
    }  
]
```

## Options

**assignment** A *range* (page 193) 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 list of *ranges* (page 193) that a point's values must pass in order for the assignment to be performed. [Default: none]

## **filters.cluster**

The Cluster filter first performs Euclidean Cluster Extraction on the input PointView and then labels each point with its associated cluster ID. Cluster IDs start with the value 1. Points that don't belong to any cluster will be given a cluster ID of 0.

---

### **Default Embedded Stage**

This stage is enabled by default

---

## **Example**

```
[  
    "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]

## **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 141) and *maximum* (page 141), and the data are scaled for the given *dimension* (page 141) accordingly.
2. You provide a *k* (page 141) and a *mad* (page 141) setting, and the scaling is set based on Median Absolute Deviation.
3. You provide a *k* (page 141) setting and the scaling is set based on the *k* (page 141)-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 139) for more information.

---

**Note:** *filters.colorinterp* (page 138) 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"  
]
```

---

### 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 141) option to the filter and it will be used. Otherwise, provide a **GDAL** (<http://www.gdal.org>)-readable raster filename.



Fig. 7.4: Image data with interpolated colors based on Z dimension and pestel\_shades ramp.

`awesome_green`

---

`black_orange`

---

`blue_orange`

---

`blue_hue`

---

`blue_orange`

---

`blue_red`

---



`heat_map`

---



`pestel_shades`

---



## Options

**ramp** The raster file to use for the color ramp. Any format supported by [GDAL](http://www.gdal.org) (<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](#) (page 141) value is also provided, the [k](#) (page 141) 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](#) (page 141) value is also provided, the [k](#) (page 141) 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](#) (page 141) and [maximum](#) (page 141) will be computed from the median and setting them will have no effect.

**mad** If true, [minimum](#) (page 141) and [maximum](#) (page 141) will be computed by the median absolute deviation. See [filters.mad](#) (page 187) for discussion. [Default: false]

**mad\_multiplier** MAD threshold multiplier. Used in conjunction with [k](#) (page 141) to threshold the differencing. [Default: 1.4862]

## `filters.colorization`

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. 7.5: After colorization, points take on the colors provided by the input image

---

**Note:** [GDAL](http://www.gdal.org) (<http://www.gdal.org>) is used to read the color information and any GDAL-readable supported [format](https://www.gdal.org/formats_list.html) ([https://www.gdal.org/formats\\_list.html](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",  
        "raster": "image.tif",  
        "bands": [1, 2, 3],  
        "scale": 256  
    }  
]
```

```

    "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](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 141) using the striped **TIFF** ([http://www.gdal.org/frmt\\_gtiff.html](http://www.gdal.org/frmt_gtiff.html)) with a 268mb [`readers.las`](#) (page 69) 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 -i 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](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”]

## 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 pre-existing elevation model.

---

### Default Embedded Stage

This stage is enabled by default

---

## Example

```
[  
  {  
    "type": "filters.dem",  
    "raster": "dem.tif",  
    "limits": "Z[20:100]"  
  }  
]
```

## Options

**limits** A [range](#) (page 193) 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](http://www.gdal.org/formats_list.html)) data to use for filtering.

**band** GDAL Band number to read (count from 1) [Default: 1]

## filters.eigenvalues

The **eigvalue 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) ([https://eigen.tuxfamily.org/dox/classEigen\\_1\\_1SelfAdjointEigenSolver.html](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.

```
[  
    "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]

## 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 147) parameter defines the number of points to consider when computing the SVD and estimated rank. Second, the *thresh* (page 147) 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 147) 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 191).

```
[  
    "input.las",  
    {  
        "type": "filters.estimaterank",  
        "knn": 8,  
        "thresh": 0.01  
    },  
    {  
        "type": "filters.range",  
        "limits": "Rank! [3:3]"  
    },  
    "output.laz"  
]
```

## Options

**knn** The number of k-nearest neighbors. [Default: 8]

**thresh** The threshold used to identify nonzero singular values. [Default: 0.01]

### **filters.elm**

The Extended Local Minimum (ELM) filter marks low points as noise. This filter is an implementation of the method described in [\[Chen2012\]](#) (page 525).

ELM begins by rasterizing the input point cloud data at the given [cell](#) (page 148) 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

---

### Example #1

The following PDAL pipeline applies the ELM filter, using a [cell](#) (page 148) size of 20 and applying the [classification](#) (page 148) code of 18 to those points determined to be noise.

```
{
  "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 148) value of 2.0, and finishes by extracting all returns that are not marked as noise.

```
[  
    "input.las",  
    {  
        "type": "filters.assign",  
        "assignment": "Classification[:] = 0"  
    },  
    {  
        "type": "filters.elm",  
        "threshold": 2.0  
    },  
    {  
        "type": "filters.range",  
        "limits": "Classification![: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]

## 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.

```
[  
    "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.

## filters.hag

The **Height Above Ground (HAG) 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](http://www.asprs.org/a/society/committees/standards/LAS_1_4_r13.pdf)).

---

Ground points may be generated by [filters.pmf](#) (page 167) or [filters.smrf](#) (page 169) (see [Identifying ground returns using ProgressiveMorphologicalFilter segmentation](#) (page 264)), 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 HAG filter works by iterating through all points, finding the nearest neighbor (in XY only) amongst the ground points, and computing the distance between the two Z values.

The process of computing normalized heights is straightforward. First, we must have an estimate of the underlying terrain model. With this we can compute the difference between each point's elevation and the elevation of the terrain model at the same XY coordinate. The quality of the normalized heights will be a function of the quality of the terrain model, which of course depends on the quality of the ground segmentation approach and any interpolation that is required to arrive at the terrain elevation for a given XY coordinate. We will use a nearest neighbor interpolation scheme to estimate terrain elevations.

To compute the normalized heights, we first create a 2D KdTree (X and Y only) to accelerate our nearest neighbor search. The tree is composed of only ground returns. We then iterate over each of our points, searching for the nearest neighbor in the ground points. We then compute the difference between the elevation of the query point and the nearest neighbor in the ground set. This value is encoded as a new dimension called `HeightAboveGround`.

---

### Default Embedded Stage

This stage is enabled by default

---

### Example #1

Using the autzen dataset (here shown colored by elevation)



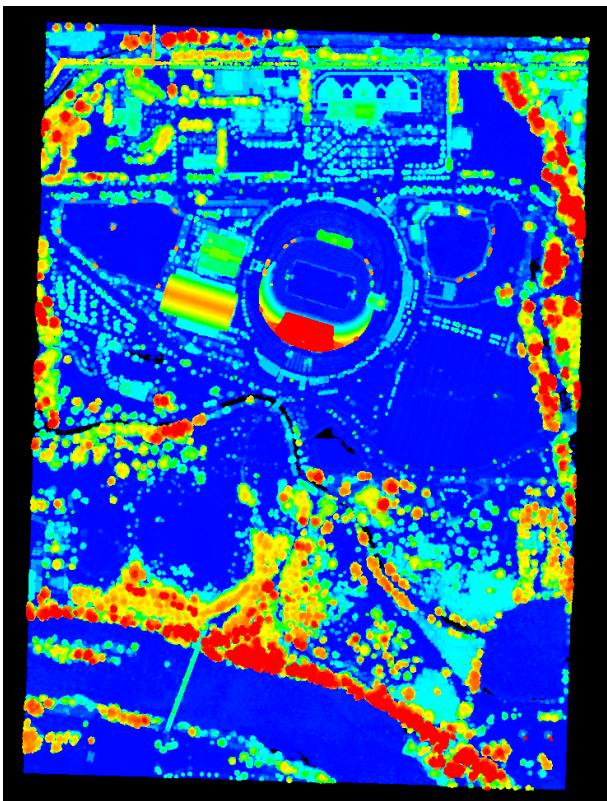
we execute the following pipeline

```
[  
    "autzen.laz",  
    {  
        "type": "filters.hag"  
    },  
    {  
        "type": "writers.bpf",  
        "filename": "autzen-height.bpf",  
        "output_dims": "X,Y,Z,HeightAboveGround"  
    }  
]
```

which is equivalent to the pdal translate command

```
$ pdal translate autzen.laz autzen-height.bpf hag \  
    --writers.bpf.output_dims="X,Y,Z,HeightAboveGround"
```

In either case, the result, when colored by the normalized height instead of elevation is



## Example #2

In the previous example, we chose a [writer](#) (page 104) that could output custom dimensions. If you'd instead like to overwrite your Z values, then follow the height filter with [filters.ferry](#) (page 148) as shown

```
[  
    "autzen.laz",  
    {  
        "type": "filters.hag"  
    },  
    {  
        "type": "filters.ferry",  
        "dimensions": "HeightAboveGround=Z"  
    },  
    "autzen-height-as-Z.laz"  
]
```

which is equivalent to the command

```
$ pdal translate autzen.laz autzen-height-as-Z.laz hag ferry \  
    --filters.ferry.dimensions="HeightAboveGround=Z"
```

## Example #3

If you don't yet have points classified as ground, start with [filters.pmf](#) (page 167) or [filters.smrf](#) (page 169) to label ground returns, as shown

```
[  
    "autzen.laz",  
    {  
        "type": "filters.smrf"  
    },  
    {  
        "type": "filters.hag"  
    },  
    {  
        "type": "filters.ferry",  
        "dimensions": "HeightAboveGround=Z"  
    },  
    "autzen-height-as-Z-smrf.laz"  
]
```

which is once again equivalent to the command

```
$ pdal translate autzen.laz autzen-height-as-Z-smrf.bpf smrf hag_
→ferry \
--filters.ferry.dimensions="HeightAboveGround=Z"
```

## Options

None

### **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 154) option can’t be used with the *query* (page 154) 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 154) option can't be used with the [point](#) (page 154) option. [Default: no points are selected.]

## filters.kdistance

The **K-Distance filter** creates a new attribute `KDistance` that contains the euclidean distance to a point's k-th nearest neighbor.

---

**Note:** The K-distance filter is deprecated and has been replaced by [filters.nndistance](#) (page 159).

---

### Default Embedded Stage

This stage is enabled by default

---

## Example

```
[  
    "input.las",  
    {  
        "type": "filters.kdistance",  
        "k": 8  
    },  
    {  
        "type": "writers.bpf",  
        "filename": "output.las",  
        "output_dims": "X,Y,Z,KDistance"  
    }  
]
```

## Options

**k** The number of k nearest neighbors. [Default: 10]

## 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 [\[Breunig2000\]](#) (page 525).

The filter creates three new dimensions, `KDistance`, `LocalReachabilityDistance` and `LocalOutlierFactor`, all of which are double-precision floating values. The `KDistance` 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 157) 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 `KDistance`. 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 [minpts](#) (page 157) 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 [minpts](#) (page 157) values, which users of this filter should find instructive.

---

**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 uses 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]

### **filters.mongus**

The **mongus filter** determines ground returns using the approach outlined in [\[Mongus2012\]](#) (page 526).

---

**Note:** The mongus filter is deprecated and has been replaced by [filters.pmf](#) (page 167) and [filters.smrf](#) (page 169).

---

The current implementation of this filter differs slightly from the original paper. We weren't too happy with the criteria for how control points at the current level are compared against the TPS at the previous scale and were exploring some alternate metrics.

Some warts about the current implementation:

- It writes many intermediate/debugging outputs to the current directory while processing.
- We require the specification of a max level, whereas the original paper automatically determined an appropriate max level.

---

### Default Embedded Stage

This stage is enabled by default

---

### Example

The sample pipeline below uses the filter to segment ground and non-ground returns, writing only the ground returns to the output file.

```
[  
    "input.las",  
    {  
        "type": "filters.mongus",  
        "extract": true  
    },  
    "output.laz"  
]
```

## Options

**cell** Cell size. [Default: 1.0]

**classify** Apply classification labels (i.e., ground = 2)? [Default: true]

**extract** Extract ground returns (non-ground returns are cropped)? [Default: false]

**k** Standard deviation multiplier to be used when thresholding values. [Default: 3.0]

**l** Maximum level in the hierarchical decomposition. [Default: 8]

## 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 159) 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

---

## Example 1

This pipeline updates the Classification of all points with classification 1 (unclassified) based on the consensus (majority) of its nearest 10 neighbors.

```
[  
    "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.

```
[  
    "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 193) 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.

## 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 160) 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 160) nearest points. [Default: ‘kth’]

**k** The number of k nearest neighbors to consider. [Default: **10**]

### **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](https://eigen.tuxfamily.org/dox/classEigen_1_1SelfAdjointEigenSolver.html)).

Normals will be automatically flipped towards the viewpoint to be consistent. By default the viewpoint is located at the midpoint of the X and Y extents, and 1000 units above the max Z value. Users can override any of the XYZ coordinates, 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 161), normals will instead be inverted such that they are oriented towards the viewpoint, regardless of the [always\\_up](#) (page 161) flag. To

disable all normal flipping, do not provide a *viewpoint* (page 161) and set *always\_up* (page 161) to false.

---

## 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.

```
[  
    "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]

## 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](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 191) to their pipeline, downstream from the outlier filter.

---

### Default Embedded Stage

This stage is enabled by default

---

```
{  
  "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 165)). 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 165).

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.

$$\text{outlier}_i = \begin{cases} \text{true}, & \text{if } \mu_i \geq t \\ \text{false}, & \text{otherwise} \end{cases}$$

Before outlier removal, noise points can be found both above and below the scene.



After outlier removal, the noise points are removed.

See [\[Rusu2008\]](#) (page 526) 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.

```
[  
    "input.las",  
    {  
        "type": "filters.outlier",  
        "method": "statistical",  
        "mean_k": 12,  
        "multiplier": 2.2  
    },  
    "output.las"  
]
```

### 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 165)). If  $k_i < k_{min}$ , where  $k_{min}$  is the minimum number of neighbors specified by `min_k` (page 165), it is marked as an outlier.

$$outlier_i = \begin{cases} \text{true}, & \text{if } k_i < k_{min} \\ \text{false}, & \text{otherwise} \end{cases}$$

### Example

The following example will mark points as outliers when there are fewer than four neighbors within a radius of 1.0.

```
[  
    "input.las",  
    {  
        "type": "filters.outlier",  
        "method": "radius",  
        "radius": 1.0,  
        "min_k": 4  
    },  
    "output.las"  
]
```

```
    "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]

## 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

---

## OGR SQL support

You can limit your queries based on OGR’s SQL support. If the filter has both a *datasource* (page 166) and a *query* (page 167) 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](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.

```
[  
    "autzen-dd.las",  
    {  
        "type": "filters.overlay",  
        "dimension": "Classification",  
        "datasource": "attributes.shp",  
        "layer": "attributes",  
        "column": "CLS"  
    },  
    {  
        "filename": "attributed.las",  
        "scale_x": 0.0000001,  
        "scale_y": 0.0000001  
    }  
]
```

## Example 2

This example sets the Intensity attribute to CLS values read from the [OGR SQL](#) ([http://www.gdal.org/ogr\\_sql\\_sqlite.html](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

**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. [Defalt: first layer]

## 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 [\[Zhang2003\]](#) (page 526).

---

### Default Embedded Stage

This stage is enabled by default

---

## Example

```
[  
    "input.las",  
    {  
        "type": "filters.pmf"  
    },  
    "output.las"  
]
```

## Notes

- *slope* (page 168) controls the height threshold at each iteration. A slope of 1.0 represents a 1:1 or 45°.
- *initial\_distance* (page 168) 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 168) 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 168) by the difference in window size between the current and last iteration, plus the *initial\_distance* (page 168). This height threshold is constant across all cells and is maxed out at the *max\_distance* (page 168) 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 168) values will result in a lot of potentially extra iteration. This parameter can have a strongly negative impact on computation performance.
- *exponential* (page 168) is used to control the rate of growth of morphological window sizes toward *max\_window\_size* (page 168). 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 191) to the pipeline.

```
{  
  "type": "filters.range",  
  "limits": "Classification[2:2]"  
}
```

---

**Note:** [\[Zhang2003\]](#) (page 526) 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]

## 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* (page 169) (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 169) 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]

## filters.smrf

The **Simple Morphological Filter (SMRF)** classifies ground points based on the approach outlined in [*Pingel2013*] (page 526).

## 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.

```
[  
    "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*] (page 526).

```
[  
    "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]

**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 193) 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**]

***filters.approximatecoplanar* (page 136)** 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.assign* (page 137)** Assign values for a dimension range to a specified value.

***filters.cluster* (page 138)** 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.

***filters.colorinterp* (page 138)** Assign RGB colors based on a dimension and a ramp

***filters.colorization* (page 141)** Fetch and assign RGB color information from a GDAL-readable datasource.

***filters.eigenvalues* (page 145)** Compute pointwise eigenvalues, based on k-nearest neighbors.

***filters.estimaterank* (page 146)** Compute pointwise rank, based on k-nearest neighbors.

***filters.elm* (page 147)** Marks low points as noise.

***filters.ferry* (page 148)** Copy data from one dimension to another.

***filters.hag* (page 150)** Compute pointwise height above ground estimate. Requires points to be classified as ground/non-ground prior to estimating.

***filters.kdistance* (page 155)** Compute pointwise K-Distance (the Euclidean distance to a point’s k-th nearest neighbor). [Deprecated - use *filters.nndistance* (page 159)]

***filters.lof* (page 155)** Compute pointwise Local Outlier Factor (along with K-Distance and Local Reachability Distance).

***filters.mongus* (page 157)** Label ground/non-ground returns using [*Mongus2012*] (page 526).

*filters.neighborclassifier* (page 158) Update pointwise classification using k-nearest neighbor consensus voting.

*filters.nndistance* (page 159) Compute a distance metric based on nearest neighbors.

*filters.normal* (page 160) Compute pointwise normal and curvature, based on k-nearest neighbors.

*filters.outlier* (page 161) Label noise points using either a statistical or radius outlier detection.

*filters.overlay* (page 165) Assign values to a dimension based on the extent of an OGR-readable data source or an OGR SQL query.

*filters.pmf* (page 167) Label ground/non-ground returns using [Zhang2003] (page 526).

*filters.radialdensity* (page 169) Compute pointwise density of points within a given radius.

*filters.smrf* (page 169) Label ground/non-ground returns using [Pingel2013] (page 526).

## 7.4.2 Order

There are currently three PDAL filters that can be used to reorder points. These filters will invalidate an existing KD-tree.

### **filters.mortonorder**

Sorts the XY data using [Morton ordering](http://en.wikipedia.org/wiki/Z-order_curve) ([http://en.wikipedia.org/wiki/Z-order\\_curve](http://en.wikipedia.org/wiki/Z-order_curve)).

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) (<https://github.com/Oslandia/lopocs>) and [pgmorton](https://github.com/Oslandia/pgmorton) (<https://github.com/Oslandia/pgmorton>) for some use case examples of the Reverse Morton algorithm.

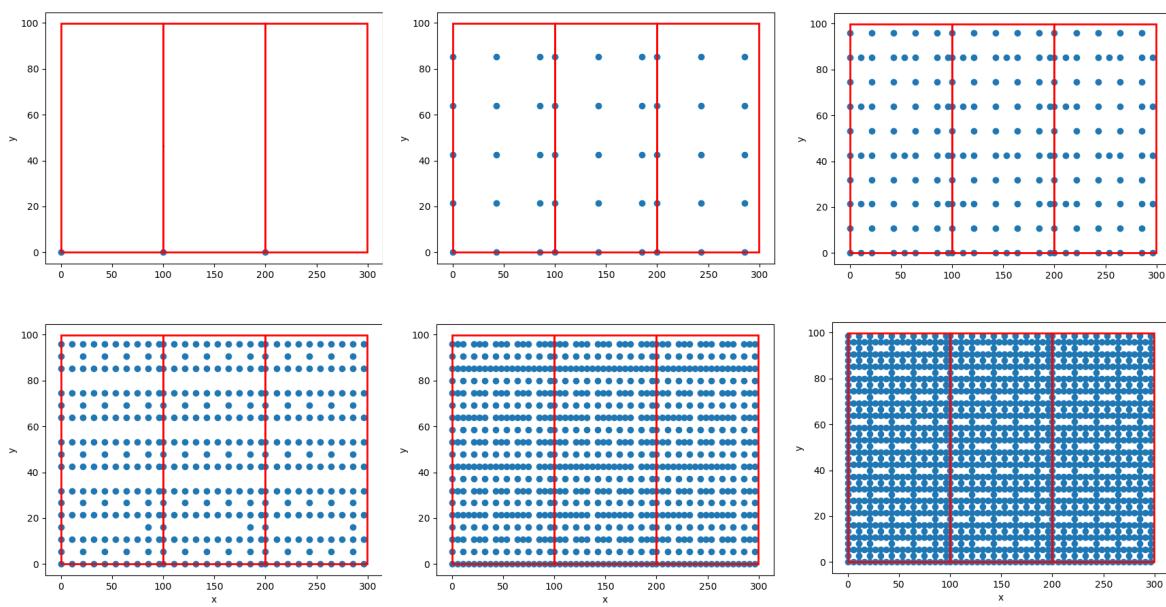
---

### **Default Embedded Stage**

This stage is enabled by default

---

### **Example**



```
[  
    "uncompressed.las",  
    {  
        "type": "filters.mortonorder",  
        "reverse": "false"  
    },  
    {  
        "type": "writers.las",  
        "filename": "compressed.laz",  
        "compression": "true"  
    }  
]
```

## Options

None.

### **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

None.

### **filters.sort**

The sort filter orders a point view based on the values of a *dimension* (page 175). The sorting can be done in increasing (ascending) or decreasing (descending) *order* (page 175).

---

#### **Default Embedded Stage**

This stage is enabled by default

---

## 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”]

***filters.mortonorder* (page 172)** Sort XY data using Morton ordering (aka Z-order/Z-curve).

***filters.randomize* (page 173)** Randomize points in a view.

***filters.sort* (page 174)** Sort data based on a given dimension.

### 7.4.3 Move

PDAL filters that move XYZ coordinates will invalidate an existing KD-tree.

#### ***filters.cpd***

The **Coherent Point Drift (CPD) filter** uses the algorithm of [\[MS10\]](#) (page 525) 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 [\[YG88\]](#) (page 525) 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](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

```
[  
    "fixed.las",  
    "moving.las",  
    {  
        "type": "filters.cpd",  
        "method": "rigid"  
    },  
    "output.las"  
]
```

If *method* (page 177) 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:

```
{  
    "stages":  
    {  
        "filters.cpd":  
        {  
            "iterations": 10,  
            "method": "rigid",  
            "runtime": 0.003839,  
            "sigma2": 5.684342128e-16,  
            "transform": "  
                1 -6.21722e-17 1.30104e-18 5.  
                1 2.60209e-18 -3.49247e-10 -2.  
                1 -1.53477e-12 0  
                0 0 1"  
        },  
    },  
}
```

See also:

*filters.transformation* (page 181) to apply a transform to other points. *filters.icp* (page 177) for deterministic binary point pair assignments.

## Options

**method** Change detection method to use. Valid values are “rigid”, “affine”, and “nonrigid”.  
[Default: “rigid”“】

### **filters.icp**

The **ICP filter** uses the [PCL’s Iterative Closest Point \(ICP\)](http://docs.pointclouds.org/trunk/classpcl_1_1_iterative_closest_point.html) ([http://docs.pointclouds.org/trunk/classpcl\\_1\\_1\\_iterative\\_closest\\_point.html](http://docs.pointclouds.org/trunk/classpcl_1_1_iterative_closest_point.html)) 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 change 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 that the initial pose of the two point sets to be adequately close, which are not always available, especially when transformation is non-rigid. ICP can handle limited nonrigid transformations but be aware ICP may be unable to escape a local minimum.  
Consider using CPD instead.

From [Xuechen2019]:

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.

---

---

### Dynamic Plugin

This stage requires a dynamic plugin to operate

---

## 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":  
        {  
            "converged": true,  
            "fitness": 0.01953125097,  
            "transform": "  
                1 2.60209e-18 -1.97906e-09  
                1 5.58794e-09 -0.5625 6.  
                1 0.00411987 0  
                1"  
        }  
    }  
}
```

### See also:

[filters.transformation](#) (page 181) to apply a transform to other points. [filters.cpd](#) (page 175) for the use of a probabilistic assignment of correspondences between pointsets.

## Options

None.

### [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 148) 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.

```
[  
  {  
    "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.

```
[
    "./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]

## filters.transformation

The transformation filter applies an arbitrary rotation+translation transformation, represented as a 4x4 *matrix* (page 181), to each xyz triplet.

The filter does *no* checking to ensure the matrix is a valid affine transformation.

---

**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.

```
[  
    "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"  
    }  
]
```

## Options

**matrix** A whitespace-delimited transformation matrix. The matrix is assumed to be presented in row-major order. Only matrices with sixteen elements are allowed.

**filters.cpd** (page 175) Compute and apply transformation between two point clouds using the Coherent Point Drift algorithm.

[\*filters.icp\* \(page 177\)](#) Compute and apply transformation between two point clouds using the Iterative Closest Point algorithm.

[\*filters.reprojection\* \(page 178\)](#) Reproject data using GDAL from one coordinate system to another.

[\*filters.transformation\* \(page 181\)](#) Transform each point using a 4x4 transformation matrix.

## 7.4.4 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.

### **filters.crop**

The **crop filter** removes points that fall outside or inside a cropping bounding box (2D), 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\* \(page 183\)](#) 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**

```
[  
    "file-input.las",  
    {  
        "type": "filters.crop",  
        "bounds": "([0,1000000], [0,1000000])"
```

```
    },
    {
        "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.

**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. Requires *distance* (page 183).

**distance** Distance in units of common X, Y, and Z *Dimensions* (page 229) to crop circle or sphere in combination with *point* (page 183).

**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.

## 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"  
  }  
]
```

## See also:

[filters.voxelgrid](#) (page 227) provides grid-style point decimation.

## 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]

## 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 173) and then picking the first 10000 using the HeadFilter.

```
[  
  {  
    "type": "filters.randomize"  
  },  
  {  
    "type": "filters.head",  
    "count": 10000  
  }  
]
```

## Example #2

Compute height above ground and extract the ten highest points.

```
[  
  {  
    "type": "filters.smrf"  
  },  
  {  
    "type": "filters.hag"  
  },  
  {  
    "type": "filters.sort",  
    "dimension": "HeightAboveGround",  
    "order": "DESC"  
  },  
  {  
    "type": "filters.head",  
    "count": 10  
  }  
]
```

## See also:

[filters.tail](#) (page 194) is the dual to [filters.head](#) (page 184).

## Options

**count** Number of points to return. [Default: 10]

## **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",  
        "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.

## filters.locate

The Locate filter searches the specified *dimension* (page 187) 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.

## filters.mad

The **MAD filter** filter crops the input point cloud based on the distribution of points in the specified *dimension* (page 188). 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.

### filters.mongoexpression

The **Mongo Expression 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.expression",  
        "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.expression",  
        "expression": { "$and": [  
            { "ReturnNumber": "NumberOfReturns" },  
            { "NumberOfReturns": { "$gt": 1 } }  
        ] }  
    },  
    "filtered.las"  
]
```

## Options

**expression** A JSON query *Expression* (page 189) containing a combination of query comparisons and logical operators.

## 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.

```
{ "Classification": { "$eq": 2 } }
```

```
{ "Intensity": { "$gt": 0 } }
```

```
{ "Classification": { "$in": [2, 6, 9] } }
```

The \$eq comparison operator may be implicitly invoked by setting an attribute name directly to a value.

```
{ "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:

```
{ "$or": [
    { "Classification": 2 },
    { "Intensity": { "$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

---

### 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 193). 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.

## 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.sample**

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](#)] (page 525) and [[Dippe1985](#)] (page 525), and has been applied to point clouds in other software [[Mesh2009](#)] (page 525).

The sampling can be performed in a single pass through the point cloud. To begin, each input point is assumed to be kept. As we iterate through the kept points, we retrieve all neighbors within a given `radius`, and mark these neighbors as points to be discarded. All remaining kept points are appended to the output `PointView`. The full layout (i.e., the dimensions) of the input `PointView` is kept in tact (the same cannot be said for [`filters.voxelgrid`](#) (page 227)).

### **See also:**

[`filters.decimation`](#) (page 183) and [`filters.voxelgrid`](#) (page 227) also perform decimation.

---

### **Default Embedded Stage**

This stage is enabled by default

---

## **Options**

**radius** Minimum distance between samples. [Default: 1.0]

## **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 184) is the dual to [filters.tail](#) (page 194).

**Options**

**count** Number of points to return. [Default: 10]

**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.

---

**Note:** This is similar to the existing [filters.voxelgrid](#) (page 227). However, in the case of the VoxelGrid, the centroid of the points falling within the voxel is added to the output point cloud. The drawback with this approach is that all dimensional data is lost, and the sampled cloud now consists of only XYZ coordinates.

---

**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 196) 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.

### Options

**cell** Cell size in the X, Y, and Z dimension. [Default: 1.0]

### **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, the centroid of the points within that voxel is computed. This centroid is 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.

---

**Note:** This is similar to the existing [filters.voxelgrid](#) (page 227). However, in the case of the VoxelGrid, the centroid itself is added to the output point cloud. The drawback with this approach is that all dimensional data is lost, and the sampled cloud now consists of only XYZ coordinates.

---

### Default Embedded Stage

This stage is enabled by default

---

### Example

```
[  
    "input.las",  
    {  
        "type": "filters.voxelcentroidnearestneighbor",  
    },  
    "output.las"
```

```
    "cell": 10.0
},
"output.las"
]
```

## See also:

[\*filters.voxelcenternearestneighbor\* \(page 195\)](#) 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]

[\*filters.crop\* \(page 182\)](#) Filter points inside or outside a bounding box or a polygon

[\*filters.decimation\* \(page 183\)](#) Keep every Nth point.

[\*filters.dem\* \(page 144\)](#) Remove points that are in a raster cell but have a value far from the value of the raster.

[\*filters.head\* \(page 184\)](#) Return N points from beginning of the point cloud.

[\*filters.iqr\* \(page 186\)](#) Cull points falling outside the computed Interquartile Range for a given dimension.

[\*filters.locate\* \(page 187\)](#) Return a single point with min/max value in the named dimension.

[\*filters.mad\* \(page 187\)](#) Cull points falling outside the computed Median Absolute Deviation for a given dimension.

[\*filters.mongoexpression\* \(page 188\)](#) Cull points using MongoDB-style expression syntax.

[\*filters.range\* \(page 191\)](#) Pass only points given a dimension/range.

[\*filters.sample\* \(page 194\)](#) Perform Poisson sampling and return only a subset of the input points.

[\*filters.tail\* \(page 194\)](#) Return N points from end of the point cloud.

[\*filters.voxelcenternearestneighbor\* \(page 195\)](#) Return the point within each voxel that is nearest the voxel center.

[\*filters.voxelcentroidnearestneighbor\* \(page 196\)](#) Return the point within each voxel that is nearest the voxel centroid.

## 7.4.5 New

PDAL filters can be used to split the incoming point cloud into subsets. These filters will invalidate an existing KD-tree.

### **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 a an irregular tiling of the input data.

---

**Note:** Each chip will have approximately, but not exactly, the [capacity](#) (page 201) point count specified.

---

#### See also:

The [PDAL split command](#) (page 35) utilizes the [filters.chipper](#) (page 198) to split data by capacity.

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

---

### **Example**

```
[  
    "example.las",  
    {  
        "type": "filters.chipper",  
        "capacity": "400",  
    },  
    {  
        "type": "writers.pgpointcloud",  
        "connection": "dbname='lidar' user='user'"  
    }  
]
```

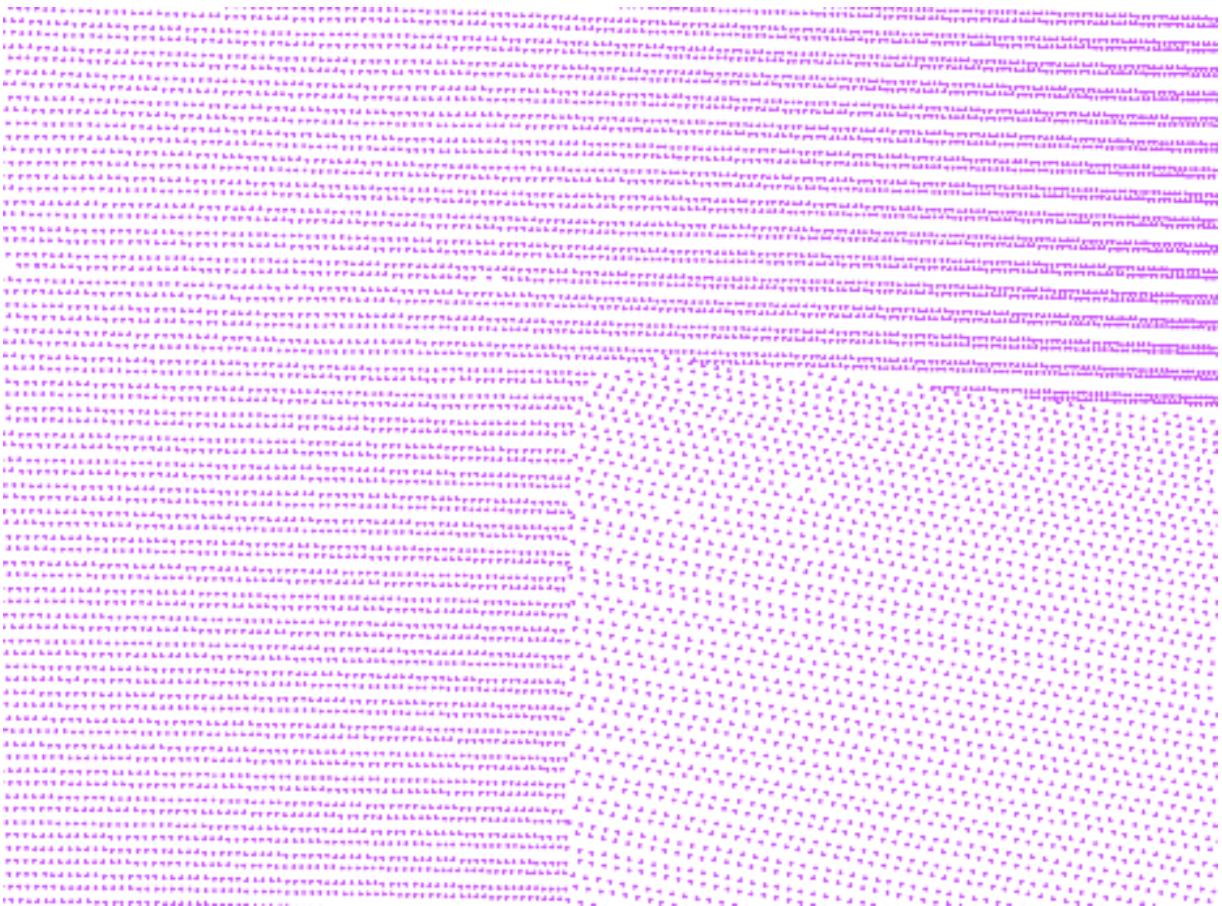


Fig. 7.6: Before chipping, the points are all in one collection.

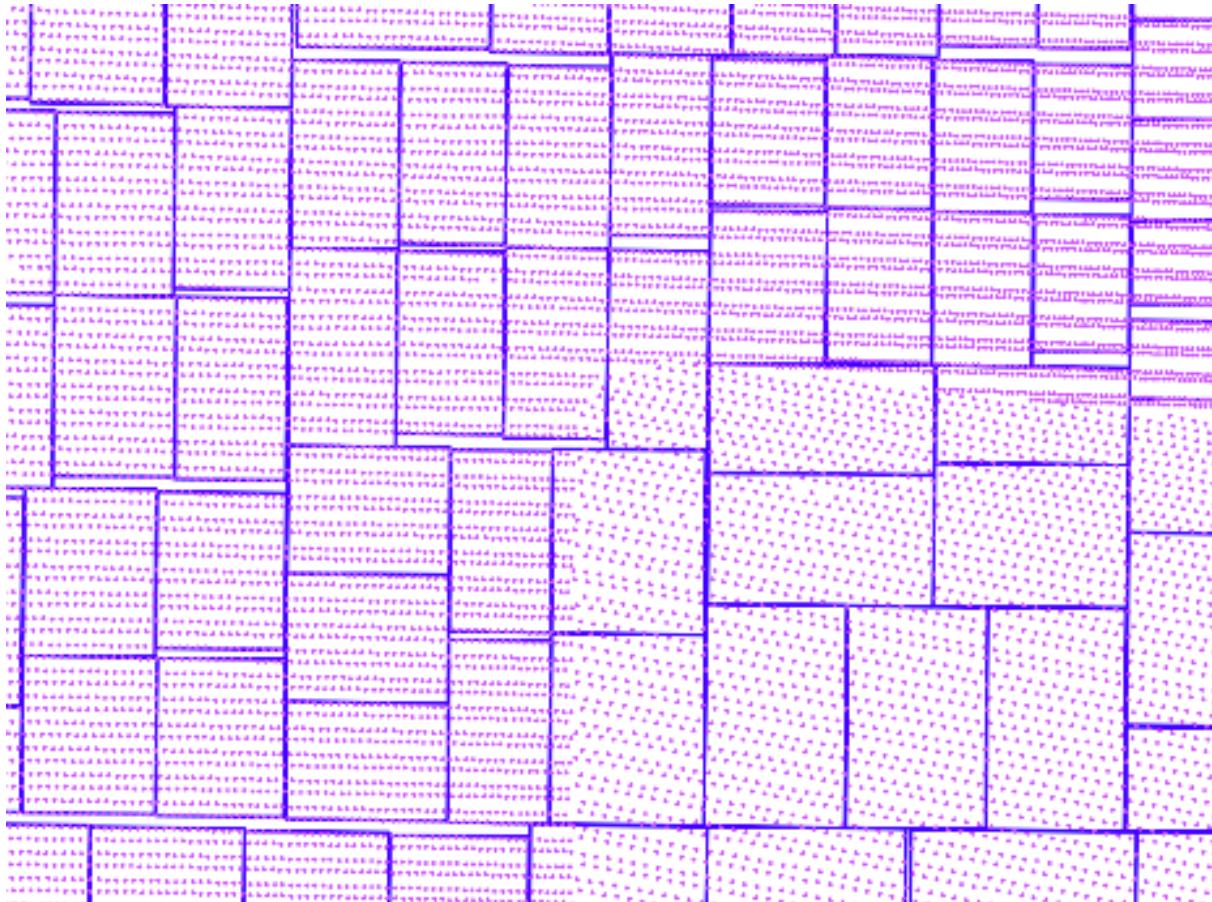


Fig. 7.7: After chipping, the points are tiled into smaller contiguous chips.

## 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]

### **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.

```
[  
    "example.las",  
    {  
        "type": "filters.divider",  
        "count": "10"  
    },  
    {  
        "type": "writers.las",  
        "filename": "out_#.las"  
    }  
]
```

## 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]

**Warning:** You must specify exactly one of either [count](#) (page 201) or [capacity](#) (page 202).

## filters.groupby

The **Groupby Filter** takes a single PointView as its input and creates a PointView for each category in the named [dimension](#) (page 202) 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"  
]
```

## Options

**dimension** The dimension containing data to be grouped.

## filters.returns

The **Returns Filter** takes a single PointView as its input and creates a PointView for each of the user-specified [groups](#) (page 203) 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”]

## 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 204) and `origin_y` (page 204) 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

```
[  
    "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]

*filters.chipper* (page 198) Organize points into spatially contiguous, squarish, and non-overlapping chips.

*filters.divider* (page 201) Divide points into approximately equal sized groups based on a simple scheme.

*filters.groupby* (page 202) Split data categorically by dimension.

*filters.returns* (page 202) Split data by return order (e.g., ‘first’, ‘last’, ‘intermediate’, ‘only’).

*filters.splitter* (page 203) Split data based on a X/Y box length.

### 7.4.6 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",  
    {  
        "type": "filters.merge"  
    },  
    "out1.las",  
    "out2.las",  
    "out3.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",
    "out#.las"
]
```

[filters.merge \(page 205\)](#) Merge data from two different readers into a single stream.

### 7.4.7 Metadata

PDAL filters can be used to create new metadata. These filters will not invalidate an existing KD-tree.

---

**Note:** [filters.cpd \(page 175\)](#) and [filters.icp \(page 177\)](#) can optionally create metadata as well, inserting the computed transformation matrix.

---

### filters.hexbin

A common question 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:

---

### Streamable Stage



Fig. 7.8: Hexbin output shows boundary of actual points in point buffer, not just rectangular extents.

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":  
        {  
            "area": 746772.7543,  
            "avg_pt_per_sq_unit": 22.43269935,  
            "avg_pt_spacing": 2.605540869,  
            "count": 33333333333333333  
        }  
    }  
}
```

```

    "boundary": "MULTIPOLYGON (((636274.38924399 848834.99817891,
→637242.52219686 848834.99817891, 637274.79329529 849226.26445367,
→637145.70890157 849338.05481789, 637242.52219686 849505.74036422,
→636016.22045656 849505.74036422, 635983.94935813 849114.47408945,
→636113.03375184 848890.89336102, 636274.38924399 848834.99817891)))
→",
    "boundary_json": { "type": "MultiPolygon", "coordinates": [ [
→[ [ 636274.38924399, 848834.99817891 ], [ 637242.52219686, 848834.
→99817891 ], [ 637274.79329529, 849226.26445367 ], [ 637145.
→70890157, 849338.05481789 ], [ 637242.52219686, 849505.74036422 ],
→[ 636016.22045656, 849505.74036422 ], [ 635983.94935813, 849114.
→47408945 ], [ 636113.03375184, 848890.89336102 ], [ 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
}
},
...

```

## Example 2

As a convenience, the `pdal info` command will produce similar output:

```
$ pdal info --boundary /Users/me/test/data/las/autzen_trim.las
```

```
{
  "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, 637274.79329529 849226.26445367,
→637145.70890157 849338.05481789, 637242.52219686 849505.74036422,
→636016.22045656 849505.74036422, 635983.94935813 849114.47408945,
→636113.03375184 848890.89336102, 636274.38924399 848834.99817891)))
→",
    "boundary_json": { "type": "MultiPolygon", "coordinates": [ [ [
→[ 636274.38924399, 848834.99817891 ], [ 637242.52219686, 848834.
→99817891 ], [ 637274.79329529, 849226.26445367 ], [ 637145.
→70890157, 849338.05481789 ], [ 637242.52219686, 849505.74036422 ],
→[ 636016.22045656, 849505.74036422 ], [ 635983.94935813, 849114.
→47408945 ], [ 636113.03375184, 848890.89336102 ], [ 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
}
},
...

```

```

    "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
  },
  "filename": "\\\Users\\\\acbell\\\\pdal\\\\test\\\\data\\\\las\\\\autzen_trim.
  ↪las",
  "pdal_version": "1.6.0 (git-version: 675afe)"
}

```

## 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 209) 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]

## 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”.

## 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 210) option.

**count** Identical to the *enumerate* (page 210) 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]

***filters.hexbin* (page 206)** Tessellate XY domain and determine point density and/or point boundary.

***filters.info* (page 154)** Generate metadata about the point set, including a point count and spatial reference information.

***filters.stats* (page 209)** Compute statistics about each dimension (mean, min, max, etc.).

### 7.4.8 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 is implemented using the [delaunator-cpp](https://github.com/delfrrr/delaunator-cpp) (<https://github.com/delfrrr/delaunator-cpp>) library, a C++ port of the JavaScript **Delaunator** (<https://github.com/mapbox/delaunator>) library.

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",  
        "filename": "output.ply",  
        "faces": true  
    }  
]
```

## Options

None.

### 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](http://www.pointclouds.org/documentation/tutorials/greedy_projection.php)) library.

---

### Default Embedded Stage

This stage is enabled by default

---

## Example

```
[  
    "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]

## filters.gridprojection

The **Grid Projection Filter** passes data through the Point Cloud Library [GridProjection](#) ([http://docs.pointclouds.org/1.7.1/classpcl\\_1\\_1\\_grid\\_projection.html](http://docs.pointclouds.org/1.7.1/classpcl_1_1_grid_projection.html)) algorithm.

GridProjection is an implementation of the surface reconstruction method described in [\[Li2010\]](#) (page 525).

---

## Dynamic Plugin

This stage requires a dynamic plugin to operate

---

## Example

```
[
  "input.las",
  {
    "type": "filters.gridprojection"
  },
  {
    "type": "writers.ply",
    "faces": true,
    "filename": "output.ply"
  }
]
```

## Options

None.

### **filters.movingleastquares**

The Moving Least Squares filter passes data through the Point Cloud Library [moving least squares](http://docs.pointclouds.org/trunk/classpcl_1_1_moving_least_squares.html) ([http://docs.pointclouds.org/trunk/classpcl\\_1\\_1\\_moving\\_least\\_squares.html](http://docs.pointclouds.org/trunk/classpcl_1_1_moving_least_squares.html)) algorithm.

Moving least squares is intended to smooth data and improve normal estimation as described in [\[Alexa2003\]](#) (page 525). It also contains methods for upsampling the resulting cloud based on the parametric fit.

---

### **Dynamic Plugin**

This stage requires a dynamic plugin to operate

---

## Example

```
[
  "input.las",
  {
    "type": "filters.movingleastquares"
  },
  {
    "type": "writers.las",
  }
]
```

```
        "filename": "output.las"
    }
]
```

## Options

None.

### filters.poisson

The **Poisson Filter** passes data Mischa Kazhdan's poisson surface reconstruction algorithm. [\[Kazhdan2006\]](#) (page 525) 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 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",  
        "filename": "isosurface.ply"  
    }  
]
```

```
    }  
]
```

---

**Note:** The algorithm is slow. On a reasonable desktop machine, the surface reconstruction shown below took about 15 minutes.

---

## 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]

*filters.delaunay* (page 210) Create mesh using Delaunay triangulation.

*filters.greedyprojection* (page 211) Create mesh using the Greedy Projection Triangulation approach.

*filters.gridprojection* (page 212) Create mesh using the Grid Projection approach [*Li2010* (page 525)].

*filters.movingleastssquares* (page 213) Data smoothing and normal estimation using the approach of [*Alexa2003*] (page 525).

*filters.poisson* (page 214) Create mesh using the Poisson surface reconstruction algorithm [*Kazhdan2006*] (page 525).

### 7.4.9 Languages

PDAL has two 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 45) that interacts with a struct array of the data and allows you to modify those points. Additionally, some global *Metadata* (page 402) 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 45) exited.

**See also:**



Fig. 7.9: Point cloud (800,000 points)



Fig. 7.10: Reconstruction (1.8 million vertices, 3.7 million faces)

*writers.matlab* (page 117) can be used to write .mat files.

---

**Note:** *filters.matlab* (page 215) embeds the entire Matlab interpreter, and it will require a fully licensed version of Matlab to execute your script.

---

### Dynamic Plugin

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”]

## filterspclblock

The **PCL Block filter** allows users to specify a block of Point Cloud Library ([PCL](http://www.pointclouds.org) (<http://www.pointclouds.org>)) operations on a PDAL `PointView`, applying the necessary conversions between PDAL and PCL point cloud representations.

The PCL Block filter creates a PCL pipeline object and passes it a single argument, the JSON file containing the PCL block definition. After filtering, the resulting indices can be retrieved and used to create a new PDAL `PointView` containing only those points that passed the filtering stages.

At this stage in its development, the PCL pipeline does not allow complex operations that may change the point type (e.g., `PointXYZ` to `PointNormal`) or alter points. We will continue to look into use cases that are of value and feasible, but for now are limited primarily to PCL functions that filter or segment the point cloud, returning a list of indices of the filtered points (e.g., ground or object, noise or signal). The main reason for this design decision is that we want to avoid converting all `PointView` dimensions to the PCL `PointCloud`. In the case of an LAS reader, we may very well not want to operate on fields such as `ReturnNumber`, but we do not want to lose this information post PCL filtering. The easy solution is to simply retain the index between the `PointView` and `PointCloud` objects and update as necessary.

---

**Note:** Most of the functionality of this filter has been superceded by native PDAL filters that re-implement the functionality of the supported PCL filters.

---

### See also:

See [Filtering data with PCL](#) (page 259) for more on using the PCL Block including examples.

See [pcl\\_json\\_specification](#) for complete details on the PCL Block JSON syntax and the filters available.

---

### Dynamic Plugin

This stage requires a dynamic plugin to operate

---

### Implemented Filters

The list of PCL filters that are accessible through the PCL Block depends on PCL itself. PDAL is rather dumb in this respect, merely converting the PDAL `PointView` to a PCL `PointCloud` object and passing the JSON filename. The parsing of the JSON file and implementation of the PCL filters is entirely embedded within the PCL pipeline.

A summary of the currently available filters is listed below. For full details of the filters and their parameters, see the [pcl\\_json\\_specification](#).

**ApproximateProgressiveMorphologicalFilter** faster (and potentially less accurate) version of the **ProgressiveMorphologicalFilter**

**GridMinimum** assembles a local 2D grid over a given PointCloud, then downsamples the data

**PassThrough** allows the user to set min/max bounds on one dimension of the data

**ProgressiveMorphologicalFilter** removes nonground points to produce a bare-earth point cloud

**RadiusOutlierRemoval** removes outliers if the number of neighbors in a certain search radius is smaller than a given K

**StatisticalOutlierRemoval** uses point neighborhood statistics to filter outlier data

**VoxelGrid** assembles a local 3D grid over a given PointCloud, then downsamples and filters the data

## Adding a New Filter

Adding a new PCL filter to the PCLBlock ecosystem is mostly a process of judicious copying and pasting.

1. Add the filter function declaration of the form `applyMyFilter` to `PCLPipeline.h`.
2. Add the implementation of `applyMyFilter` to `PCLPipeline.hpp`.
3. Add a one-line description of the shiny new filter to this file, `filterspclblock.rst`.
4. Add a full description of the new filter to `pcl_spec.rst`, including example JSON, all parameters, and default settings.
5. Add a test to `PCLBlockFilterTest.cpp`. Make sure each parameter is independently verified.

## Example

The PCL Block json object describes the filter chain to be constructed within PCL. Here is an example:

```
[  
  {  
    "name": "FilterOne",  
    "setFooParameter": "value"  
  },  
  {  
    "name": "FilterTwo",  
    "setBarParameter": false,  
  }
```

```

    "setBounds":
    {
        "upper": 42,
        "lower": 17
    }
}
]

```

## Options

**filename** Path to external PCL JSON file describing the pipeline

**methods** Raw PCL JSON array describing the pipeline

## filters.python

The **Python Filter** allows Python (<http://python.org/>) software to be embedded in a *Pipeline* (page 45) that allows modification of PDAL points through a **NumPy** (<http://www.numpy.org/>) array. Additionally, some global **Metadata** (page 402) 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:** Each array contains all the **Dimensions** (page 229) 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 *True* upon success. If the function returned *False*, an error would be thrown and the *Pipeline* (page 45) exited.
2. If you want write a dimension that might not be available, you can specify it with the *add\_dimension* (page 226) option:

```
"add_dimension": "NewDimensionOne"
```

To create more than one dimension, this option also accepts an array:

```
"add_dimension": [ "NewDimensionOne", "NewDimensionTwo",
                   "NewDimensionThree" ]
```

### Modification Example

```
[  
    "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"  
    }  
]
```

The JSON pipeline file referenced the external *multiply\_z.py* Python (<http://python.org/>) script, which scales the Z coordinate by a factor of 10.

```
import numpy as np  
  
def multiply_z(ins, outs):  
    Z = ins['Z']  
    Z = Z * 10.0  
    outs['Z'] = Z  
    return True
```

## 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.

```
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 191) 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 221) is the tool you can use for prototyping point stream processing operations.

---

### See also:

If you want to read a [Pipeline](#) (page 45) 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 229), *Metadata* (page 402), and coordinate system information. Additionally, the `metadata` object can be set by the function to modify metadata for the in-scope `filters.python` (page 221) `pdal::Stage` (page 487).

```
def myfunc(ins,outs):
    print ('schema: ', schema)
    print ('srs: ', spatialreference)
    print ('metadata: ', metadata)
    outs = ins
    return True
```

## Updating metadata

The filter can update the global `metadata` dictionary as needed, define it as a **global** Python variable for the function's scope, and the updates will be reflected back into the pipeline from that stage forward.

```
def myfunc(ins,outs):
    global metadata
    metadata = {'name': 'root', 'value': 'a string', 'type': 'string',
    ↪'description': 'a description', 'children': [{'name': 'filters.
    ↪python', 'value': 52, 'type': 'integer', 'description': 'a filter
    ↪description', 'children': []}, {'name': 'readers.faux', 'value':
    ↪'another string', 'type': 'string', 'description': 'a reader
    ↪description', 'children': []}]}
    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 32) with substitutions.

If we needed to be able to provide the Z scaling factor of [Example Pipeline](#) (page 223) 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.

```
[  
    "input.las",  
    {  
        "type": "filters.python",  
        "module": "anything",  
        "function": "filter",  
        "source": "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 226) dictionary in your Python script and use it:

```
import numpy as np  
  
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/) (<http://python.org/>) file, the file name to read from.

**source** The literal [Python](http://python.org/) (<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.

[\*\*filters.matlab\*\* \(page 215\)](#) Embed MATLAB software in a pipeline.

[\*\*filterspclblock\*\* \(page 219\)](#) Embed select PCL filters in a pipeline.

[\*\*filters.python\*\* \(page 221\)](#) Embed Python software in a pipeline.

### 7.4.10 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

None.

## filters.voxelgrid

The **Voxel Grid Filter** passes data through the Point Cloud Library ([PCL](http://www.pointclouds.org) (<http://www.pointclouds.org>)) VoxelGrid algorithm.

VoxelGrid assembles a local 3D grid over a given PointCloud, and downsamples and filters the data. The VoxelGrid class creates a *3D voxel grid* (think about a voxel grid as a set of tiny 3D boxes in space) over the input point cloud data. Then, in each *voxel* (i.e., 3D box), all the points present will be approximated (i.e., *downsampled*) with their centroid. This approach is a bit slower than approximating them with the center of the voxel, but it represents the underlying surface more accurately.

---

### Default Embedded Stage

This stage is enabled by default

---

## Example

```
[  
    "untransformed.las",  
    {  
        "type": "filters.voxelgrid"  
    },  
    {  
        "type": "writers.las",  
        "filename": "transformed.las"  
    }  
]
```

### See also:

[filters.decimation](#) (page 183) does simple every-other-X -style decimation.

## Options

**leaf\_x** Leaf size in X dimension. [Default: 1.0]

**leaf\_y** Leaf size in Y dimension. [Default: 1.0]

**leaf\_z** Leaf size in Z dimension. [Default: 1.0]

[filters.streamcallback](#) (page 226) Provide a hook for a simple point-by-point callback.

*filters.voxelgrid* (page 227) Create a new point cloud composed of voxel centroids computed from the input point cloud. All incoming dimension data (e.g., intensity, RGB) will be lost.

---

CHAPTER  
**EIGHT**

---

**DIMENSIONS**

## 8.1 Dimensions

PDAL dimensions describe the combination of data's type, size, and meaning. The following table provides a list of known dimension names you can use in *Filters* (page 135), *Writers* (page 104), and *Readers* (page 55) descriptions.

Name	Type	Description
Alpha	uint16	Alpha
Amplitude	float	This is the ratio of the received power to the power received at the detection limit expressed in dB
Azimuth	double	Scanner azimuth
BackgroundRadiation	float	A measure of background radiation.
Blue	uint16	Blue image channel value
ClassFlags	uint8	Class Flags
Classification	uint8	ASPRS classification. 0 for no classification. See LAS specification for details.
Curvature	double	Curvature of surface at this point
Density	double	Estimate of point density
Deviation	float	A larger value for deviation indicates larger distortion.
EchoRange	double	Echo Range
EdgeOfFlightLine	int8	Indicates the end of scanline before a direction change with a value of 1 - 0 otherwise
ElevationCentroid	double	Elevation Centroid
ElevationHigh	double	Elevation High
ElevationLow	double	Elevation Low
Flag	uint8	Flag
GpsTime	double	GPS time that the point was acquired
Green	uint16	Green image channel value
HeightAboveGround	double	Height Above Ground
Infrared	uint16	Infrared

Continued on next page

Table 8.1 – continued from previous page

Name	Type	Description
Intensity	uint16	Representation of the pulse return magnitude
InternalTime	double	Scanner's internal time when the point was acquired, in seconds
IsPpsLocked	uint8	The external PPS signal was found to be synchronized at the time of the current laser shot.
LatitudeCentroid	double	Latitude Centroid
LatitudeHigh	double	Latitude High
LatitudeLow	double	Latitude Low
LongitudeCentroid	double	Longitude Centroid
LongitudeHigh	double	Longitude High
LongitudeLow	double	Longitude Low
LvisLfid	uint64	LVIS_LFID
Mark	uint8	Mark
NNDistance	double	Distance metric related to a point's nearest neighbors.
NormalX	double	X component of a vector normal to surface at this point
NormalY	double	Y component of a vector normal to surface at this point
NormalZ	double	Z component of a vector normal to surface at this point
NumberOfReturns	int8	Total number of returns for a given pulse.
OffsetTime	uint32	Milliseconds from first acquired point
Omit	uint8_t	Used to shallowly mark a point as being omitted without removing it
OriginId	uint32	A file source ID from which the point originated. This ID is global to a derivative dataset which may be aggregated from multiple files.
PassiveSignal	int32	Relative passive signal
PassiveX	double	Passive X footprint
PassiveY	double	Passive Y footprint
PassiveZ	double	Passive Z footprint
Pdop	float	GPS PDOP (dilution of precision)
Pitch	float	Pitch in degrees
PointId	uint32	An explicit representation of point ordering within a file, which allows this usually-implicit information to be preserved when re-ordering points.
PointSourceId	uint16	File source ID from which the point originated. Zero indicates that the point originated in the current file
PulseWidth	float	Laser received pulse width (digitizer samples)
Red	uint16	Red image channel value
Reflectance	float	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.
ReflectedPulse	int32	Relative reflected pulse signal strength

Continued on next page

Table 8.1 – continued from previous page

Name	Type	Description
ReturnNumber	uint8	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
Roll	float	Roll in degrees
ScanAngleRank	float	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
ScanChannel	uint8	Scan Channel
ScanDirectionFlag	uint8	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
ShotNumber	uint64	Shot Number
StartPulse	int32	Relative pulse signal strength
UserData	uint8	Unspecified user data
WanderAngle	double	Wander Angle
X	double	X coordinate
XBodyAccel	double	X Body Acceleration
XBodyAngRate	double	X Body Angle Rate
XVelocity	double	X Velocity
Y	double	Y coordinate
YBodyAccel	double	Y Body Acceleration
YBodyAngRate	double	Y Body Angle Rate
YVelocity	double	Y Velocity
Z	double	Z coordinate
ZBodyAccel	double	Z Body Acceleration
ZBodyAngRate	double	Z Body Angle Rate
ZVelocity	double	Z Velocity



---

CHAPTER  
NINE

---

PYTHON

## 9.1 Python

PDAL provides Python support in two significant ways. First it [embeds](https://docs.python.org/3/extending/embedding.html) (<https://docs.python.org/3/extending/embedding.html>) Python to allow you to write Python programs that interact with data using [\*filters.python\*](#) (page 221) filter. Second, it [extends](https://docs.python.org/3/extending/extending.html) (<https://docs.python.org/3/extending/extending.html>) 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/) (<http://www.numpy.org/>) support. PDAL's data is provided to both the filters and the extension as Numpy arrays.

---

### 9.1.1 Versions

PDAL supports both Python 2.7 and Python 3.4+. [\*Continuous Integration\*](#) (page 452) tests Python 2.7 on both Linux and Windows. Python 3 is used by a number of developers for adhoc development and testing.

### 9.1.2 Embed

PDAL allows users to embed Python functions inline with other [\*Pipeline\*](#) (page 45) 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.



Fig. 9.1: Embedding a Python function to take Z values read from a *readers.las* (page 69) and then output them to a *writers.bpf* (page 104).

### 9.1.3 Extend

PDAL provides a Python [extension](https://pypi.python.org/pypi/PDAL) (<https://pypi.python.org/pypi/PDAL>) that gives users access to executing [pipeline](#) (page 45) 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 45) 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:

```

json = """
{
  [
    {
      "1.2-with-color.las",
      {
        "type": "filters.sort",
        "dimension": "X"
      }
    ]
}
"""

import pdal
pipeline = pdal.Pipeline(json)
pipeline.validate() # check if our JSON and options were good
pipeline.loglevel = 8 #really noisy
count = pipeline.execute()
arrays = pipeline.arrays
metadata = pipeline.metadata
log = pipeline.log
  
```

## Installation

The PDAL Python extension requires a working *PDAL installation* (page 13). Unless you choose the Conda installation method, make sure that you a current, working version of PDAL before installing the extension.

### 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/) (<https://pip.pypa.io/en/stable/installing/>)

---

### Installation from Source

The PDAL Python extension is hosted on [GitHub](https://github.com/PDAL/python) (<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  
$ python setup.py build  
# this should be run as administrator/super user  
$ python setup.py install
```

### Install using Conda

The PDAL Python extension can also be installed using the [Conda](https://conda.io/docs/) (<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

```
conda install -n <environment name> -c conda-forge python-pdal
```

Use the following command to install PDAL and the PDAL Python extension into a new environment and activate that environment

```
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.

---

---

CHAPTER  
TEN

---

TUTORIALS

## 10.1 Tutorials

This section provides a collection of tutorials on how to use the PDAL *Applications* (page 25) and *Pipelines* (page 45) to process data.

---

**Note:** Users looking for documentation on how to contribute to PDAL should look [here](#) (page 381) and users looking to use the PDAL API in their own applications should look [here](#) (page 453).

---

### 10.1.1 Reading with PDAL

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**Date** 01/21/2015

#### Contents

- *Reading with PDAL* (page 237)
  - *A basic inquiry example* (page 238)
  - *A conversion example* (page 239)
    - \* *Metadata* (page 239)
  - *A Pipeline Example* (page 240)
    - \* *Simple conversion* (page 240)
    - \* *Loop a directory and filter it through a pipeline* (page 240)

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](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
```

```
{  
  "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,  
      "Y": 849028,  
      "Z": 431.66  
    }  
  }  
}
```

## A conversion example

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* (page 229) 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
```

```
"X", "Y", "Z", "Intensity", "ReturnNumber", "NumberOfReturns",
↳ "ScanDirectionFlag", "EdgeOfFlightLine", "Classification",
↳ "ScanAngleRank", "UserData", "PointSourceId", "Time", "Red", "Green",
↳ "Blue"
637012.24, 849028.31, 431.66, 143, 1, 1, 1, 0, 1, -9, 132, 7326, 245381, 68, 77, 88
636896.33, 849087.70, 446.39, 18, 1, 2, 1, 0, 1, -11, 128, 7326, 245381, 54, 66, 68
636784.74, 849106.66, 426.71, 118, 1, 1, 0, 0, 1, -10, 122, 7326, 245382, 112, 97,
↳ 114
636699.38, 848991.01, 425.39, 100, 1, 1, 0, 0, 1, -6, 124, 7326, 245383, 178, 138,
↳ 162
636601.87, 849018.60, 425.10, 124, 1, 1, 1, 0, 1, -4, 126, 7326, 245383, 134, 104,
↳ 134
636451.97, 849250.59, 435.17, 48, 1, 1, 0, 0, 1, -9, 122, 7326, 245384, 99, 85, 95
...
...
```

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](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](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* (page 402) for each stage through the PDAL *processing pipeline* (page 45). The metadata can be written in JSON form using the pdal [info](#) (page 29) command

```
$ pdal info --metadata interesting.las
```

This produces metadata that looks like [this](#). You can use your [JSON](#) (<http://www.json.org/>) 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* (page 32) 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* (page 45), for more detailed exposition of the topic.

The *pipeline* (page 32) 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 (<http://www.json.org/>) document defines a pipeline that takes the `file.las` LAS ([http://www.asprs.org/a/society/committees/standards/lidar\\_exchange\\_format.html](http://www.asprs.org/a/society/committees/standards/lidar_exchange_format.html)) file and converts it to a new file called `output.las`.

```
[  
    "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  
}
```

## 10.1.2 Reading data from EPT

### Introduction

This tutorial describes how to use [Conda](https://conda.io) (<https://conda.io>), [Entwine](https://entwine.io) (<https://entwine.io>), PDAL (<https://pdal.io>), and [GDAL](https://gdal.org) (<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) (<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) (<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) (<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) (<https://pdal.io/stages/filters.smrf.html>), and we will write out a digital terrain model with *writers.gdal*. Once our elevation model is constructed, we will use GDAL [gdaldem](https://www.gdal.org/gdaldem.html) (<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) (<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) (<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

```
conda create -n iowa -y
```

2. Activate the environment

```
conda activate iowa
```

3. Install PDAL

```
conda install -c conda-forge pdal -y
```

4. Insure PDAL works by listing the available drivers

```
pdal --drivers
```

```
(iowa) [hobu@kasai ~]$ 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) (<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.

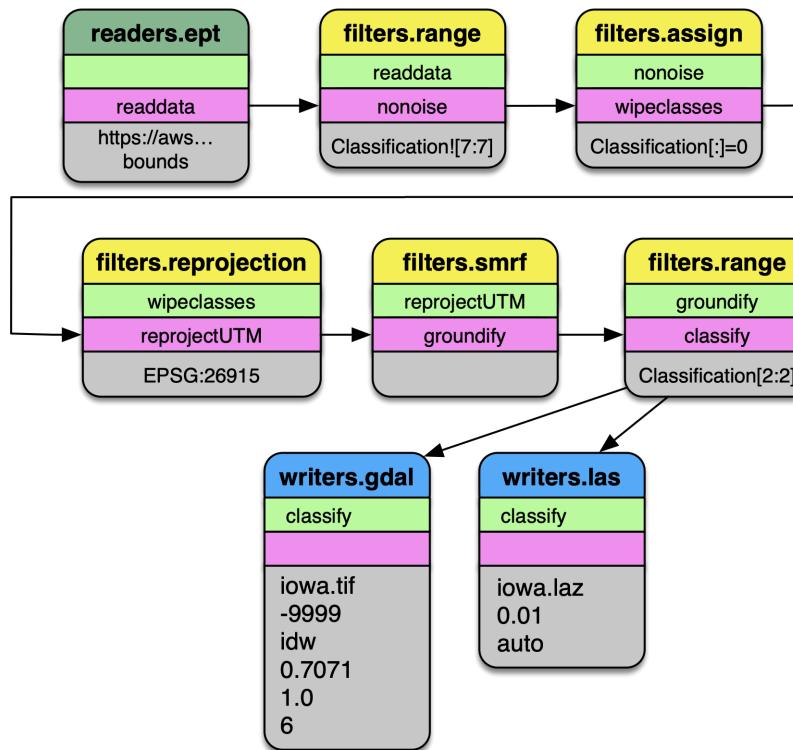


Fig. 10.1: Pipeline diagram. The data are read from the Entwine Point Tile (<https://entwine.io/entwine-point-tile.html>) resource at <https://usgs.entwine.io> for Iowa using *readers.ept* (page 57) and filtered through a number of steps until processing is complete. The data are then written to an `iowa.laz` 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], [5164494.710, 5166494.  
             ↪710])",  
            "filename": "https://s3-us-west-2.amazonaws.com/usgs-lidar-public/IA_  
             ↪FullState",  
            "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"  
        },  
        {  
            "filename": "iowa.laz",  
            "inputs": [ "classify" ],  
            "tag": "writerslas",  
            "type": "writers.las"  
        },  
        {  
    ]  
}
```

```
        "filename": "iowa.tif",
        "gdalopts": "tiled=yes,      compress=deflate",
        "inputs": [ "writerslas" ],
        "nodata": -9999,
        "output_type": "idw",
        "resolution": 1,
        "type": "writers.gdal",
        "window_size": 6
    }
]
}
```

## Stages

### readers.ept

*readers.ept* (page 57) 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.

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...

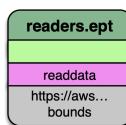


Fig. 10.2: The EPT reader reads data from an EPT resource with PDAL. Options available in PDAL 1.9+ allow users to select data at or above specified resolutions.

### filters.range

The data we are selecting may have noise properly classified, and we can use *filters.range* (page 191) to keep all data that does not have a Classification *Dimensions* (page 229) value of 7.

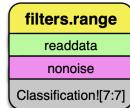


Fig. 10.3: The [filters.range](#) (page 191) filter utilizes range selection to allow users to select data for processing or removal. The [filters.mongoexpression](#) (page 188) filter can be used for even more complex logic operations.

## **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 137) takes the expression Classification [:]=0 and assigns the Classification for each point to 0.

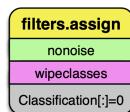


Fig. 10.4: :ref:`filters.assign` can also take in an option to apply assignments based on a conditional. If you want to assign values based on a bounding geometry, use [filters.overlay](#) (page 165).

## **filters.reprojection**

The data on the AWS 3DEP Public Dataset are stored in [Web Mercator](#) ([https://en.wikipedia.org/wiki/Web\\_Mercator\\_projection](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. 10.5: [filters.reprojection](#) (page 178) can also take override the incoming coordinate system using the a\_srs option.

## **filters.smrf**

The Simple Morphological Filter ([filters.smrf](#) (page 169)) classifies points as ground or not-ground.

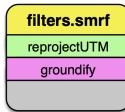


Fig. 10.6: [filters.smrf](#) (page 169) provides a number of tuning options, but the defaults tend to work quite well for mixed urban environments on flat ground (ie, Iowa).

### **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.

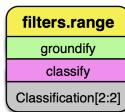


Fig. 10.7: Remove any point that is not ground classification for our DTM generation.

### **writers.gdal**

Having filtered our point data, we're now ready to write a raster digital terrain model with [writers.gdal](#) (page 108). 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 108) for more options.



Fig. 10.8: 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 113) for more options.

## **Execute the Pipeline**

1. Save the PDAL pipeline in [Pipeline](#) (page 242) to a file called `iowa.json`



Fig. 10.9: Also output the LAZ file as part of our processing pipeline.

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`

```

# Color ramp for Iowa State Campus
270.187,250,250,250,255,270.2
272.059,230,230,230,255,272.1
272.835,209,209,209,255,272.8
273.985,189,189,189,255,274
276.204,168,168,168,255,276.2
277.835,148,148,148,255,277.8
279.199,128,128,128,255,279.2
280.964,107,107,107,255,281
282.809,87,87,87,255,282.8
283.745,66,66,66,255,283.7
284.547,46,46,46,255,284.5
286.526,159,223,250,255,286.5
296.901,94,139,156,255,296.9

```

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

### 10.1.3 LAS Reading and Writing with PDAL

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**Date** 3/27/2017

## Table of Contents

- *LAS Reading and Writing with PDAL* (page 247)
  - *Introduction* (page 248)
  - *LAS Versions* (page 248)
  - *Spatial Reference System* (page 249)
  - *Point Formats* (page 252)
  - *Extra Dimensions* (page 253)
  - *Required Header Fields* (page 254)
  - *Coordinate Scaling* (page 255)
  - *Compression* (page 256)
  - *PDAL Metadata* (page 258)

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 69) and *writers.las* (page 113) 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 113) 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.

```

1  [
2      {
3          "type" : "readers.las",
4          "filename" : "input.las"
5      },
6      {
7          "type" : "writers.las",
8          "minor_version": 1,
9          "filename" : "output.las"
10     }
11 ]

```

---

**Note:** PDAL defaults to writing a LAS 1.2 version if no `minor_version` is specified or the `forward` option of [writers.las](#) (page 113) 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](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 113) 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 113) to EPSG:4326.

```

1  [
2      {
3          "type" : "readers.las",

```

```
4     "filename" : "input.las"
5   },
6   {
7     "type" : "writers.las",
8     "a_srs": "EPSG:4326",
9     "filename" : "output.las"
10   }
11 ]
```

---

**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 256) 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/gravitymod/egm2008/egm08\\_wgs84.html](http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/egm08_wgs84.html)). In [Well Known Text](#) ([https://en.wikipedia.org/wiki/Well-known\\_text#Coordinate\\_reference\\_systems](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,
            AUTHORITY["EPSG","1027"]],
        EXTENSION["PROJ4_GRIDDS","egm08_25.gtx"]],
UNIT["metre",1,
    AUTHORITY["EPSG","9001"]],
AXIS["Up",UP],
AUTHORITY["EPSG","3855"]]

```

As in [Assignment Example](#) (page 249), 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.

```

1  [
2      {
3          "type" : "readers.las",
4          "filename" : "input.las"
5      },
6      {
7          "type" : "writers.las",
8          "a_srs": "EPSG:26915+5703",
9          "filename" : "output.las"
10     }
11 ]

```

---

**Note:** Any coordinate system description format supported by GDAL's [SetFromUserInput](#) ([http://www.gdal.org/ogr\\_srs\\_api\\_8h.html#a927749db01cec3af8aa5e577d032956bk](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 178).

```

1  [
2      {

```

```
3     "type" : "readers.las",
4     "filename" : "input.las"
5   },
6   {
7     "type": "filters.reprojection",
8     "out_srs": "EPSG:26915"
9   },
10  {
11    "type" : "writers.las",
12    "filename" : "output.las"
13  }
14 ]
```

---

**Note:** If the input data doesn't specify a projection, you must specify the `in_srs` option of [filters.reprojection](#) (page 178). `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 229) 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 `dataformat_id` is an integer that defines the set of fixed [dimensions](#) (page 229) stored for each point in a LAS file. All point formats specify the following dimensions as part of a point record:

Table 10.1: Base LAS Dimensions

X	Y	Z
Intensity	ReturnNumber	NumberOfReturns
ScanDirectionFlag	EdgeOfFlightLine	Classification
ScanAngleRank	UserData	PointSourceId

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.

```
1  [
2      {
3          "type" : "readers.las",
4          "filename" : "input.las"
5      },
6      {
7          "type" : "writers.las",
8          "forward": "all",
9          "dataformat_id": 0,
10         "filename" : "output.las"
11     }
12 ]
```

---

**Note:** The [LASzip](http://laszip.org) (<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 229) a file must store, but softwares 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:

```
1  [
2      "some_non_las_file",
3      {
4          "type" : "writers.las",
5          "extra_dims": "all",
6          "minor_version" : "4",
7          "filename" : "output.las"
```

```
8     }
9 ]
```

## 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*
- *filesource\_id*

## Header Fields Example

The “forward” option of [writers.las](#) (page 113) 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 167) to reassign them. During this scenario, we’d like to keep all of the other LAS header information, such as *Variable Length Records* (page 256), extent information, and format settings.

```
1 [
2   {
3     "type" : "readers.las",
4     "filename" : "input.las"
5   },
6   {
7     "type" : "filters.assign",
8     "assignment" : "Classification[0:32]=0"
9   },
10  {
11    "type" : "filters.pmf",
12    "cell_size" : 2.5,
13    "approximate" : false,
14    "max_distance" : 25
15  },
16  {
```

```

17     "type" : "writers.las",
18     "forward": "all",
19     "filename" : "output.las"
20   }
21 ]

```

---

**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) (<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) (<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) (<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.

```

1  [
2    {
3      "type" : "readers.las",
4      "filename" : "input.las"
5    },
6    {

```

```
7     "type" : "writers.las",
8     "scale_x": "0.0000001",
9     "scale_y": "0.0000001",
10    "scale_z": "0.01",
11    "offset_x": "auto",
12    "offset_y": "auto",
13    "offset_z": "auto",
14    "filename" : "output.las"
15  }
16 ]
```

## Compression

LASzip (<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>) 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 69) and *writers.las* (page 113). 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:

```
1 [
2   {
3     "type" : "readers.las",
4     "filename" : "input.las"
5   },
6   {
7     "type" : "writers.las",
8     "compression": "laszip",
9     "filename" : "output.laz"
10  }
11 ]
```

## 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 113) `vlrs` 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.

```
[  
    "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=="  
        }  
    ]  
}
```

```
        ]
    }
]
```

## PDAL Metadata

The [writers.las](#) (page 113) driver supports an option, pdal\_metadata, that writes two PDAL VLRs to LAS files. The first is the equivalent of [info](#) (page 29)'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 402) 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/misic/las-key-list.html>).

```
1  [
2      {
3          "type" : "readers.las",
4          "filename" : "input.las"
5      },
6      {
7          "type" : "writers.las",
8          "pdal_metadata": "true",
9          "filename" : "output.laz"
10     }
11 ]
```

**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.

## 10.1.4 Filtering data with PCL

### Introduction

PDAL is both a C++ library and a collection of command-line utilities for data processing operations. While the PDAL library addresses point cloud exploitation and filtering, this takes a back seat to its primary objective of being a data translation library, helping developers to navigate the a wide variety of point cloud formats. [PCL](http://www.pointclouds.org) (<http://www.pointclouds.org>) is another C++ library that is focused on developing a rich set of point cloud processing routines, with less of a focus on formats and data translation. Acknowledging this, the PCL Block filter was developed to serve as a bridge between the two libraries, enabling rapid development of point cloud processing pipelines.

### See also:

See [filters.pclblock](#) (page 219) for details on PDAL's PCL Block filter.

### Contents

- [Filtering data with PCL](#) (page 259)
  - [Introduction](#) (page 259)
  - [Quick Start](#) (page 259)
  - [PDAL Pipeline kernel](#) (page 259)
  - [PDAL PCL kernel](#) (page 261)
  - [Examples](#) (page 262)
    - \* [Simple point cloud cropping](#) (page 262)
    - \* [Point cloud cropping with outlier removal](#) (page 262)
    - \* [Ground return filtering](#) (page 263)

### Quick Start

The [Quickstart](#) (page 17) document describes how to use PDAL with Docker, which includes built-in PCL support. After you have worked through that document, you should be able to run any PDAL PCL operations.

### PDAL Pipeline kernel

**Note:** A full description of the PDAL pipeline concept is beyond the scope of this tutorial but the [Pipeline](#) (page 45), [pipeline](#) (page 32), and [Reading with PDAL](#) (page 237) documents contain detailed examples and background information.

---

The [filterspclblock](#) (page 219) is implemented as a PDAL filter stage and as such is easily accessed via the PDAL pipeline. It accepts a single, required option - the name of the [JSON](#) (<http://www.json.org/>) file describing the PCL Block.

A sample pipeline JSON which reads/writes LAS and has a single PCL Block filter is shown below.

```
{  
  "pipeline": [  
    "autzen-point-format-3.las",  
    {  
      "type": "filterspclblock",  
      "filename": "passthrough.json"  
    },  
    "foo.las"  
  ]  
}
```

And is run from the command line thusly.

```
$ pdal pipeline passthrough.json
```

This simple pipeline reads the input LAS (`autzen-point-format-3.las`), passes it through the PCL Block (`passthrough.json`), and writes the output LAS (`foo.las`).

When run, it should produce output similar to this:

```
Requested to read 106 points  
Requested to write 106 points  
0  
Processing /home/vagrant/pdal/test/data/filters/pcl/passthrough.json  
-----  
→-----  
NAME: PassThroughExample ()  
HELP:  
AUTHOR:  
-----  
→-----  
106 points copied  
Step 1) PassThrough
```

```
Field name: z
Limits: 410.000000, 440.000000

76(writers.las DEBUG: 3): Wrote 81 points to the LAS file
.100
```

## PDAL PCL kernel

For users that would like to bypass the creation (and subsequent modification) of the pipeline JSON for every file they wish to process, there is another option: the `pdal pcl` command.

```
$ pdal pcl -i /path/to/input/las -p /path/to/pcl/block/json -o /path/
↪to/output/las
```

This is functionally equivalent to the original *pdal pipeline* command, but does not afford the flexibility of constructing the pipeline (i.e., none the other PDAL filters are accessible).

The same can be accomplished with the `pdal pcl` command. The basic syntax for the command is

```
$ pdal pcl -i <input cloud> -p <PCL Block JSON> -o <output cloud>
```

where the JSON file specified with `-p` is the same file that would be embedded in the pipeline JSON file. This can be useful when the pipeline does not change frequently, but the input/output filenames do.

For example, the above *pdal pipeline* example can be written with *pdal pcl* like this:

```
$ cd pdal # your PDAL source tree
$ cd test/data
$ ../../bin/pdal pcl -i autzen/autzen-point-format-3.las -p filters/
↪pcl/example_PassThrough_1.json -o ../temp/foo.las -v4
```

This should produce the output

```
Requested to read 106 points
Requested to write 106 points
0
Processing /home/vagrant/pdal/test/data/filters/pcl/passthrough.json

-----
↪-----  
NAME: PassThroughExample ()
HELP:
AUTHOR:
```

```
-->
106 points copied

Step 1) PassThrough

    Field name: z
    Limits: 410.000000, 440.000000

76(writers.las DEBUG: 3): Wrote 81 points to the LAS file
.100
```

## Examples

### Simple point cloud cropping

The power of the PCL Block is really exposed through the JSON description. In this example, we apply a single PCL filter to the PointView. The [PassThrough](#) (<http://pointclouds.org/documentation/tutorials/passthrough.php>) filter removes points that lie outside a given range for the specified dimension. Here, we are asking PCL to crop the input point cloud, returning only those points with z values in the range 100 to 200.

```
[

    {
        "name": "PassThrough",
        "setFilterFieldName": "z",
        "setFilterLimits":
        {
            "min": 410.0,
            "max": 440.0
        }
    }
]
```

(This example is taken from the unit test *PCLBlockFilterTest\_example\_PassThrough\_1*.)

### Point cloud cropping with outlier removal

Building on the previous example, we can string together multiple PCL filtering stages, such as the [StatisticalOutlierRemoval](#) ([http://pointclouds.org/documentation/tutorials/statistical\\_outlier.php](http://pointclouds.org/documentation/tutorials/statistical_outlier.php)) filter. Note that the name field identifies the PCL filter by its class name, and furthermore that as of now only a

handful of the PCL filtering options are accessible through the PCL Block. Similarly, select parameters of these classes can be set by specifying their public member functions by name.

```
[
  {
    "name": "PassThrough",
    "help": "filter z values to the range [410,440]",
    "setFilterFieldName": "z",
    "setFilterLimits":
    {
      "min": 410.0,
      "max": 440.0
    }
  },
  {
    "name": "StatisticalOutlierRemoval",
    "help": "apply outlier removal",
    "setMeanK": 8,
    "setStddevMulThresh": 0.2
  }
]
```

(This example is taken from the unit test *PCLBlockFilterTest\_example\_PassThrough\_2.*)

## Ground return filtering

The Progressive Morphological Filter (PMF) is an openly published approach to identifying ground vs. non-ground returns in point cloud data. An implementation of PMF is included with PCL and accessible through the PDAL's PCL Block filter.

A complete description of the algorithm can be found in the article “[A Progressive Morphological Filter for Removing Nonground Measurements from Airborne LIDAR Data](#)” (<http://users.cis.fiu.edu/~chens/PDF/TGRS.pdf>) by K. Zhang, S. Chen, D. Whitman, M. Shyu, J. Yan, and C. Zhang.

To run the PMF with default settings, the PCL Block JSON is simply:

```
[
  {
    "name": "ProgressiveMorphologicalFilter"
    "setMaxWindowSize": 200,
  }
]
```

Additional parameters can be set by advanced users:

```
[  
  {  
    "name": "ProgressiveMorphologicalFilter",  
    "setCellSize": 1.0,  
    "setMaxWindowSize": 200,  
    "setSlope": 1.0,  
    "setInitialDistance": 0.5,  
    "setMaxDistance": 3.0,  
    "setExponential": true  
  }  
]
```

(These examples are taken from the unit tests *PCLBlockFilterTest\_example\_PMF\_1* and *PCLBlockFilterTest\_example\_PMF\_2*.)

See [here](#) (page 264) for a more detailed explanation of the PMF parameters.

### 10.1.5 Identifying ground returns using ProgressiveMorphological-Filter segmentation

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**Date** 10/28/2015

Implements the Progressive Morphological Filter for segmentation of ground points.

---

**Note:** `filters.ground` required PCL and has since been replaced by [`filters.pmf`](#) (page 167), which is a native PDAL filter. [`ground`](#) (page 27) has been retained, but now calls [`filters.pmf`](#) (page 167) under the hood as opposed to `filters.ground` and is installed as a native PDAL kernel independent of the PCL plugin. As such, the outputs shown in this tutorial may vary slightly, but the underlying algorithm is identical.

---

#### Background

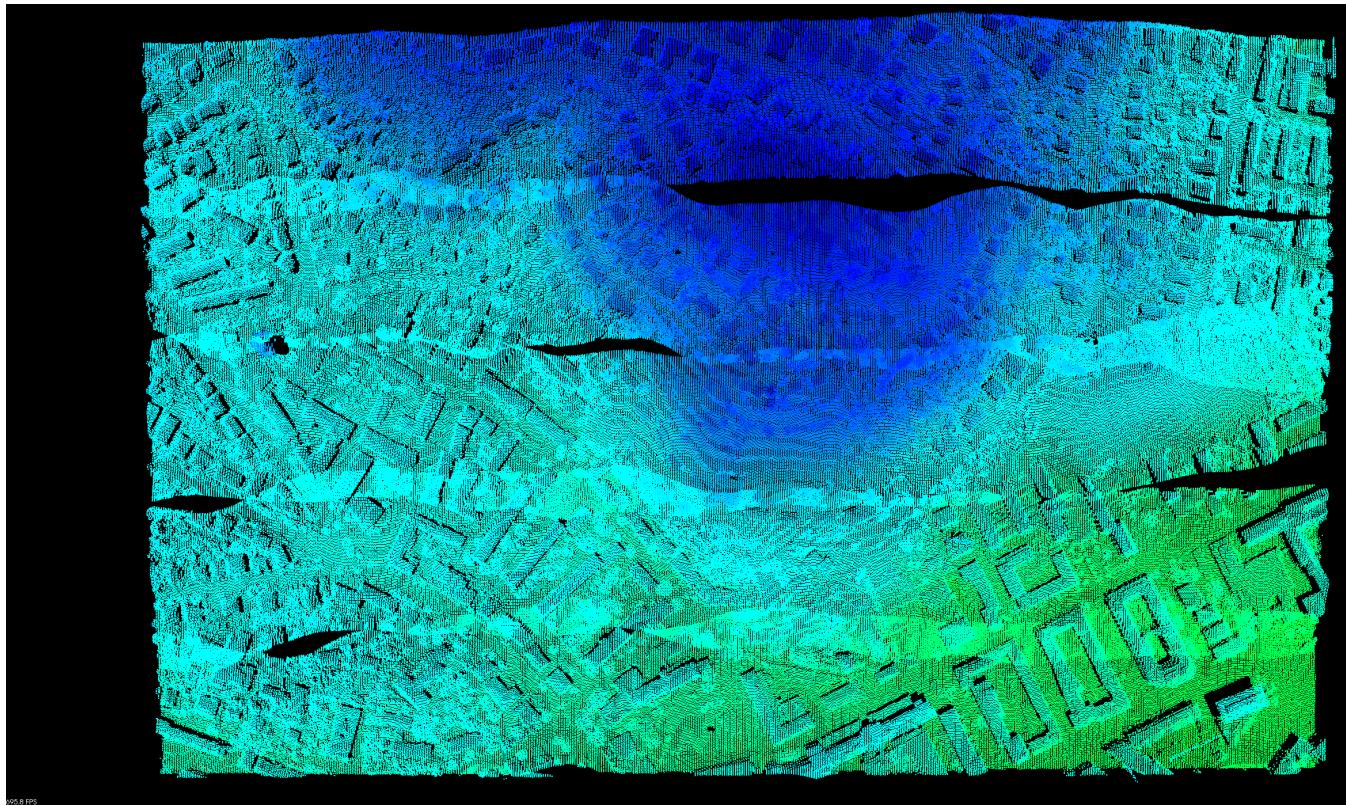
A complete description of the algorithm can be found in the article “A Progressive Morphological Filter for Removing Nonground Measurements from Airborne LIDAR Data” (<http://users.cis.fiu.edu/~chens/PDF/TGRS.pdf>) by K. Zhang, S. Chen, D. Whitman, M. Shyu, J. Yan, and C. Zhang.

For more information on how to invoke this PCL-based filter programmatically, see the [ProgressiveMorphologicalFilter](#)

([http://pointclouds.org/documentation/tutorials/progressive\\_morphological\\_filtering.php](http://pointclouds.org/documentation/tutorials/progressive_morphological_filtering.php)) tutorial on the PCL website.

We have chosen to demonstrate the algorithm using data from the 2003 report “ISPRS Comparison of Filters.” For more on the data and the study itself, please see <http://www.itc.nl/isprswgIII-3/filtertest/> as well as “Experimental comparison of filter algorithms for bare-earth extraction from airborne laser scanning point clouds” (<http://dx.doi.org/10.1016/j.isprsjprs.2004.05.004>) by G. Sithole and G. Vosselman.

First, download the dataset [CSite1\\_orig-utm.laz](#) ([https://raw.github.com/PDAL/data/master/isprs/CSite1\\_orig-utm.laz](https://raw.github.com/PDAL/data/master/isprs/CSite1_orig-utm.laz)) and save it somewhere to disk.



## Using the Ground kernel

The [pdal ground](#) (page 27) kernel can be used to filter ground returns, allowing the user to tweak filtering parameters at the command-line.

Let’s start by running `pdal ground` with the default parameters.

```
$ pdal ground -i CSite1_orig-utm.laz -o CSite1_orig-utm-ground.laz
```

To get an idea of what’s happening during each iteration, you can optionally increase the verbosity of the output. We’ll try `-v4`. Here we see a summary of the parameters, along with

height threshold, window size, and number of remaining ground points.

```
$ pdal ground -i CSitel_orig-utm.laz -o CSitel_orig-utm-ground.laz -  
↳v4  
  
-----  
↳  
NAME:      ()  
HELP:  
AUTHOR:  
  
-----  
↳  
process tile 0 through the pipeline  
  
Step 1) ProgressiveMorphologicalFilter  
  
    max window size: 33  
    slope: 1.000000  
    max distance: 2.500000  
    initial distance: 0.150000  
    cell size: 1.000000  
    base: 2.000000  
    exponential: true  
    negative: false  
    Iteration 0 (height threshold = 0.150000, window size = 3.  
↳000000)...ground now has 872413 points  
    Iteration 1 (height threshold = 2.150000, window size = 5.  
↳000000)...ground now has 833883 points  
    Iteration 2 (height threshold = 2.500000, window size = 9.  
↳000000)...ground now has 757030 points  
    Iteration 3 (height threshold = 2.500000, window size = 17.  
↳000000)...ground now has 625333 points  
    Iteration 4 (height threshold = 2.500000, window size = 33.  
↳000000)...ground now has 580852 points  
    1366408 points filtered to 580852 following progressive  
↳morphological filter
```

The resulting filtered cloud can be seen in this top-down and front view. When viewed from the side, it is apparent that there are a number of low noise points that have fooled the PMF filter.



To address, we introduce an alternate way to call PMF, as part of a PCL pipeline, where we preprocess with an outlier removal step. The command is nearly identical, replacing ground

with pcl and adding a pipeline JSON specified with -p.

```
{  
    "pipeline": {  
        "name": "Progressive Morphological Filter with Outlier Removal",  
        "version": 1.0,  
        "filters": [{  
            "name": "StatisticalOutlierRemoval",  
            "setMeanK": 8,  
            "setStddevMulThresh": 3.0  
        }, {  
            "name": "ProgressiveMorphologicalFilter"  
        }]  
    }  
}
```

```
$ pdal pcl -i CSite1_orig-utm.laz -o CSite1_orig-utm-ground.laz -p ↵  
sor-pmf.json -v4
```

```
-----  
→-----  
NAME: Progressive Morphological Filter with Outlier Removal (1.0)
```

```
HELP:
```

```
AUTHOR:
```

```
-----  
→-----  
process tile 0 through the pipeline
```

```
Step 1) StatisticalOutlierRemoval
```

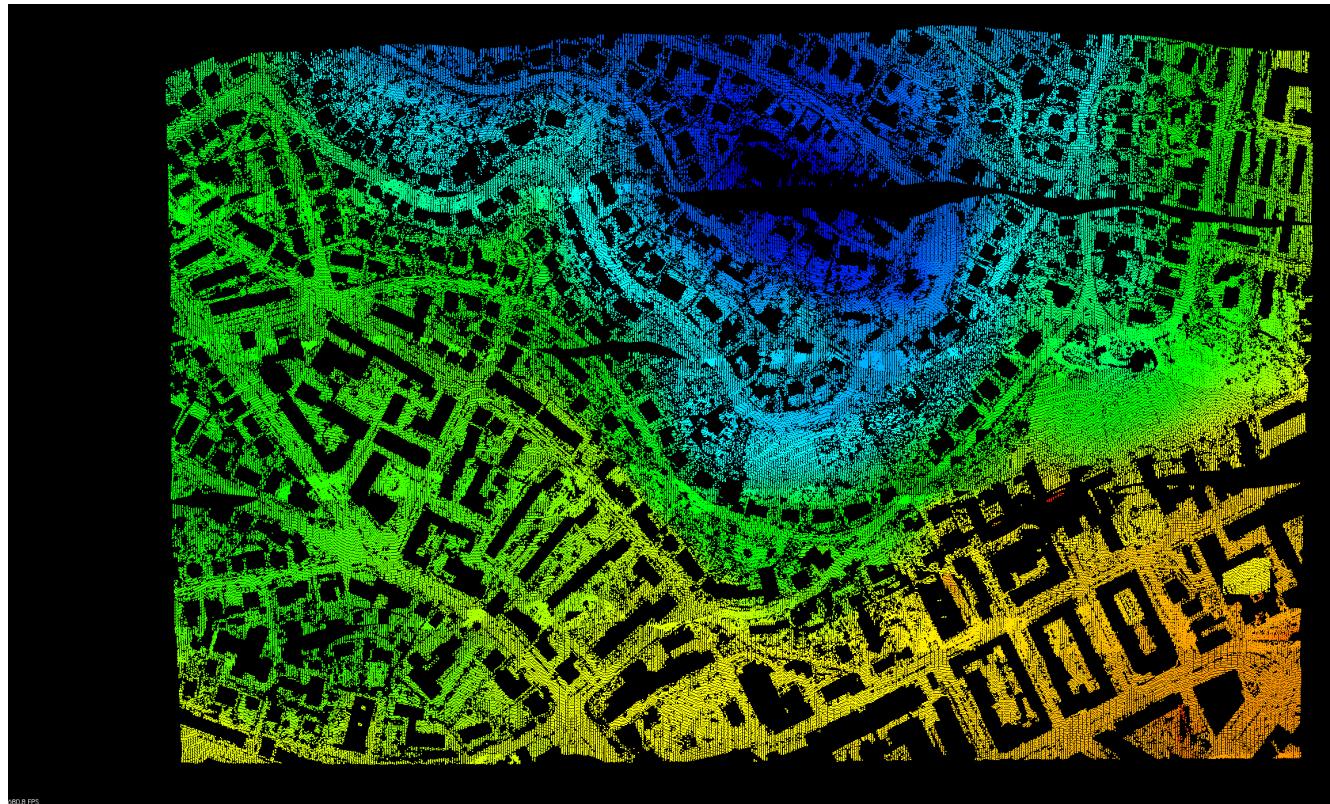
```
    8 neighbors and 3.000000 multiplier  
    1366408 points filtered to 1356744 following outlier removal
```

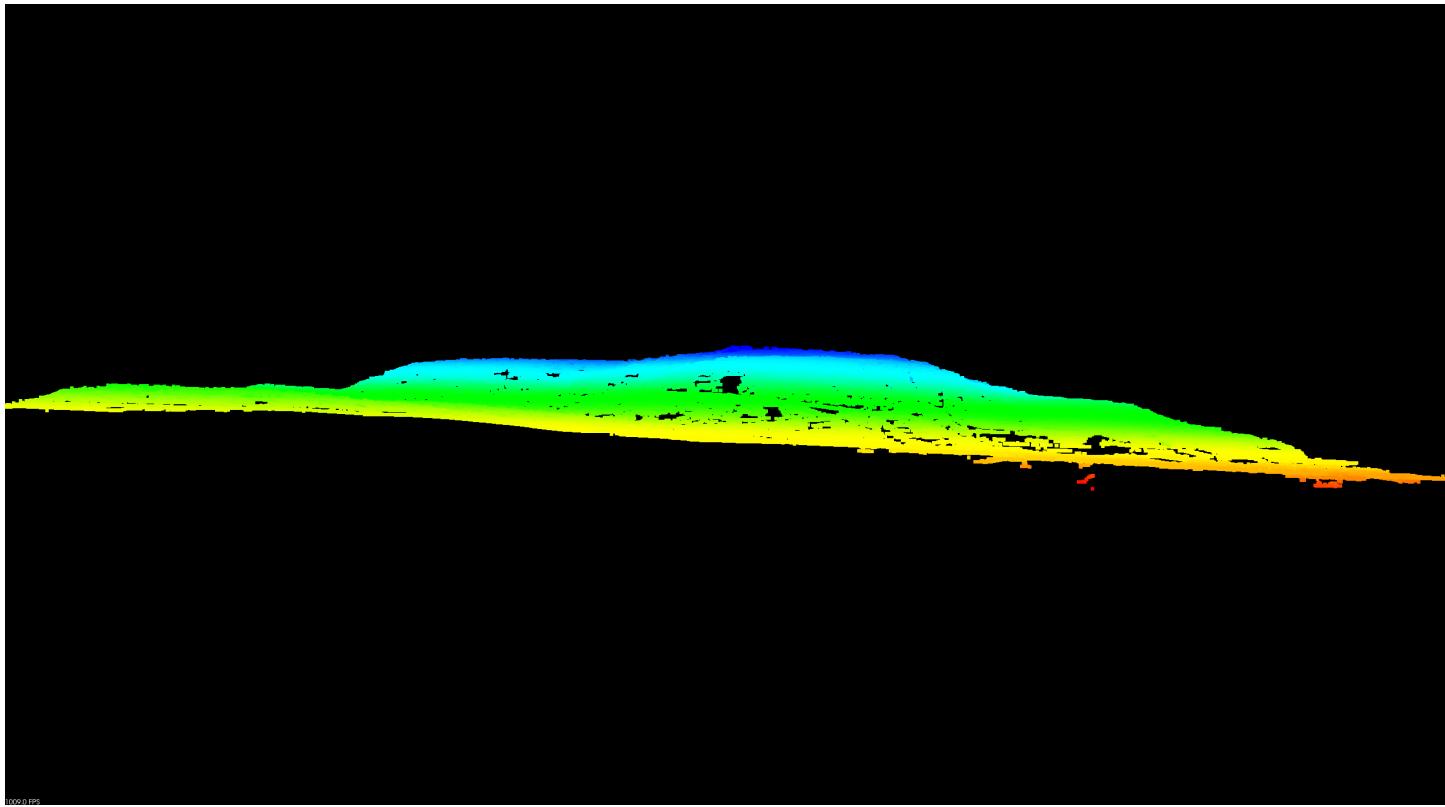
```
Step 2) ProgressiveMorphologicalFilter
```

```
    max window size: 33  
    slope: 1.000000  
    max distance: 2.500000  
    initial distance: 0.150000  
    cell size: 1.000000  
    base: 2.000000  
    exponential: true  
    negative: false  
    Iteration 0 (height threshold = 0.150000, window size = 3.  
→000000)...ground now has 874094 points  
    Iteration 1 (height threshold = 2.150000, window size = 5.  
→000000)...ground now has 837141 points
```

```
Iteration 2 (height threshold = 2.500000, window size = 9.  
→000000)...ground now has 762213 points  
Iteration 3 (height threshold = 2.500000, window size = 17.  
→000000)...ground now has 632827 points  
Iteration 4 (height threshold = 2.500000, window size = 33.  
→000000)...ground now has 596620 points  
    1356744 points filtered to 596620 following progressive  
→morphological filter
```

The result is noticeably cleaner in both the top-down and front views.





Unfortunately, you may notice that we still have a rather large building in the lower right of the image. By tweaking the parameters slightly, in this case, increasing the cell size, we can do a better job of removing such features.

```
{  
    "pipeline": {  
        "name": "Progressive Morphological Filter with Outlier Removal",  
        "version": 1.0,  
        "filters": [{  
            "name": "StatisticalOutlierRemoval",  
            "setMeanK": 8,  
            "setStddevMulThresh": 3.0  
        }, {  
            "name": "ProgressiveMorphologicalFilter",  
            "setCellSize": 1.5  
        }]  
    }  
}
```

```
$ pdal pcl -i CSite1_orig-utm.laz -o CSite1_orig-utm-ground.laz -p  
→sor-pmf2.json -v4
```

```
NAME: Progressive Morphological Filter with Outlier Removal (1.0)
HELP:
AUTHOR:
-----
→ process tile 0 through the pipeline

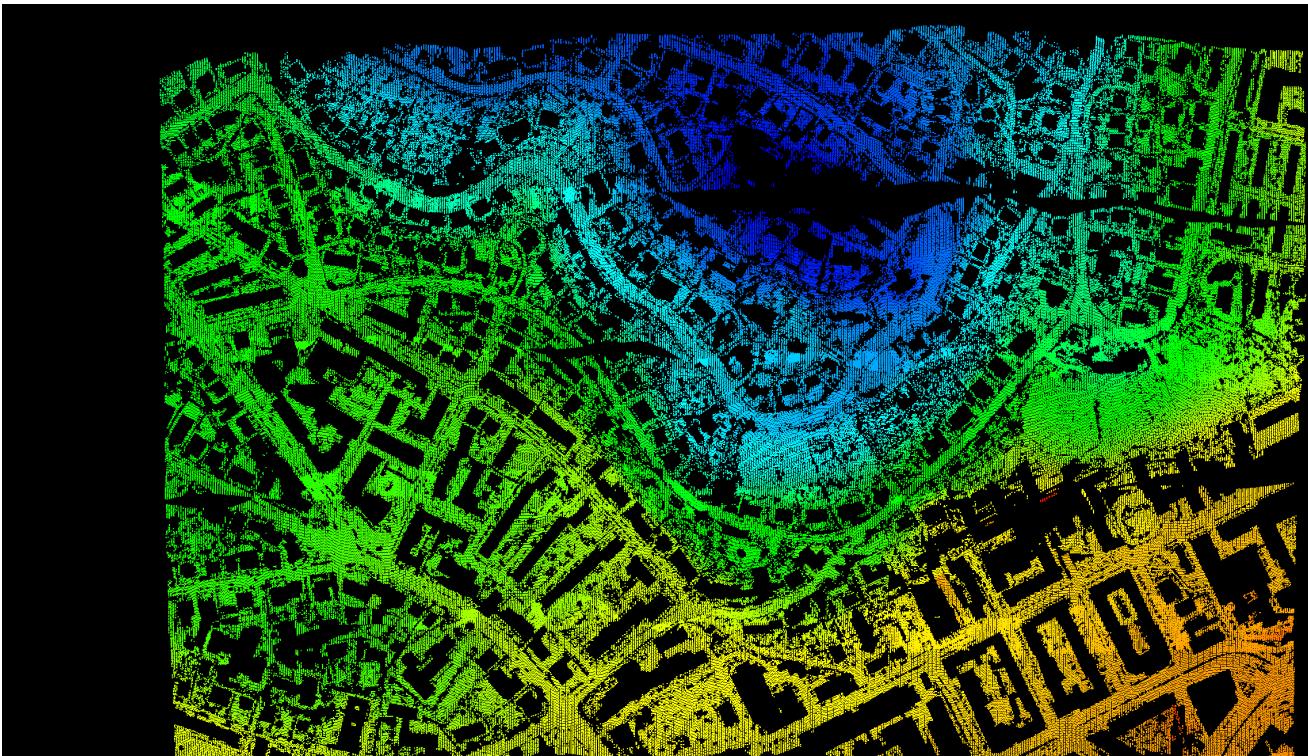
Step 1) StatisticalOutlierRemoval

    8 neighbors and 3.000000 multiplier
    1366408 points filtered to 1356744 following outlier removal

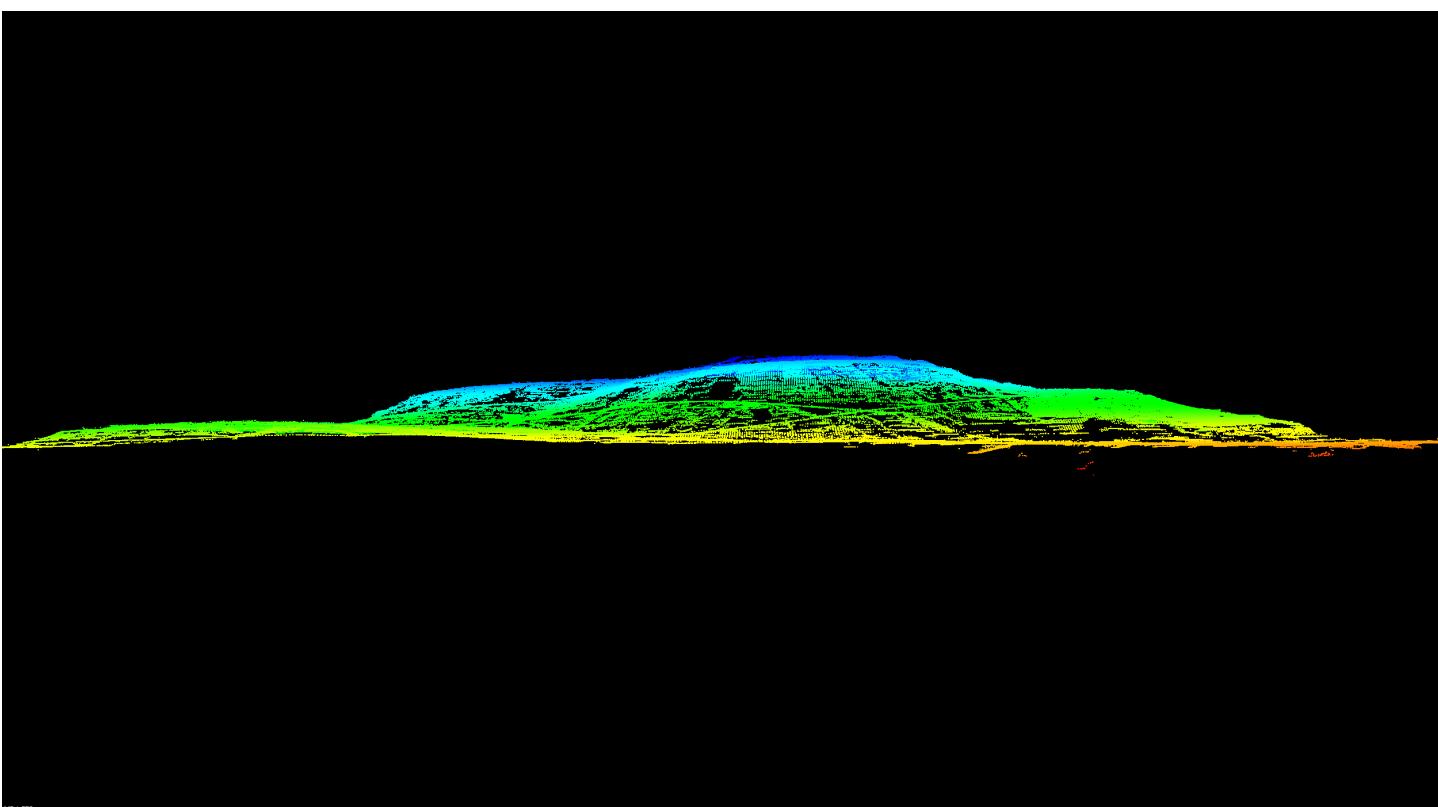
Step 2) ProgressiveMorphologicalFilter

    max window size: 33
    slope: 1.000000
    max distance: 2.500000
    initial distance: 0.150000
    cell size: 1.500000
    base: 2.000000
    exponential: true
    negative: false
    Iteration 0 (height threshold = 0.150000, window size = 4.
→ 500000) ...ground now has 785496 points
    Iteration 1 (height threshold = 2.500000, window size = 7.
→ 500000) ...ground now has 728738 points
    Iteration 2 (height threshold = 2.500000, window size = 13.
→ 500000) ...ground now has 623385 points
    Iteration 3 (height threshold = 2.500000, window size = 25.
→ 500000) ...ground now has 581679 points
    Iteration 4 (height threshold = 2.500000, window size = 49.
→ 500000) ...ground now has 551006 points
    1356744 points filtered to 551006 following progressive_
→ morphological filter
```

Once again, the result is noticeably cleaner in both the top-down and front views.



521.5 FPS



489.0 FPS

## 10.1.6 Clipping with Geometries

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**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 auxillary data sources such as [OGR](http://www.gdal.org) (<http://www.gdal.org>)-readable [Shapefiles](https://en.wikipedia.org/wiki/Shapefile) (<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 273)
  - *Introduction* (page 273)
  - *Example Data* (page 273)
  - *Stage Operations* (page 274)
  - *Data Preparation* (page 274)
  - *Pipeline* (page 275)
  - *Processing* (page 276)
  - *Conclusion* (page 277)

### 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/PDAL/raw/master/test/data/autzen/attributes.json>

### Stage Operations

This operation depends on two stages PDAL provides. The first is the [filters.overlay](#) (page 165) stage, which allows you to assign point values based on polygons read from [OGR](#) (<http://www.gdal.org>). The second is [filters.range](#) (page 191), which allows you to keep or reject points from the set that match given criteria.

#### See also:

[filters.python](#) (page 221) allow you to construct sophisticated logic for keeping or rejecting points in a more expressive environment.

### Data Preparation



Fig. 10.10: Autzen Stadium, a 100 million+ point cloud file.

The data are mixed in two different coordinate systems. The [LAZ](#) (page 69) 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](http://www.gdal.org/drv_vrt.html)) capability to reproject the data for us on-the-fly:

```
<OGRVRTDataSource>
  <OGRVRTWarpedLayer>
    <OGRVRTLayer name="OGREGeoJSON">
      <SrcDataSource>attributes.json</SrcDataSource>
```

```

<LayerSRS>EPSG:4326</LayerSRS>
</OGRVRTLayer>
<TargetSRS>+proj=lcc +lat_1=43 +lat_2=45.5 +lat_0=41.75 +lon_
-120.5 +x_0=399999.999999999 +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.

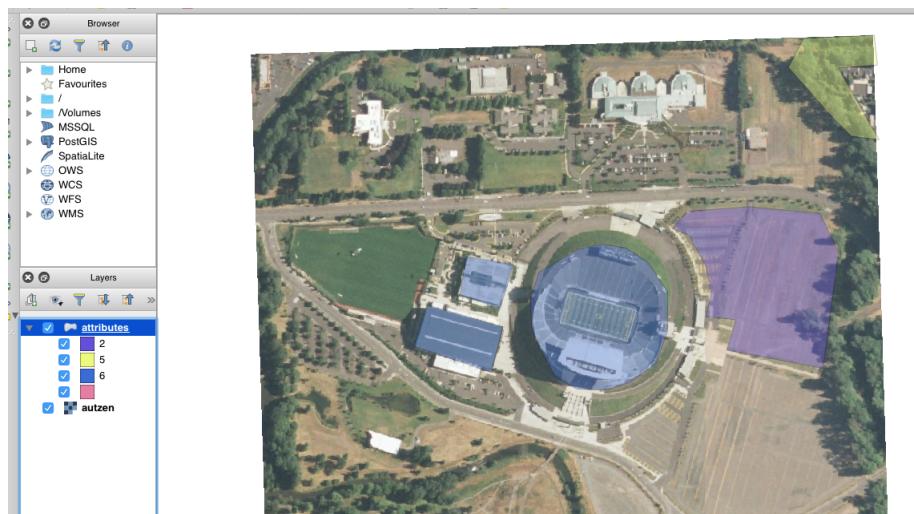


Fig. 10.11: We want to clip out the polygon in the upper right hand corner. We can view the GeoJSON (<http://geojson.org>) geometry using something like QGIS (<http://qgis.org>)

## Pipeline

A PDAL *pipeline* (page 45) is how you define a set of actions to apply to data as they are read, filtered, and written.

```
[  
    "autzen.laz",  
    {  
        "type": "filters.overlay",  
        "dimension": "Classification",  
        "datasource": "attributes.vrt",  
        "layer": "OGRGeoJSON",  
        "column": "CLS"  
    },  
    {  
        "type": "filters.range",  
        "limits": "Classification[5:5]"  
    },  
    "output.las"  
]
```

- *readers.las* (page 69): 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 165): Using the VRT we defined in *Data Preparation* (page 274), read attribute polygons out of the data source and assign the values from the CLS column to the Classification field.
- *filters.range* (page 191): 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.
- *writers.las* (page 113): write our content out using an **ASPRS LAS** (<http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html>) writer.

---

**Note:** You don't have to use only Classification to set the attributes with *filters.overlay* (page 165). 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> or [CloudCompare](http://www.danielgm.net/cc/) (<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 165) and `filters.range` (page 191) stages to clip points with shapefiles.

### 10.1.7 Ground Filter Tutorial

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**Date** 04/17/2017

## Background

In previous tutorials we introduced our implementation of the *Progressive Morphological Filter (PMF)* (page 167), a *ground kernel* (page 27) to simplify command-line access to PMF, and a filter for *removing outliers* (page 161).

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.

```
1  {
2      "pipeline": [
3          {
4              "type": "filters.reprojection",
5              "out_srs": "EPSG:32632"
6          },
7          {
8              "type": "filters.assign",
9              "assignment": "Classification[:] = 0"
10         },
11         {
12             "type": "filters.elm"
13         },
14         {
15             "type": "filters.outlier"
16         },
17         {
18             "type": "filters.smrf",
19             "last": true,
20             "ignore": "Classification[7:7]",
21             "slope": 0.2,
22             "window": 16,
23             "threshold": 0.45,
24             "scalar": 1.2
25         },
26     ]
```

```
27     "type": "filters.range",
28     "limits": "Classification[2:2]"
29   }
30 ]
31 }
```

---

**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 39) 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.

```
3  {
4    "type": "filters.reprojection",
5    "out_srs": "EPSG:32632"
6  },
```

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](#) (page 137) 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.

```
7  {
8      "type": "filters.assign",
9      "assignment": "Classification[:] = 0"
10 },
```

---

**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 137) and [filters.overlay](#) (page 165).

---

## Extended Local Minimum

The [Extended Local Minimum \(ELM\) method](#) (page 147) helps to identify low noise points that can adversely affect ground segmentation algorithms. ELM was first published in [\[Chen2012\]](#) (page 525) 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.

```
11  {
12      "type": "filters.elm"
13 },
```

## Outliers

PDAL's [outlier filter](#) (page 161) 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.

```
14  {
15      "type": "filters.outlier"
16 },
```

## Ground Segmentation

The [Simple Morphological Filter \(SMRF\)](#) (page 169) [\[Pingel2013\]](#) (page 526) 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 strutting element.

```

17  {
18      "type": "filters.smrf",
19      "last": true,
20      "ignore": "Classification[7:7]",
21      "slope": 0.2,
22      "window": 16,
23      "threshold": 0.45,
24      "scalar": 1.2
25  },

```

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 193), 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 167) [*Zhang2003*] (page 526). 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 191) as shown.

```
26  {
27      "type": "filters.range",
28      "limits": "Classification[2:2]"
29 }
```

The *range filter* (page 191) accepts a `limits` option that identifies the dimension(s) on which to filter and the *range* (page 193) of values to passthrough. In this case, we are indicating that the filter should only pass points whose `Classification` value is equal to 2.

---

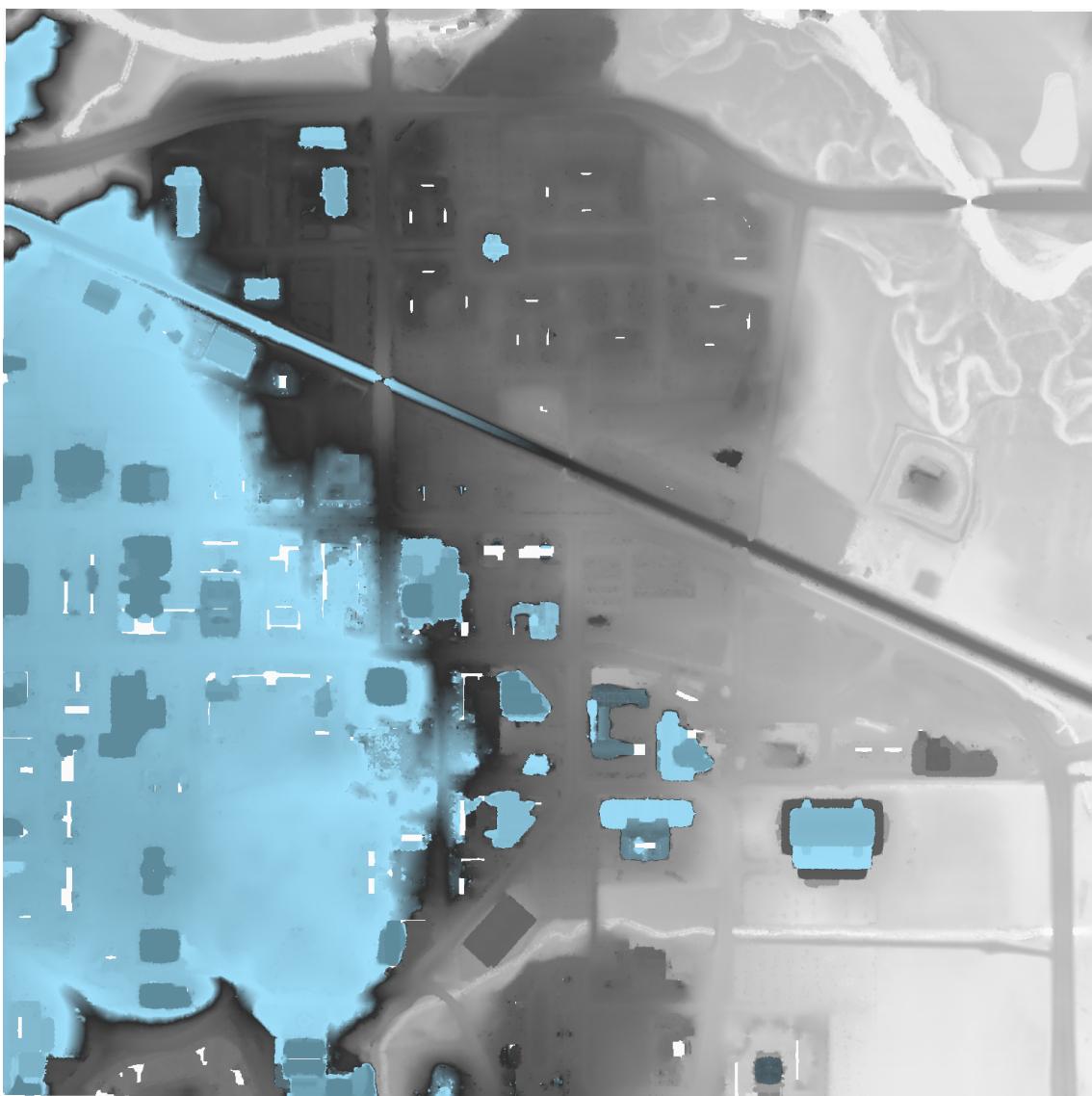
**Note:** The default behavior of both *PMF* (page 167) and *SMRF* (page 169) is to classify points, which has not changed from previous versions of PDAL. The `extract` and `classify` options have been removed in PDAL v1.5. These filters now **only** classify points, such that ground points can be identified 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 39) `input.las` to `output.las`.

```
$ pdal translate input.las output.las --json pipeline.json
```





---

CHAPTER  
ELEVEN

---

WORKSHOP

## 11.1 Point Cloud Processing and Analysis with PDAL

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**Date** 05/17/2018

### 11.1.1 Introduction

1. *Introduction to LiDAR* (page 286)
2. *Introduction to PDAL* (page 5)
3. *Software Installation* (page 292)
4. *Basic Information* (page 297)
5. *Translation* (page 304)
6. *Analysis* (page 313)
7. *Georeferencing* (page 370)

### Materials

#### Slides

- Slides (<https://pdal.io/workshop/slides/>)

## Workshop Materials

These materials are available at <http://pdal.io/workshop/> as both a PDF and an HTML website.

- [PDF download](https://pdal.io/PDAL.pdf) (<https://pdal.io/PDAL.pdf>)
- [Website](https://pdal.io/workshop/) (<https://pdal.io/workshop/>)

## USB Example Data Drive

A companion USB drive containing workshop example data is required to follow along with these examples.



---

**Note:** A drive image is available for download at  
<https://s3.amazonaws.com/pdal/workshop/PDAL.zip>

---

### 11.1.2 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 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 [\[Gle07\]](#) (page 525):

$$\mathbf{p}_G^l = \mathbf{p}_{GPS}^l + \mathbf{R}_b^l (\mathbf{R}_s^b \mathbf{r}^s - \mathbf{l}^b) \quad (11.1)$$

where:

- $\mathbf{p}_G^l$  are the coordinates of the target point in the global reference frame
- $\mathbf{p}_{GPS}^l$  are the coordinates of the GNSS sensor in the global reference frame
- $\mathbf{R}_b^l$  is the rotation matrix from the navigation frame to the global reference frame
- $\mathbf{R}_s^b$  is the rotation matrix from the scanner's frame to the navigation frame (boresight matrix)
- $\mathbf{r}^s$  is the coordinates of the laser point in the scanner's frame
- $\mathbf{l}^b$  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 ~1Hz 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 (11.1) 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 analyse or process full waveform data.

---



Fig. 11.1: A real-world outgoing LiDAR pulse.



Fig. 11.2: A real-world incoming LiDAR return. Potential discrete-return peaks are marked in red.

### 11.1.3 Software Installation

#### QGIS

##### What is QGIS (<http://qgis.org>)?

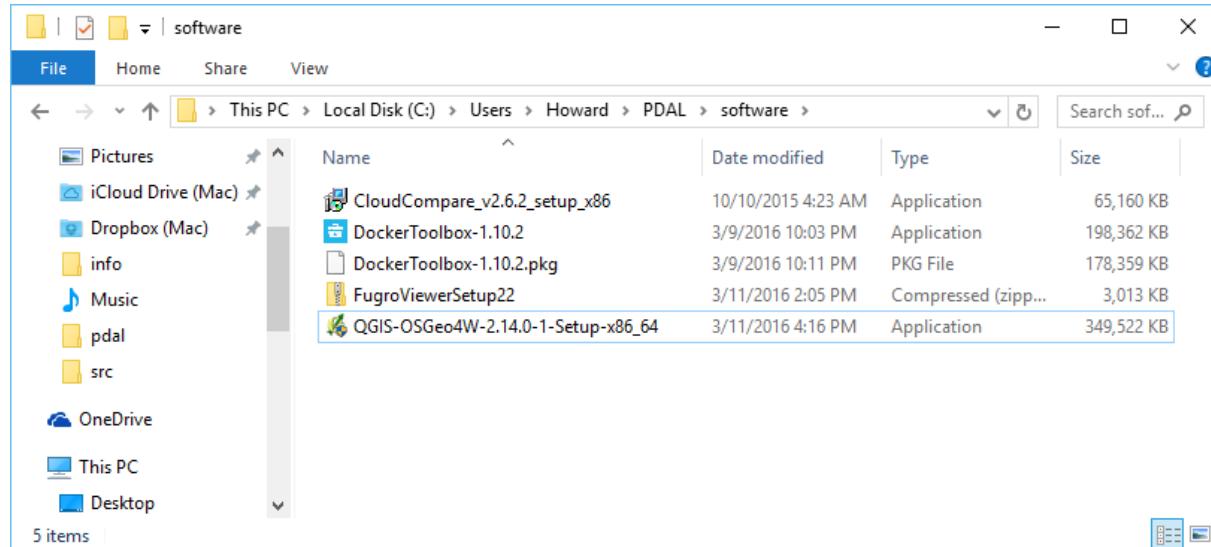
**QGIS** (<http://qgis.org>) is an open source GIS. It is extensible with **Python** (<http://python.org/>), it integrates the **GRASS** (<https://grass.osgeo.org/>) analytic environment, and it works on both Windows and OS X.

##### How will we use QGIS?

We're using **QGIS** (<http://qgis.org>) to visualize raster and vector processing product during our workshop. 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.

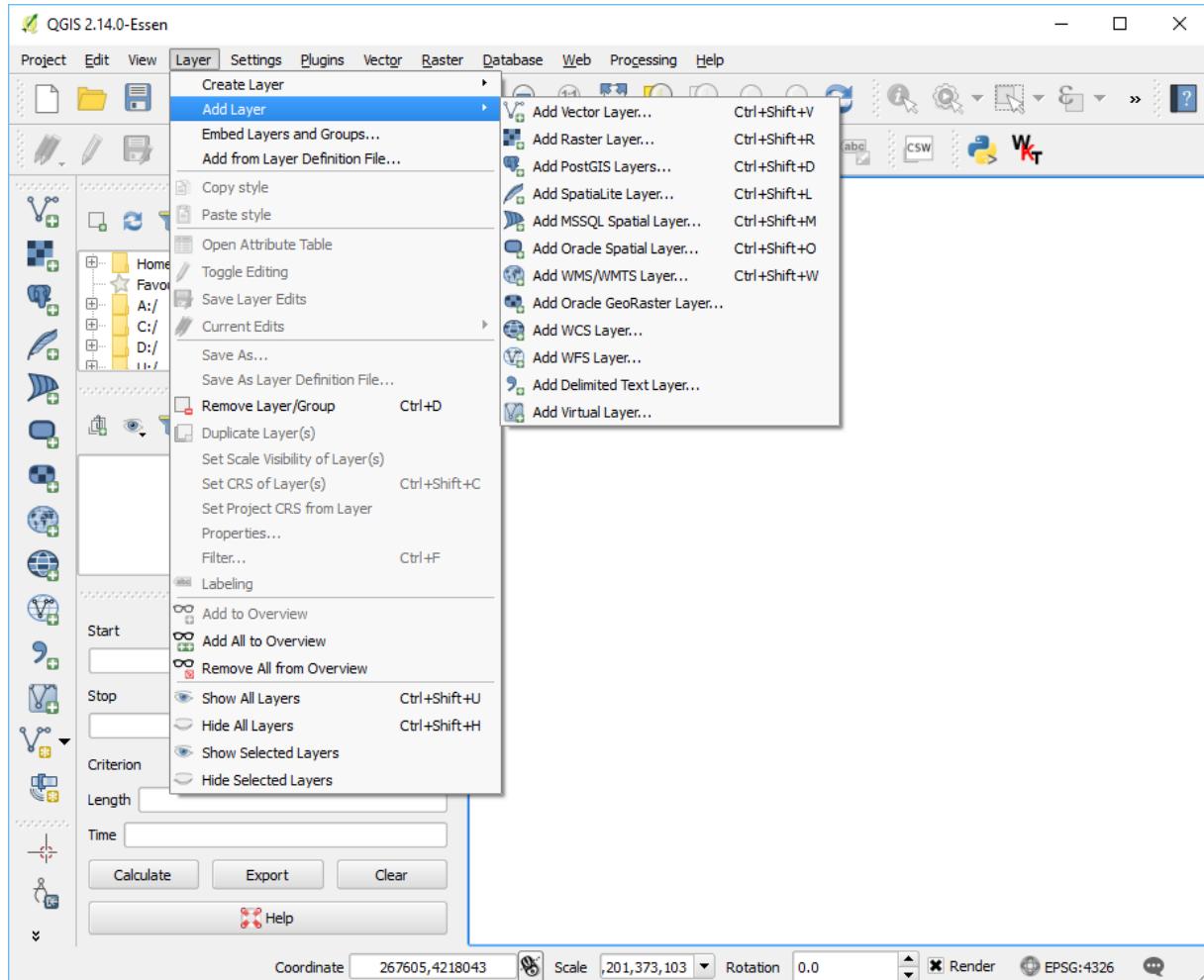
---

3. Choose the install image, Windows or Mac, and install QGIS (<http://qgis.org>) prepare your machine to run the examples.

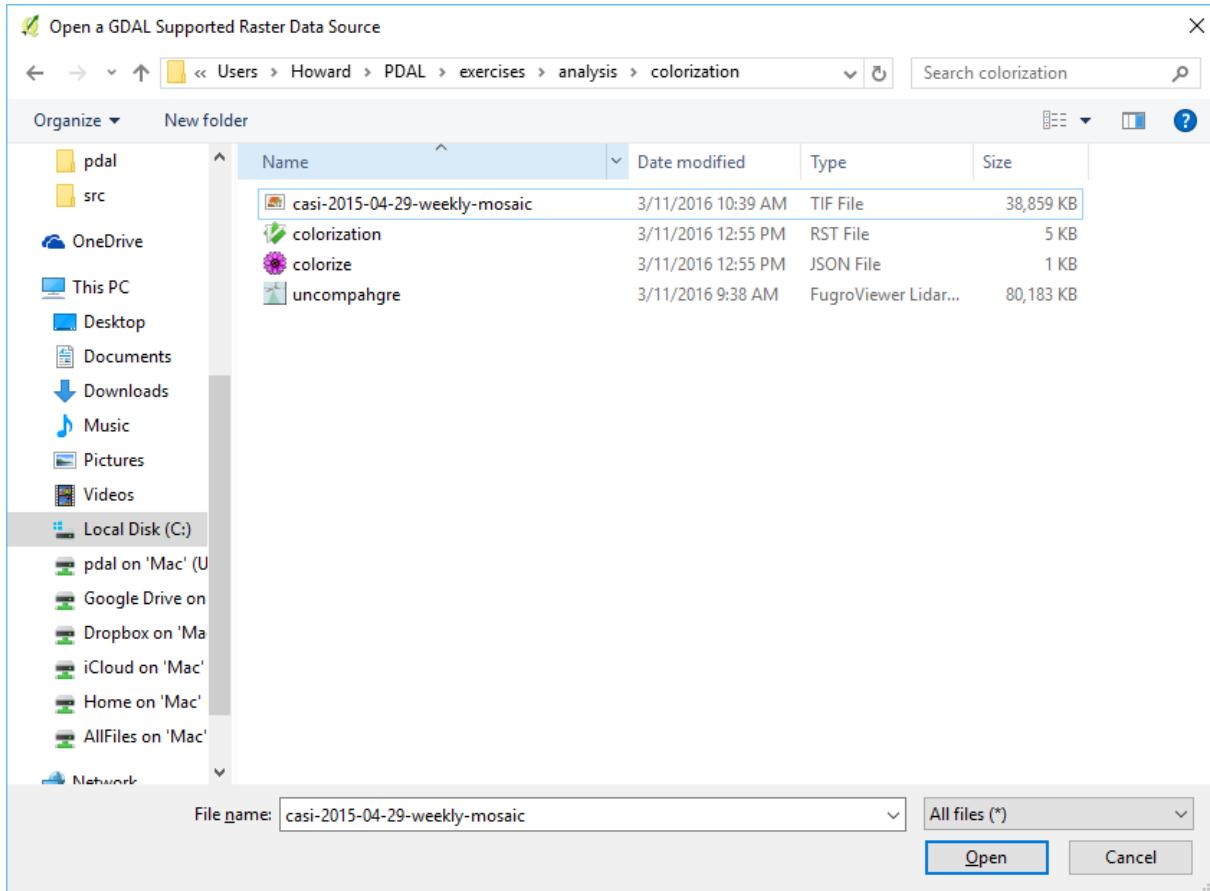




4. Once installed, verify you can run [QGIS](http://qgis.org) (<http://qgis.org>) by opening the application. Navigate to the C:\Users\hobu\PDAL\exercises\analysis\colorization directory.



5. Select the `casi-2015-04-29-weekly-mosaic.tif` image and open it for display.





## Conclusion

QGIS (<http://qgis.org>) allows everyone to have access to a fully-featured GIS. We are going to use it to visualize raster and vector data used throughout the workshop.

### 11.1.4 Exercises

#### Basic Information

##### Printing the first point

#### Exercise

This exercise uses PDAL to print information from the first point. Issue the following command in your *Anaconda Shell*:

```
1 pdal info c:/Users/hobu/PDAL/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 29) on the data. All commands are run by the pdal application.
3. c:/Users/hobu/PDAL/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 32) to override which *reader* (page 55) PDAL will use to open the file.
4. -p 0: -p corresponds to "print a point", and 0 means to print the first one (computer people count from 0).



The screenshot shows a Windows Command Prompt window titled 'cmd' with the path 'C:\WINDOWS\system32\cmd.exe'. The command entered is 'pdal info c:/Users/hobu/PDAL/exercises/info/interesting.las -p 0'. The output is a JSON object representing the first point of the LAS file:

```
{  
  "filename": "c:/Users/hobu/PDAL/exercises/info/interesting.las",  
  "pdal_version": "1.5.0 (git-version: 15fe7d)",  
  "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  
      ]  
    }  
  ]  
}
```

### Notes

1. PDAL uses **JSON** (<https://en.wikipedia.org/wiki/JSON>) as the exchange format when printing information from *info* (page 29). JSON is a structured, human-readable format

that is much simpler than its [XML](https://en.wikipedia.org/wiki/XML) (<https://en.wikipedia.org/wiki/XML>) cousin.

2. You can use the [writers.text](#) (page 132) writer to output point attributes to [CSV](#) ([https://en.wikipedia.org/wiki/Comma-separated\\_values](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 *Anaconda Shell*:

```
1 pdal info c:/Users/hobu/PDAL/exercises/info/interesting.las --  
  ↪metadata
```

```
C:\>pdal info c:/Users/hobu/PDAL/exercises/info/interesting.las --metadata
{
  "filename": "c:/Users/hobu/PDAL/exercises/info/interesting.las",
  "metadata": {
    "comp_spatialreference": "PROJCS[\"NAD_1983_Oregon_Statewide_Feet_Intl\",GEOGCS[\"GCS_North_American_1983\",DATUM[\"D_North_American_1983\",SPHEROID[\"GRS_1980\",6378137,298.257222101]],PRIMEM[\"Greenwich\",0],UNIT[\"degree\",0.0174532925199433]],PROJECTION[\"Lambert_Conformal_Conic_2SP\"],PARAMETER[\"standard_parallel_1\",43],PARAMETER[\"standard_parallel_2\",45.5],PARAMETER[\"latitude_of_origin\",41.75],PARAMETER[\"central_meridian\",-120.5],PARAMETER[\"false_easting\",400000],PARAMETER[\"false_northing\",0],UNIT[\"foot\",0.3048,AUTHORITY[\"EPSG\",\"9002\"]]]",
    "compressed": false,
    "count": 1065,
    "creation_doy": 145,
    "creation_year": 2012,
    "dataformat_id": 3,
    "dataoffset": 1488,
    "filesource_id": 0,
    "global_encoding": 0,
    "global_encoding_base64": "AAA=",
    "header_size": 227,
    "major_version": 1,
    "maxx": 638982.55,
    "maxy": 853535.43,
    "maxz": 586.38,
    "minor_version": 2,
    "minx": 635619.85,
    "miny": 848899.7,
```

**Note:** PDAL [metadata](#) (page 402) is returned a in a tree structure corresponding to processing

pipeline that produced it.

---

### See also:

Use the [JSON](https://en.wikipedia.org/wiki/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/2/library/json.html) (<https://docs.python.org/2/library/json.html>)
- [jsawk](https://github.com/micha/jsawk) (<https://github.com/micha/jsawk>) (like `awk` but for JSON data)
- [jq](https://stedolan.github.io/jq/) (<https://stedolan.github.io/jq/>) (command line processor for JSON)
- [Ruby JSON library](http://ruby-doc.org/stdlib-2.0.0/libdoc/json/rdoc/JSON.html) (<http://ruby-doc.org/stdlib-2.0.0/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) (<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 info` --metadata 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 either. Let’s focus on extracting what we want using the `jq` command.

```
1 pdal info c:/Users/hobu/PDAL/exercises/info/interesting.las --  
  ↪metadata ^  
2   | jq ".metadata.compressed, .metadata.system_id"
```



The screenshot shows a Windows command prompt window titled 'C:\WINDOWS\system32\cmd.exe'. The command entered is 'pdal info c:/Users/hobu/PDAL/exercises/info/interesting.las --metadata ^ More? | jq ".metadata.compressed, .metadata.system\_id"'. The output shows 'false' and '\"HOBU-SYSTEMID\"'. The command prompt ends with 'c:\>-'.

---

**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 29). JSON provides human and machine-readable text data.
2. The PDAL *metadata document* (page 402) 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 55) produce same-named values where possible, but it is common that variables are different. *Filters* (page 135) and even *writers* (page 104) 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.

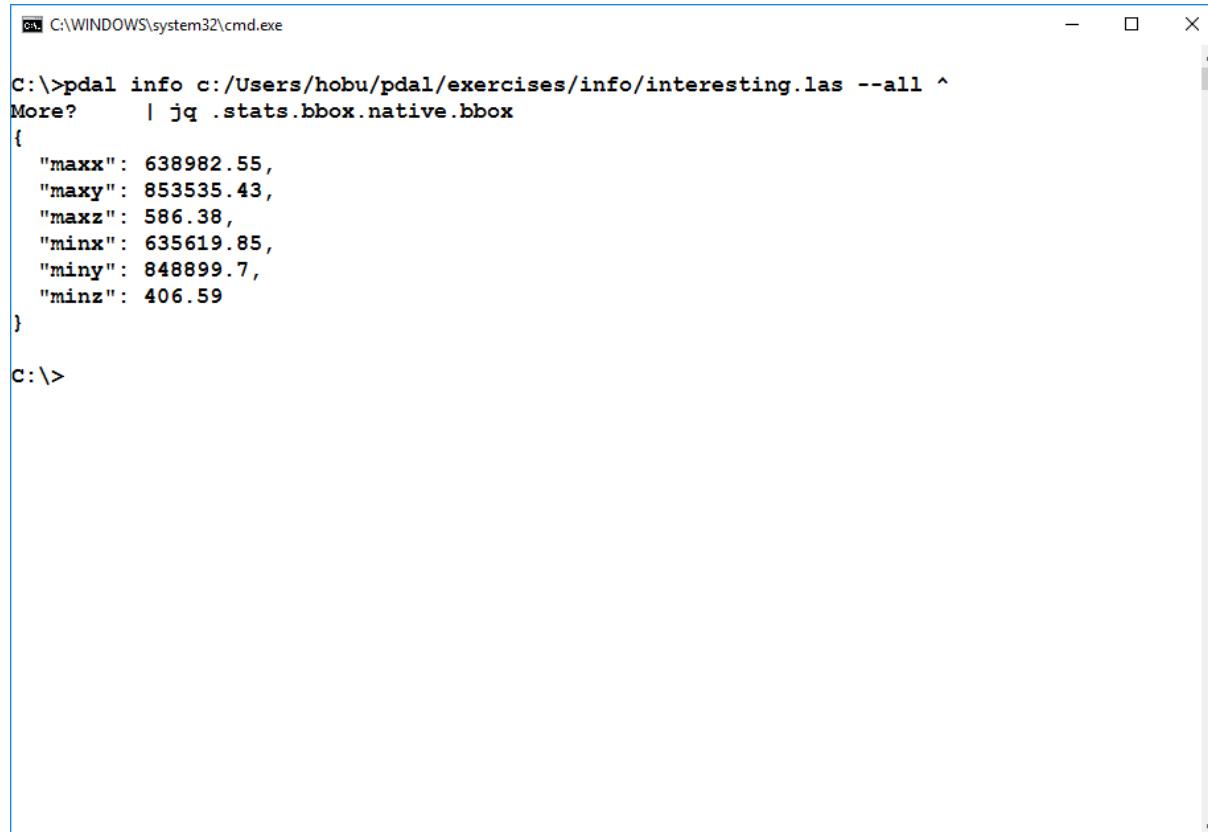
### Searching near a point

#### 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:

```
pdal info c:/Users/hobu/pdal/exercises/info/interesting.las --all ^  
| jq .stats.bbox.native.bbox
```



The screenshot shows a Windows command prompt window titled "C:\WINDOWS\system32\cmd.exe". The command entered is "pdal info c:/Users/hobu/pdal/exercises/info/interesting.las --all ^ | jq .stats.bbox.native.bbox". The output is a JSON object representing the bounding box coordinates:

```
{  
  "maxx": 638982.55,  
  "maxy": 853535.43,  
  "maxz": 586.38,  
  "minx": 635619.85,  
  "miny": 848899.7,  
  "minz": 406.59  
}
```

Find the average the X, Y, and Z values:

```
x = 635619.85 + (638982.55 - 635619.85) / 2 = 637301.20  
y = 848899.70 + (853535.43 - 848899.70) / 2 = 851217.57  
z = 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:

```
pdal info c:/Users/hobu/pdal/exercises/info/interesting.las ^
--query "637301.20, 851217.57, 496.49/3"
```

**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.

```
C:\>pdal info c:/Users/hobu/pdal/exercises/info/interesting.las ^
More?      --query "637301.20, 851217.57, 496.49/3"
{
  "unnamed": [
    {
      "0": {
        "Blue": 176,
        "Classification": 1,
        "EdgeOfFlightLine": 0,
        "GpsTime": 247185.1549,
        "Green": 158,
        "Intensity": 33,
        "NumberOfReturns": 1,
        "PointSourceId": 7329,
        "Red": 183,
        "ReturnNumber": 1,
        "ScanAngleRank": 10,
        "ScanDirectionFlag": 1,
        "UserData": 124,
        "X": 637379.69,
        "Y": 851215.09,
        "Z": 423.56
      },
      "1": {
        "Blue": 221,
        "Classification": 1,
        "EdgeOfFlightLine": 0,
        "GpsTime": 247185.1549,
        "Green": 158,
        "Intensity": 33,
        "NumberOfReturns": 1,
        "PointSourceId": 7329,
        "Red": 183,
        "ReturnNumber": 1,
        "ScanAngleRank": 10,
        "ScanDirectionFlag": 1,
        "UserData": 124,
        "X": 637301.2,
        "Y": 851217.57,
        "Z": 496.49
      }
    ]
  }
}
```

## Notes

1. PDAL uses [JSON](https://en.wikipedia.org/wiki/JSON) (<https://en.wikipedia.org/wiki/JSON>) as the exchange format when printing information from `info` (page 29). JSON is a structured, human-readable format that is much simpler than its [XML](https://en.wikipedia.org/wiki/XML) (<https://en.wikipedia.org/wiki/XML>) cousin.
2. The `--query` option of `info` (page 29) constructs a [KD-tree](https://en.wikipedia.org/wiki/K-d_tree) ([https://en.wikipedia.org/wiki/K-d\\_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.

## Translation

## 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 *Anaconda Shell*:

```
pdal translate ^
    c:/Users/hobu/pdal/exercises/translation/interesting.
    ↵las ^
        c:/Users/hobu/pdal/exercises/translation/interesting.
    ↵laz
```

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

2. Verify that the data are in fact compressed:

```
dir c:\Users\hobu\PDAL\exercises\translation\interesting.
    ↵laz

dir c:\Users\hobu\PDAL\exercises\translation\interesting.
    ↵las
```

The screenshot shows a Windows Command Prompt window titled 'C:\WINDOWS\system32\cmd.exe'. The command 'dir' is used to list files in two directories: 'c:\Users\hobu\PDAL\exercises\translation\interesting.laz' and 'c:\Users\hobu\PDAL\exercises\translation\interesting.las'. Both commands output the file size (18,794 bytes for .laz, 37,698 bytes for .las), the number of files (1), and the total free disk space (77,113,466,880 bytes). The command 'c:\>' is shown at the end of the session.

```
C:\>dir c:\Users\hobu\PDAL\exercises\translation\interesting.laz
Volume in drive C has no label.
Volume Serial Number is AC27-5D43

Directory of c:\Users\hobu\PDAL\exercises\translation

05/18/17 12:25 PM      18,794 interesting.laz
               1 File(s)       18,794 bytes
               0 Dir(s)  77,113,466,880 bytes free

C:\>
C:\>dir c:\Users\hobu\PDAL\exercises\translation\interesting.las
Volume in drive C has no label.
Volume Serial Number is AC27-5D43

Directory of c:\Users\hobu\PDAL\exercises\translation

05/18/17 12:25 PM      37,698 interesting.las
               1 File(s)       37,698 bytes
               0 Dir(s)  77,113,466,880 bytes free

C:\>
```

### See also:

*LAS Reading and Writing with PDAL* (page 247) 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>

### 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 *Anaconda Shell*:

```
1 pdal translate c:/Users/hobu/PDAL/exercises/analysis/ground/CSite1_
  ↪orig-utm.laz ^
2   c:/Users/hobu/PDAL/exercises/translation/csite-dd.laz ^
3     reprojection ^
4     --filters.reprojection.out_srs="EPSG:4326"
```



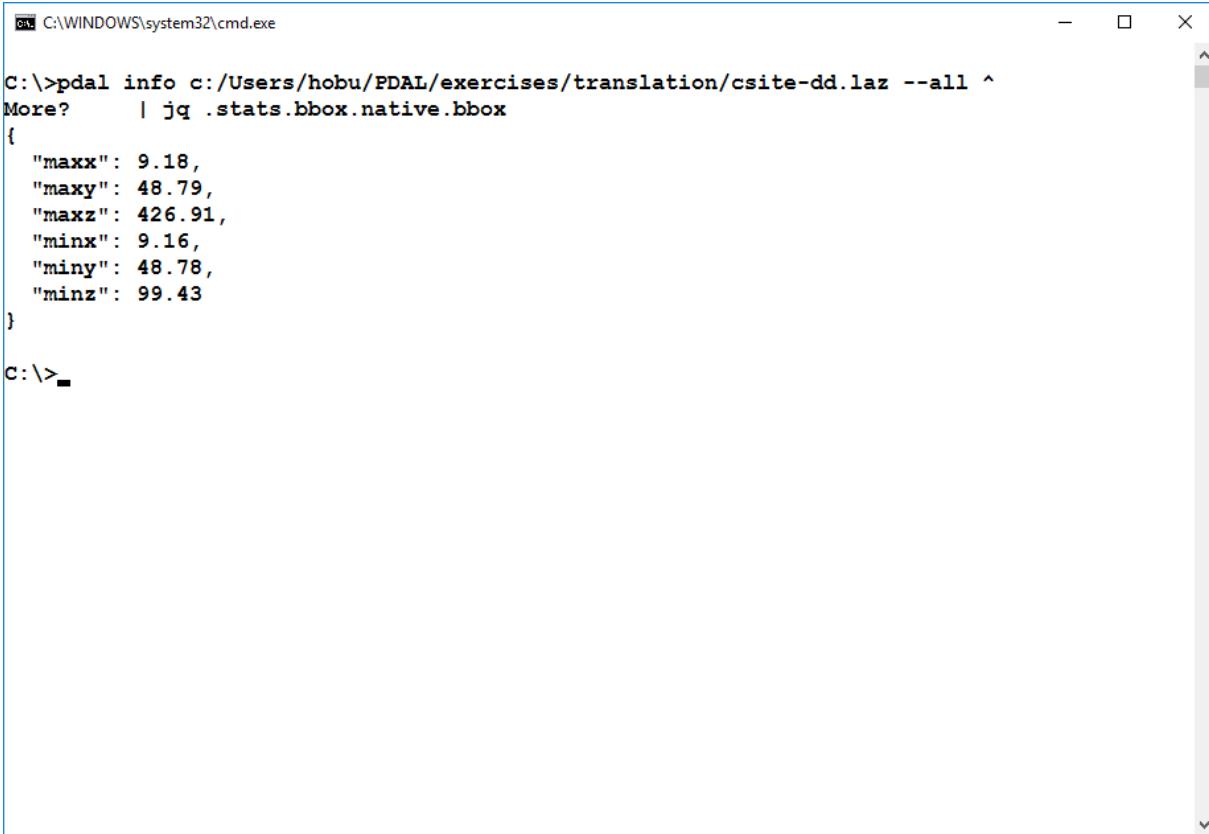
The screenshot shows a Windows Command Prompt window titled 'C:\WINDOWS\system32\cmd.exe'. The command entered is:

```
C:\>pdal translate c:/Users/hobu/PDAL/exercises/analysis/ground/CSite1_orig-utm.laz ^
More?   c:/Users/hobu/PDAL/exercises/translation/csite-dd.laz ^
More?   reprojection ^
More?   --filters.reprojection.out_srs="EPSG:4326"
```

The command prompt ends with 'C:\>'.

Unfortunately this doesn't produce the intended results for us. Issue the following pdal info command to see why:

```
pdal info c:/Users/hobu/PDAL/exercises/translation/csite-dd.laz --
  ↪all ^
  | jq .stats.bbox.native.bbox
```

A screenshot of a Windows command prompt window titled 'C:\WINDOWS\system32\cmd.exe'. The window contains the following text:

```
C:\>pdal info c:/Users/hobu/PDAL/exercises/translation/csite-dd.laz --all ^  
More? | jq .stats.bbox.native.bbox  
{  
    "maxx": 9.18,  
    "maxy": 48.79,  
    "maxz": 426.91,  
    "minx": 9.16,  
    "miny": 48.78,  
    "minz": 99.43  
}  
c:\>_
```

The command `pdal info` is run with the option `--all` followed by a pipe character `^` and the command `jq .stats.bbox.native.bbox`. This command retrieves all information from the file and filters it to show only the native bounding box statistics.

--all dumps all [info](#) (page 29) 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. As 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:

```
C:\>pdal info c:/Users/hobu/PDAL/exercises/translation/csite-dd.laz -p 0
{
  "filename": "c:/Users/hobu/PDAL/exercises/translation/csite-dd.laz",
  "pdal_version": "1.5.0 (git-version: 15fe7d)",
  "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
    }
  }
}

C:\>
```

Some formats, like [writers.las](#) (page 113) 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.

```
1 pdal translate ^
2   c:/Users/hobu/PDAL/exercises/analysis/ground/CSitel_orig-utm.laz_
3   ^
4   c:/Users/hobu/PDAL/exercises/translation/csite-dd.laz ^
5   reprojection ^
6   --filters.reprojection.out_srs="EPSG:4326" ^
7   --writers.las.scale_x=0.0000001 ^
8   --writers.las.scale_y=0.0000001 ^
9   --writers.las.offset_x="auto" ^
--writers.las.offset_y="auto"
```

```
C:\>pdal translate ^
More?   c:/Users/hobu/PDAL/exercises/analysis/ground/CSite1_orig-utm.laz ^
More?   c:/Users/hobu/PDAL/exercises/translation/csite-dd.laz ^
More?   reprojection ^
More?   --filters.reprojection.out_srs="EPSG:4326" ^
More?   --writers.las.scale_x=0.0000001 ^
More?   --writers.las.scale_y=0.0000001 ^
More?   --writers.las.offset_x="auto" ^
More?   --writers.las.offset_y="auto"

C:\>
```

Run the *pdal info* command again to verify the X, Y, and Z dimensions:

```
C:\>pdal info c:/Users/hobu/PDAL/exercises/translation/csite-dd.laz --all ^
More?   | jq .stats.bbox.native.bbox
{
  "maxx": 9.179032901,
  "maxy": 48.78976525,
  "maxz": 426.91,
  "minx": 9.164037801,
  "miny": 48.78345445,
  "minz": 99.43
}

C:\>
```

### Notes

1. *filters.reprojection* (page 178) 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) (<http://proj4.org>) library for reprojection. This library includes the capability to do both vertical and horizontal datum transformations.

### Greyhound

#### Exercise

This exercise uses PDAL to fetch data from a Greyhound server. Greyhound is a web server for point cloud data. You can learn more about what it is by visiting <http://lidarnews.com/articles/open-source-point-cloud-web-services-with-greyhound/>

See the Dublin data used in this example in your browser at

<http://potree.entwine.io/data/dublin.html>

1. In your *Anaconda Shell*, navigate to the `C:\Users\hobu\PDAL\exercises\translation` folder.

```
cd C:\Users\hobu\PDAL\exercises\translation
```

2. View the `greyhound.json` file in your editor. If the file does not exist, create it and paste the following JSON into it:

```
{
  "pipeline": [
    {
      "type": "readers.greyhound",
      "url": "data.greyhound.io",
      "depth_begin": 0,
      "depth_end": 11,
      "resource": "dublin",
      "filter": {
        "Classification": 2
      }
    },
    {
      "type": "writers.las",
      "compression": "true",
      "minor_version": "2",
    }
  ]
}
```

```
        "dataformat_id": "0",
        "filename": "just-ground.laz"
    }
}
```

---

**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 Greyhound server at <http://data.greyhound.io>

---

3. Issue the following command in your *Anaconda Shell*.

```
pdal pipeline greyhound.json
```



The screenshot shows a Windows Command Prompt window titled 'C:\WINDOWS\system32\cmd.exe'. The command 'pdal pipeline greyhound.json' was run, resulting in the following output:

```
C:\Users\hobu\pdal\exercises\translation>pdal pipeline greyhound.json
(pdal pipeline writers.las Warning) just-ground.laz: Found invalid value of '6' for point's return number.
(pdal pipeline writers.las Warning) just-ground.laz: Found invalid value of '6' for point's number of returns.
(pdal pipeline writers.las Warning) just-ground.laz: Found invalid value of '7' for point's return number.
(pdal pipeline writers.las Warning) just-ground.laz: Found invalid value of '7' for point's number of returns.

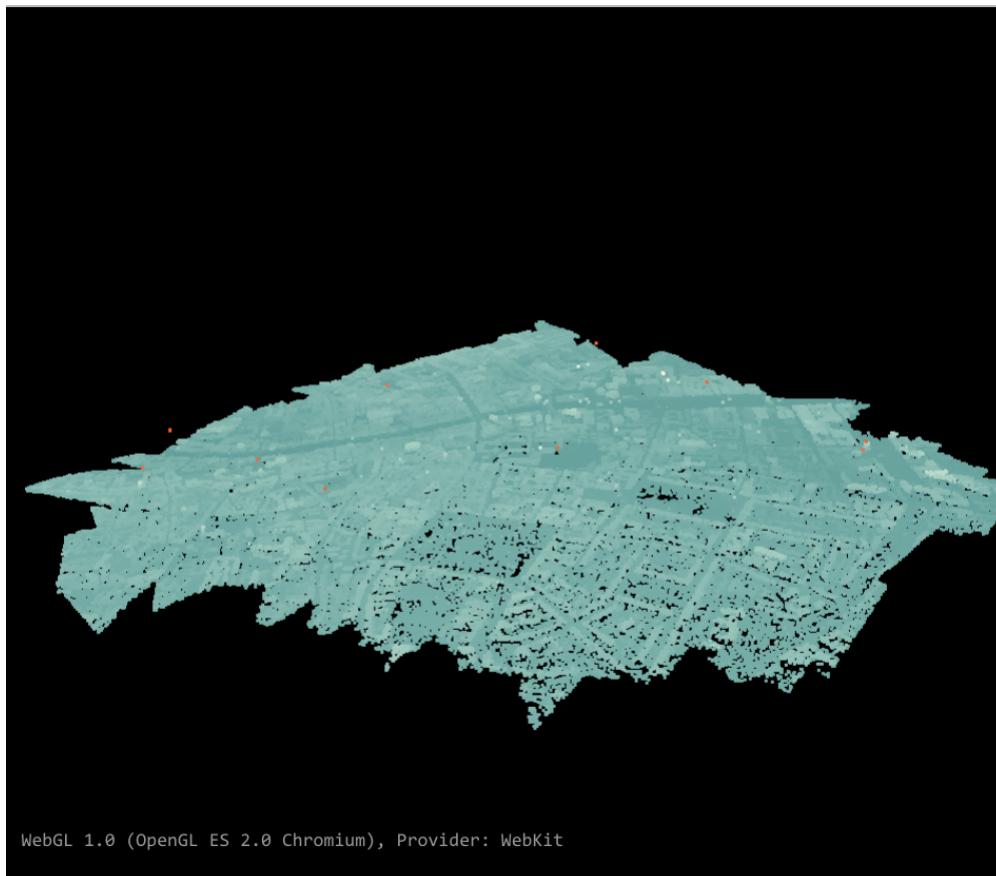
C:\Users\hobu\pdal\exercises\translation>
```

4. Verify that the data look ok:

```
pdal info just-ground.laz | jq .stats.bbox.native
```

```
Select C:\WINDOWS\system32\cmd.exe
C:\Users\hobu\pdal\exercises\translation>pdal info just-ground.laz | jq .stats.bbox.native
(pdal info readers.las Warning) just-ground.laz: Found invalid value of '6' for point's return
number.
(pdal info readers.las Warning) just-ground.laz: Found invalid value of '6' for point's number
of returns.
(pdal info readers.las Warning) just-ground.laz: Found invalid value of '7' for point's return
number.
(pdal info readers.las Warning) just-ground.laz: Found invalid value of '7' for point's number
of returns.
{
  "bbox": {
    "maxx": -693813.25,
    "maxy": 7049930.61,
    "maxz": 358.34,
    "minx": -699477.8,
    "miny": 7044490.98,
    "minz": -96.88
  },
  "boundary": {
    "coordinates": [
      [
        [
          [
            [
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................................................................
```

5. Visualize the data in <http://plas.io>



WebGL 1.0 (OpenGL ES 2.0 Chromium), Provider: WebKit

## Notes

1. *readers.greyhound* (page 63) contains more detailed documentation about how to use PDAL's [Greyhound](http://greyhound.io/) (<http://greyhound.io/>) reader .
2. As `depth_end` gets larger, the number of possible points goes up by nearly a factor of 4. Use the `bounds` option of the reader to split up the boxes you are querying to decrease the potential number of points a query might return.

## Analysis

### 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 292) 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.

---

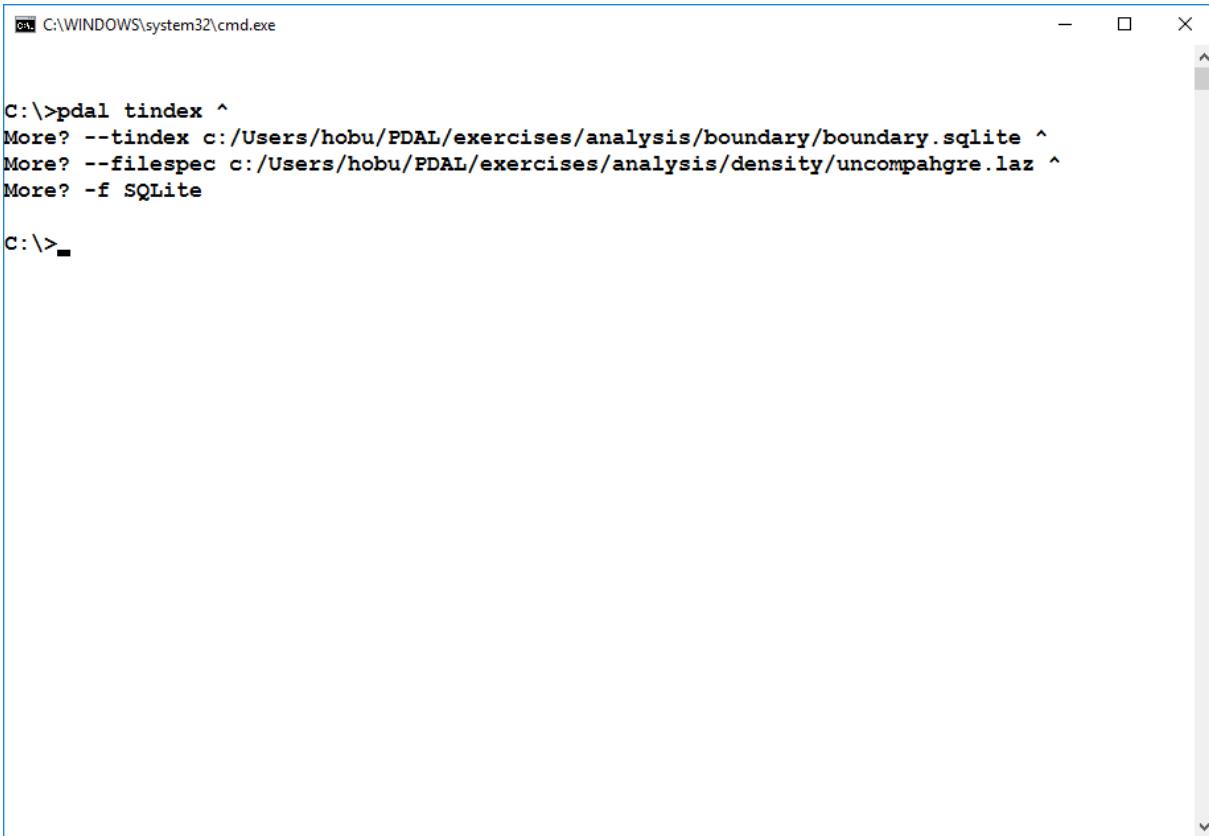
```
1 pdal info ^
2   c:/Users/hobu/PDAL/exercises/analysis/density/uncompahgre.laz ^
3   --boundary
```

```
C:\>pdal info ^
More? c:/Users/hobu/PDAL/exercises/analysis/density/uncompahgre.laz ^
More? --boundary
(pdal info readers.las Warning) c:/Users/hobu/PDAL/exercises/analysis/density/uncompahgre.laz: Found invalid value of '6' for point's number of returns.
(pdal info readers.las Warning) c:/Users/hobu/PDAL/exercises/analysis/density/uncompahgre.laz: Found invalid value of '6' for point's return number.
(pdal info readers.las Warning) c:/Users/hobu/PDAL/exercises/analysis/density/uncompahgre.laz: Found invalid value of '7' for point's return number.
(pdal info readers.las Warning) c:/Users/hobu/PDAL/exercises/analysis/density/uncompahgre.laz: Found invalid value of '7' for point's number of returns.
{
  "boundary": {
    "area": 90179889.42,
    "avg_pt_per_sq_unit": 20.23338738,
    "avg_pt_spacing": 2.576586467,
    "boundary": "MULTIPOLYGON (((245561.32347348 4208409.02201429, 245731.84225226 4208556.69560857, 246072.87980983 4208409.02201429, 246371.28767270 4208630.53240572, 246584.43614617 4208556.69560857, 246882.84400904 4208778.20600000, 247095.99248252 4208704.36920286, 247394.40034539 4208925.87959429, 247607.54881887 4208852.04279714, 247778.06759765 420899.71639143, 247991.21607113 4208925.87959429, 248161.73484991 4209073.55318857, 248374.88332339 4208999.71639143, 248545.40210218 4209147.38998571, 248758.55057565 4209073.55318857, 248929.06935444 4209221.22678285, 249184.84752261 4209221.22678285, 249184.84752261 4209516.57397142, 249014.32874383 4209664.24756571, 249184.84752261 4209811.92115999, 249014.32874383 4210107.26834856, 248673.29118626 4210254.94194285, 248801.18027035 4210476.45233428, 248502.77240748 4210697.96272570, 248673.29118626 4210993.30991427, 248502.77240748 4211140.98350856, 248502.77240748 4211731.67788570, 248673.29118626 4212027.02507427, 248502.77240748 4212174.69866855, 248545.40210218 4212543.88265426, 248374.88332339 4212691.55624855, 248417.51301809 4213208.41382855, 248119.10515522 4213429.92421997, 248289.62393400))
```

... 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 292). 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 206). We can leverage this capability to output a contiguous boundary of the uncompahgre.laz file.

```
1 pdal tindex ^
2   --tindex c:/Users/hobu/PDAL/exercises/analysis/boundary/boundary.
3   ↳sqlite ^
4   --filespec c:/Users/hobu/PDAL/exercises/analysis/density/
5   ↳uncompahgre.laz ^
6   -f SQLite
```



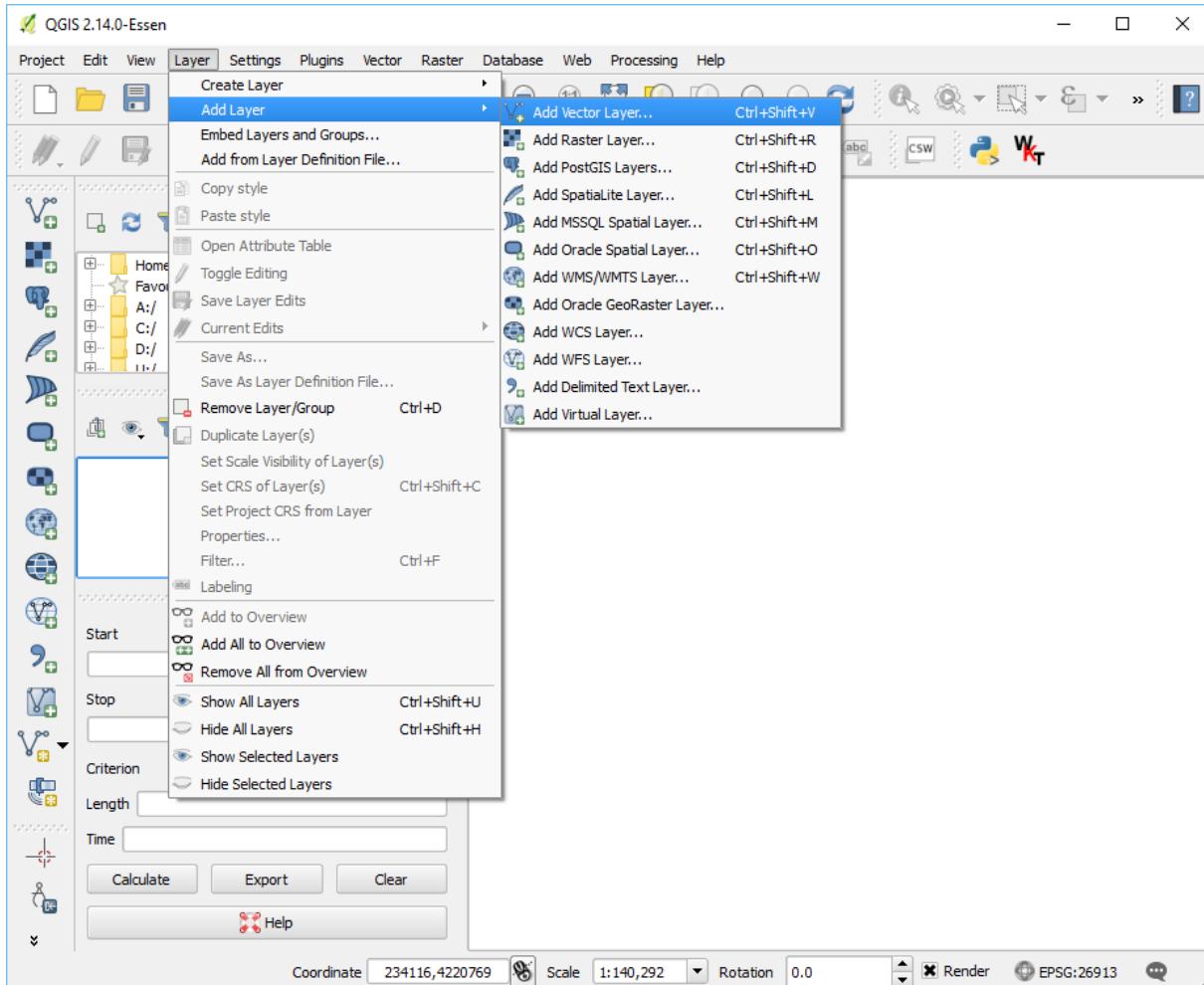
A screenshot of a Windows Command Prompt window titled 'C:\WINDOWS\system32\cmd.exe'. The window contains the following text:

```
C:\>pdal tindex ^
More? --tindex c:/Users/hobu/PDAL/exercises/analysis/boundary/boundary.sqlite ^
More? --filespec c:/Users/hobu/PDAL/exercises/analysis/density/uncompahgre.laz ^
More? -f SQLite

C:\>_
```

Once we've run the *tindex* (page 37), we can now visualize our output:

Open *QGIS* (page 292) 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 206) can also be used by the *density* (page 27) to generate a tessellated surface. See the *Visualizing acquisition density* (page 332) example for steps to achieve this.
3. The *tindex* (page 37) 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 273).

---

### Exercise

The `autzen.laz` file is a staple in PDAL and libLAS examples. We will use this file to demonstrate clipping points with a geometry. We're going to clip out the stadium into a new LAS file.



### Data preparation

The data are mixed in two different coordinate systems. The [LAZ](#) (page 69) 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](http://www.gdal.org/drv_vrt.html)) capability to reproject the data for us on-the-fly:

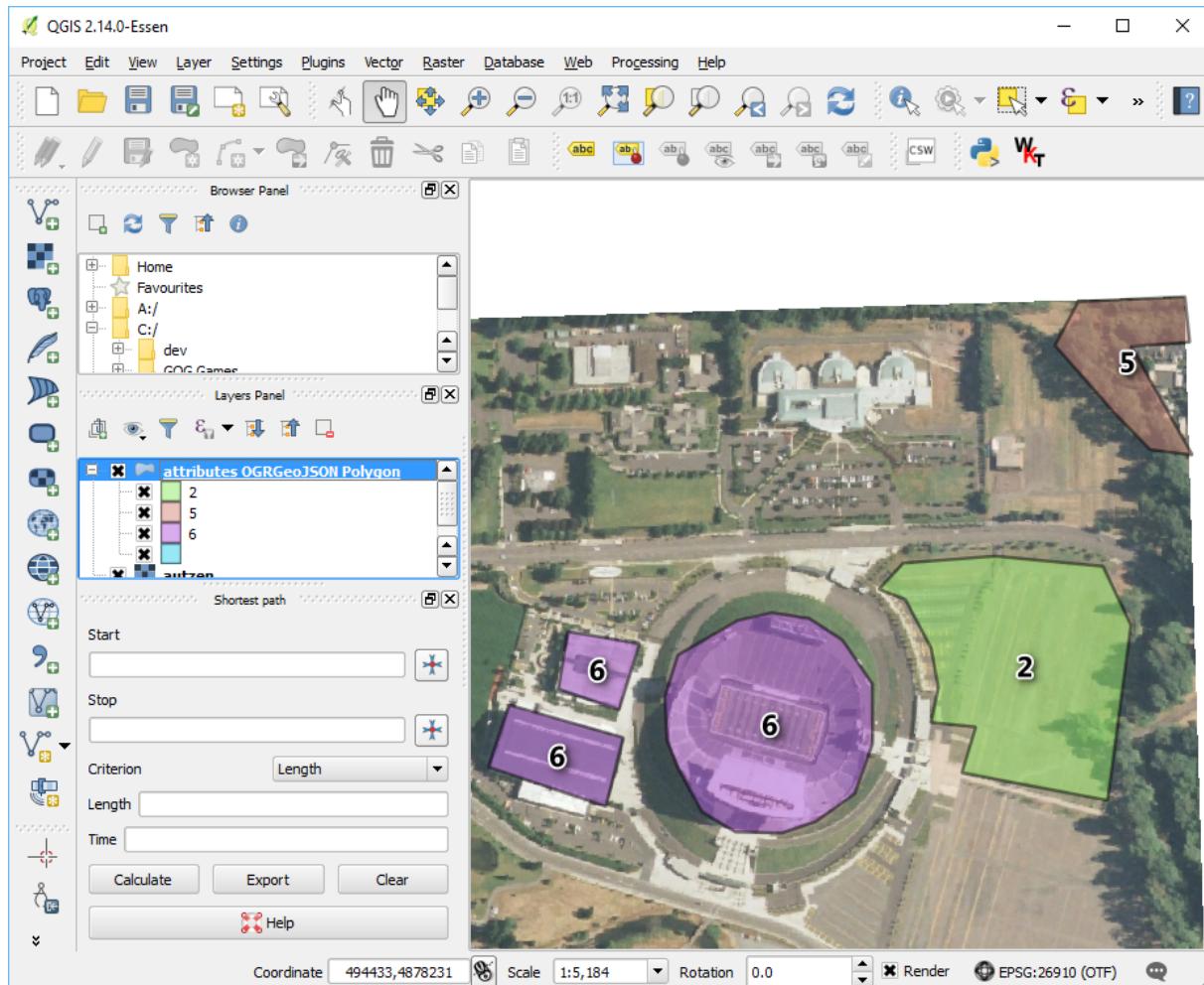
```
<OGRVRTDataSource>
    <OGRVRTWarpedLayer>
        <OGRVRTLayer name="OGRGeoJSON">
            <SrcDataSource>c:/Users/hobu/PDAL/exercises/analysis/
            ↳clipping/attributes.json</SrcDataSource>
            <SrcLayer>attributes</SrcLayer>
            <LayerSRS>EPSG:4326</LayerSRS>
        </OGRVRTLayer>
        <TargetSRS>+proj=lcc +lat_1=43 +lat_2=45.5 +lat_0=41.75 +lon_
            ↳0=-120.5 +x_0=399999.999999999 +y_0=0 +ellps=GRS80 +units=ft +no_
            ↳defs</TargetSRS>
    </OGRVRTWarpedLayer>
</OGRVRTDataSource>
```

---

**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 `c:/Users/hobu/PDAL/` 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.

---



---

**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](http://www.gdal.org/drv_vrt.html)) for more details.

---

### Pipeline breakdown

```
{  
    "pipeline": [  
        "c:/Users/hobu/PDAL/exercises/analysis/clipping/autzen.laz",  
        {  
            "column": "CLS",  
            "datasource": "c:/Users/hobu/PDAL/exercises/analysis/  
clipping/attributes.vrt",  
            "dimension": "Classification",  
            "name": "autzen",  
            "type": "GeoJSON",  
            "value": "autzen",  
            "wkt": "POLYGON ((116.555 48.782, 116.555 48.783, 116.556 48.783, 116.556 48.782, 116.555 48.782))"}  
    ]  
}
```

```
        "layer": "OGRGeoJSON",
        "type": "filters.overlay"
    },
    {
        "limits": "Classification[6:6]",
        "type": "filters.range"
    },
    "c:/Users/hobu/PDAL/exercises/analysis/clipping/stadium.las"
]
}
```

---

**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 `c:/Users/Hobu/PDAL/` in this file with the correct location for your machine.

---

## 1. Reader

`autzen.laz` is the [LASzip](http://laszip.org) (<http://laszip.org>) file we will clip.

## 2. filters.overlay

The `filters.overlay` (page 165) filter allows you to assign values for coincident polygons. Using the VRT we defined in [Data preparation](#) (page 318), `filters.overlay` (page 165) will assign the values from the `CLS` column to the `Classification` field.

## 3. filters.range

The attributes in the `attributes.json` file include polygons with values 2, 5, and 6. We will use `filters.range` (page 191) to keep points with `Classification` values in the range of `6:6`.

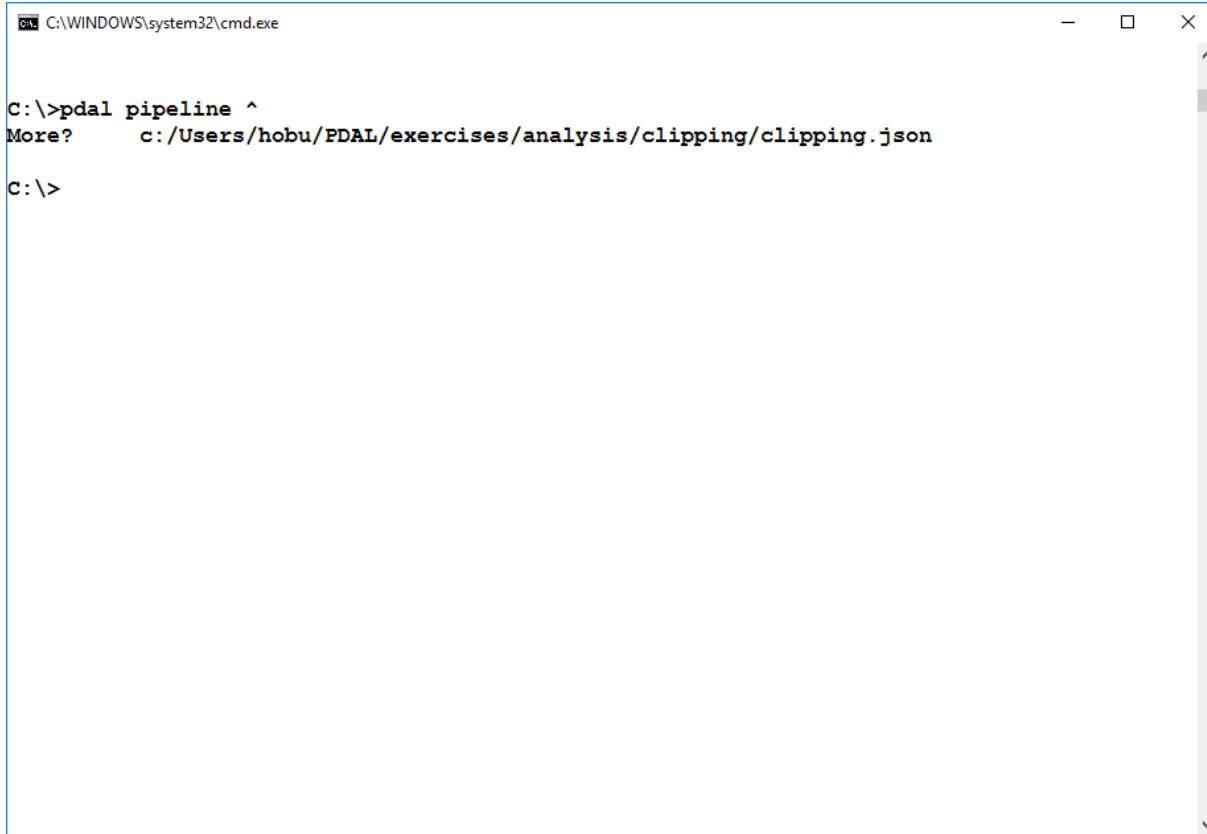
## 4. Writer

We will write our content back out using a `writers.las` (page 113).

### Execution

Invoke the following command, substituting accordingly, in your *Anaconda Shell*:

```
1 pdal pipeline ^
2     c:/Users/hobu/PDAL/exercises/analysis/clipping/clipping.json
```

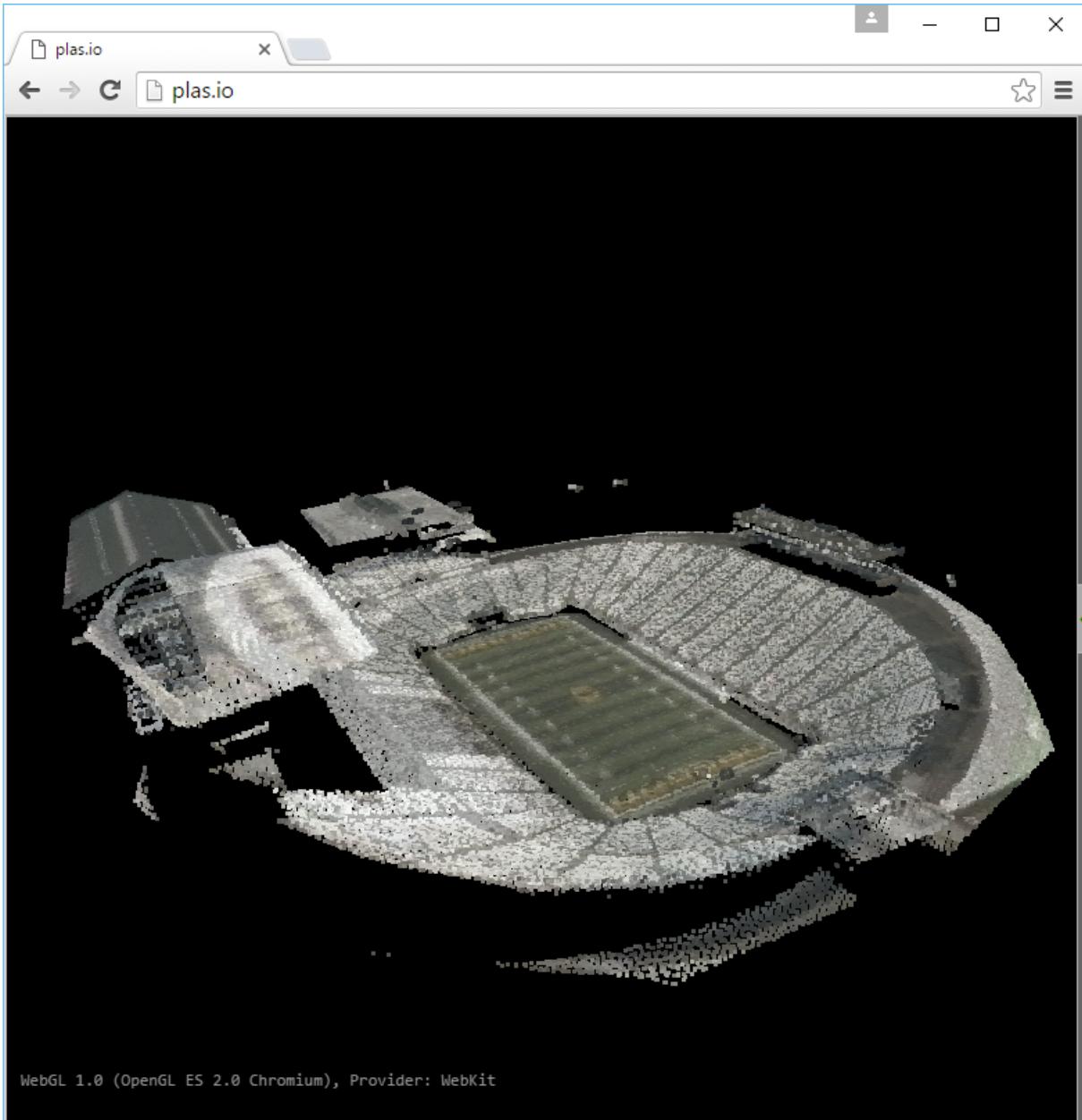


The screenshot shows a Windows Command Prompt window titled 'cmd C:\WINDOWS\system32\cmd.exe'. The window contains the following text:

```
C:\>pdal pipeline ^
More?      c:/Users/hobu/PDAL/exercises/analysis/clipping/clipping.json
C:\>
```

### Visualization

Use one of the point cloud visualization tools you installed to take a look at your `c:/Users/Howard/PDAL/exercises/analysis/clipping/stadium.las` output. In the example below, we opened the file to view it using the <http://plas.io> website.



## Notes

1. `filters.overlay` (page 165) 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 135) 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.

```
1  {
2      "pipeline": [
3          "c:/Users/hobu/PDAL/exercises/analysis/colorization/
4              ↳uncompahgre.laz",
5              {
6                  "type": "filters.colorization",
7                  "raster": "c:/Users/hobu/PDAL/exercises/analysis/
8                      ↳colorization/casi-2015-04-29-weekly-mosaic.tif"
9              },
10             {
11                 "type": "filters.range",
12                 "limits": "Red[1:]"
13             },
14             {
15                 "type": "writers.las",
16                 "compression": "true",
17                 "minor_version": "2",
18                 "dataformat_id": "3",
19                 "filename": "c:/Users/hobu/PDAL/exercises/analysis/
20                     ↳colorization/uncompahgre-colored.laz"
21             }
22         ]
23     }
```

---

**Note:** This JSON file is available in your workshop materials in the `./exercises/analysis/colorization/colorize.json` file. Remember to open this file and replace each occurrence of `c:/Users/hobu/PDAL/` with the correct path for your machine.

---

## 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.

```
"c:/Users/hobu/PDAL/exercises/analysis/colorization/uncompahgre.laz",
```

### 2. filters.colorization

The [filters.colorization](#) (page 141) 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": "c:/Users/hobu/PDAL/exercises/analysis/colorization/
    ↪casi-2015-04-29-weekly-mosaic.tif"
},
```

### 3. filters.range

A small challenge is the raster will colorize many points with NODATA values. We are going to use the [filters.range](#) (page 191) to filter keep any points that have Red  $\geq 1$ .

```
{
  "type": "filters.range",
  "limits": "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": "c:/Users/hobu/PDAL/exercises/colorization/analysis/  
    ↵uncompahgre-colored.laz"  
}
```

1. compression: [LASzip](http://laszip.org) (<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

---

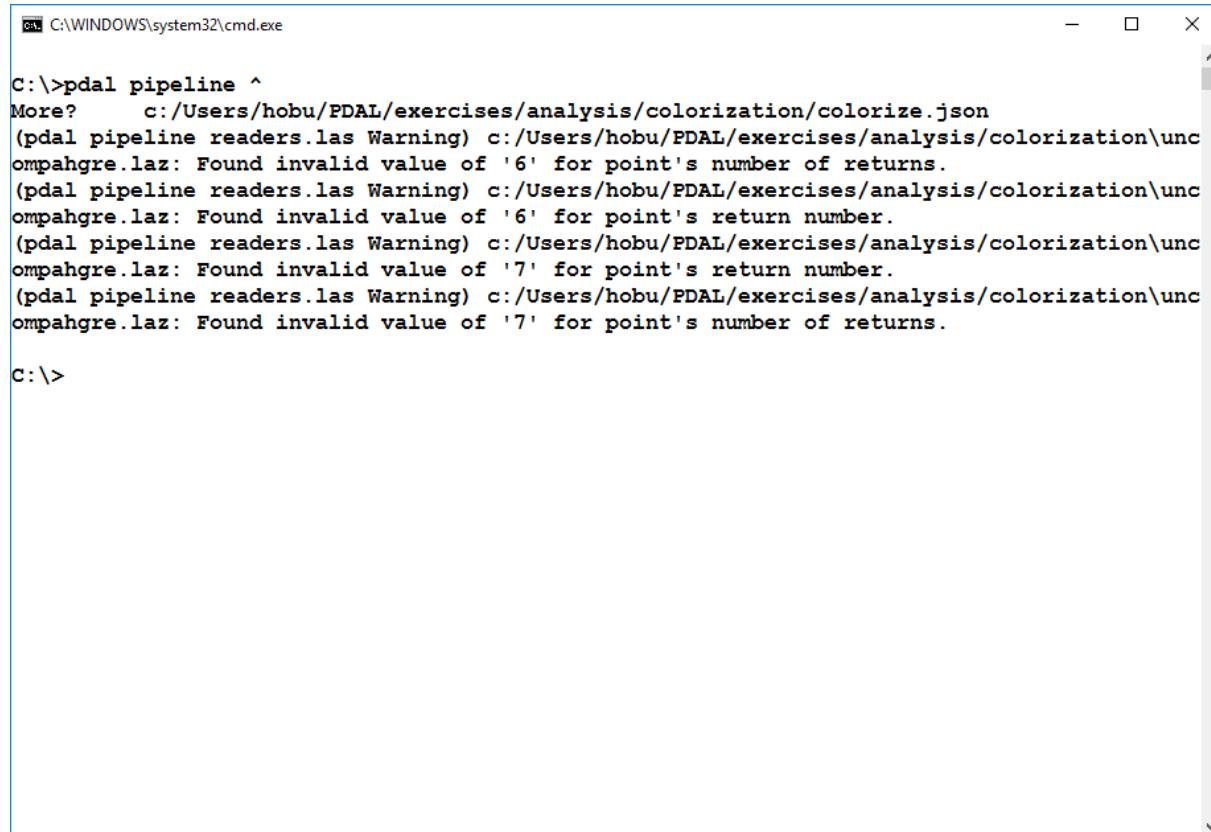
**Note:** [writers.las](#) (page 113) provides a number of possible options to control how your LAS files are written.

---

## Execution

Invoke the following command, substituting accordingly, in your *Anaconda Shell*:

```
1 pdal pipeline ^  
2     c:/Users/hobu/PDAL/exercises/analysis/colorization/colorize.json
```



```
C:\>pdal pipeline ^  
More?     c:/Users/hobu/PDAL/exercises/analysis/colorization/colorize.json  
(pdal pipeline readers.las Warning) c:/Users/hobu/PDAL/exercises/analysis/colorization\unc  
ompahgre.laz: Found invalid value of '6' for point's number of returns.  
(pdal pipeline readers.las Warning) c:/Users/hobu/PDAL/exercises/analysis/colorization\unc  
ompahgre.laz: Found invalid value of '6' for point's return number.  
(pdal pipeline readers.las Warning) c:/Users/hobu/PDAL/exercises/analysis/colorization\unc  
ompahgre.laz: Found invalid value of '7' for point's return number.  
(pdal pipeline readers.las Warning) c:/Users/hobu/PDAL/exercises/analysis/colorization\unc  
ompahgre.laz: Found invalid value of '7' for point's number of returns.  
C:\>
```

## 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 the <http://plas.io> website.



## 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 141) for more information.

4. These data are of [Uncompahgre Basin](#) ([https://en.wikipedia.org/wiki/Uncompahgre\\_River](https://en.wikipedia.org/wiki/Uncompahgre_River)) courtesy of the [NASA Airborne Snow Observatory](#) (<http://aso.jpl.nasa.gov/>).

### Removing noise

This exercise uses PDAL to remove unwanted noise in an airborne LiDAR collection.

#### Exercise

PDAL provides the [outlier filter](#) (page 161) to apply a statistical filter to data.

Because this operation is somewhat complex, we are going to use a pipeline to define it.

```
{
  "pipeline": [
    "c:/Users/hobu/PDAL/exercises/analysis/denoising/18TWK820985.
→laz",
    {
      "type": "filters.outlier",
      "method": "statistical",
      "multiplier": 3,
      "mean_k": 8
    },
    {
      "type": "filters.range",
      "limits": "Classification![7:7],Z[-100:3000]"
    },
    {
      "type": "writers.las",
      "compression": "true",
      "minor_version": "2",
      "dataformat_id": "0",
      "filename": "c:/Users/hobu/PDAL/exercises/analysis/
→denoising/clean.laz"
    }
  ]
}
```

---

**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.

```
"c:/Users/hobu/PDAL/exercises/analysis/denoising/18TWK820985.laz",
```

### 2. filters.outlier

The PDAL *outlier filter* (page 161) does most of the work for this operation.

```
{
  "type": "filters.outlier",
  "method": "statistical",
  "multiplier": 3,
  "mean_k": 8
},
```

### 3. filters.range

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 191) can remove these noise points by constructing a *range* (page 193) with the value Classification![7:7], which passes every point with a Classification value **not** equal to 7.

Even with the *filters.outlier* (page 161) operation, there is still a cluster of points with extremely negative Z values. These are some artifact or miscomputation of processing, and we don't want these points. We can construct another *range* (page 193) to keep only points that are within the range  $-100 \leq Z \leq 3000$ .

Both *ranges* (page 193) are passed as a comma-separated list to the *range filter* (page 191) via the *limits* option.

```
{
  "type": "filters.range",
  "limits": "Classification![7:7],Z[-100:3000]"
},
```

## 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": "c:/Users/hobu/PDAL/exercises/analysis/denoising/  
    ↪clean.laz"  
}
```

1. `compression`: [LASzip](http://laszip.org) (<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

---

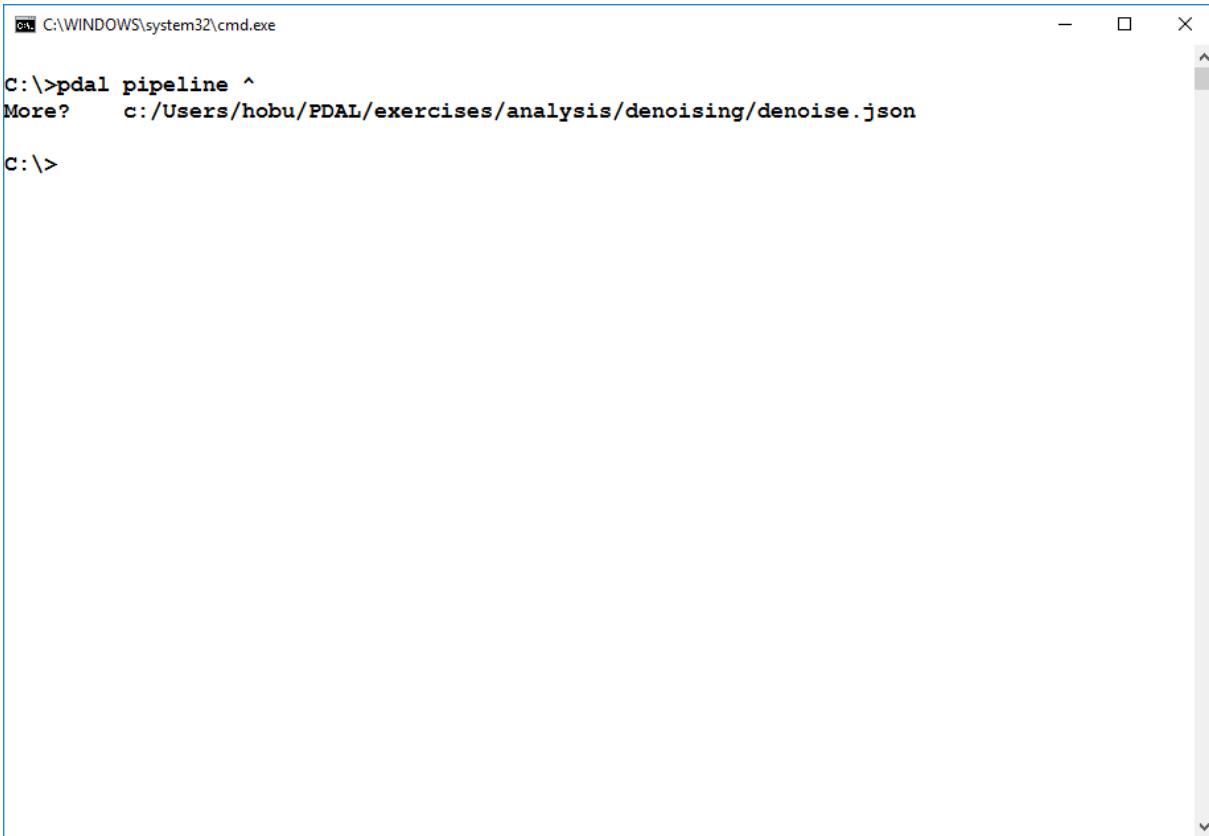
**Note:** [\*writers.las\*](#) (page 113) provides a number of possible options to control how your LAS files are written.

---

## Execution

Invoke the following command, substituting accordingly, in your *Anaconda Shell*:

```
pdal pipeline ^  
c:/Users/hobu/PDAL/exercises/analysis/denoising/denoise.json
```

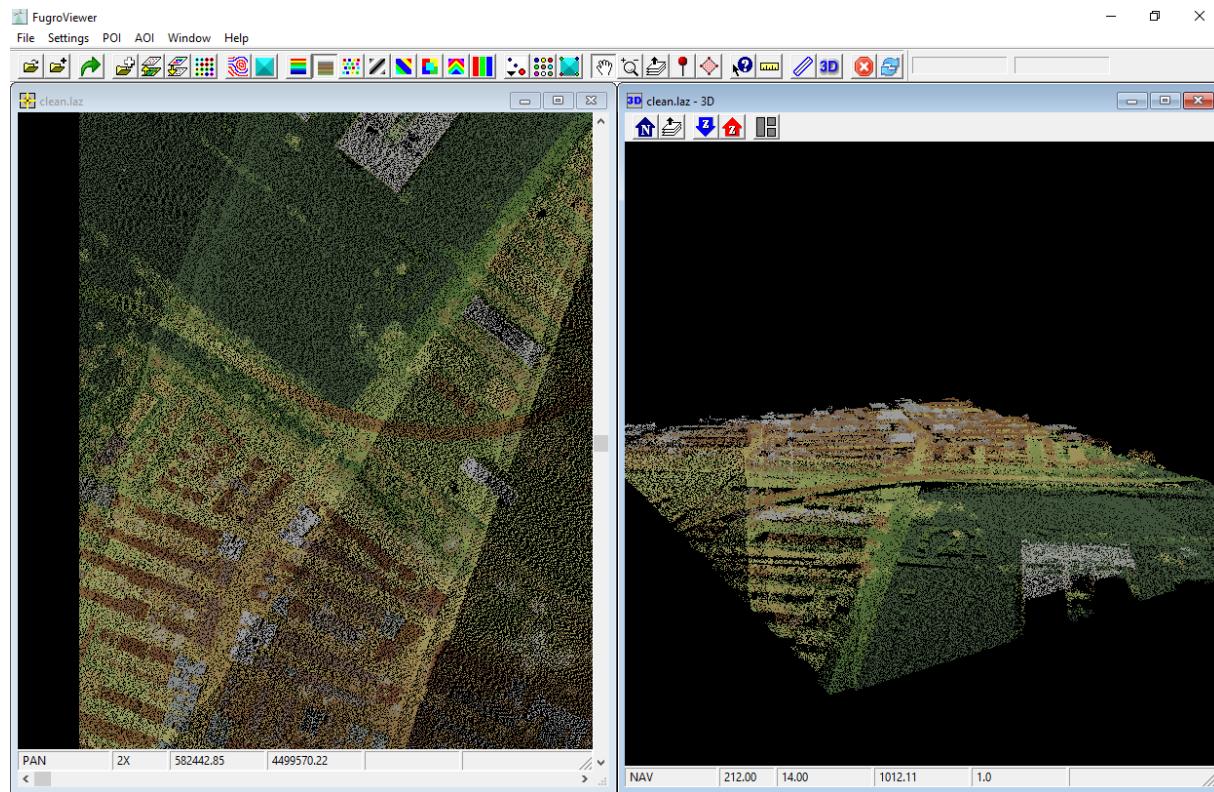


A screenshot of a Windows command prompt window titled 'C:\WINDOWS\system32\cmd.exe'. The window contains the following text:

```
C:\>pdal pipeline ^
More?  c:/Users/hobu/PDAL/exercises/analysis/denoising/denoise.json
c:\>
```

## Visualization

Use one of the point cloud visualization tools you installed to take a look at your `clean.laz` output. In the example below, we simply opened the file using the [Fugro Viewer](http://www.fugroviewer.com/) (<http://www.fugroviewer.com/>)



### Notes

1. Control the aggressiveness of the algorithm with the `mean_k` parameter.
2. `filters.outlier` (page 161) requires the entire set in memory to process. If you have really large files, you are going to need to `split` (page 203) 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.

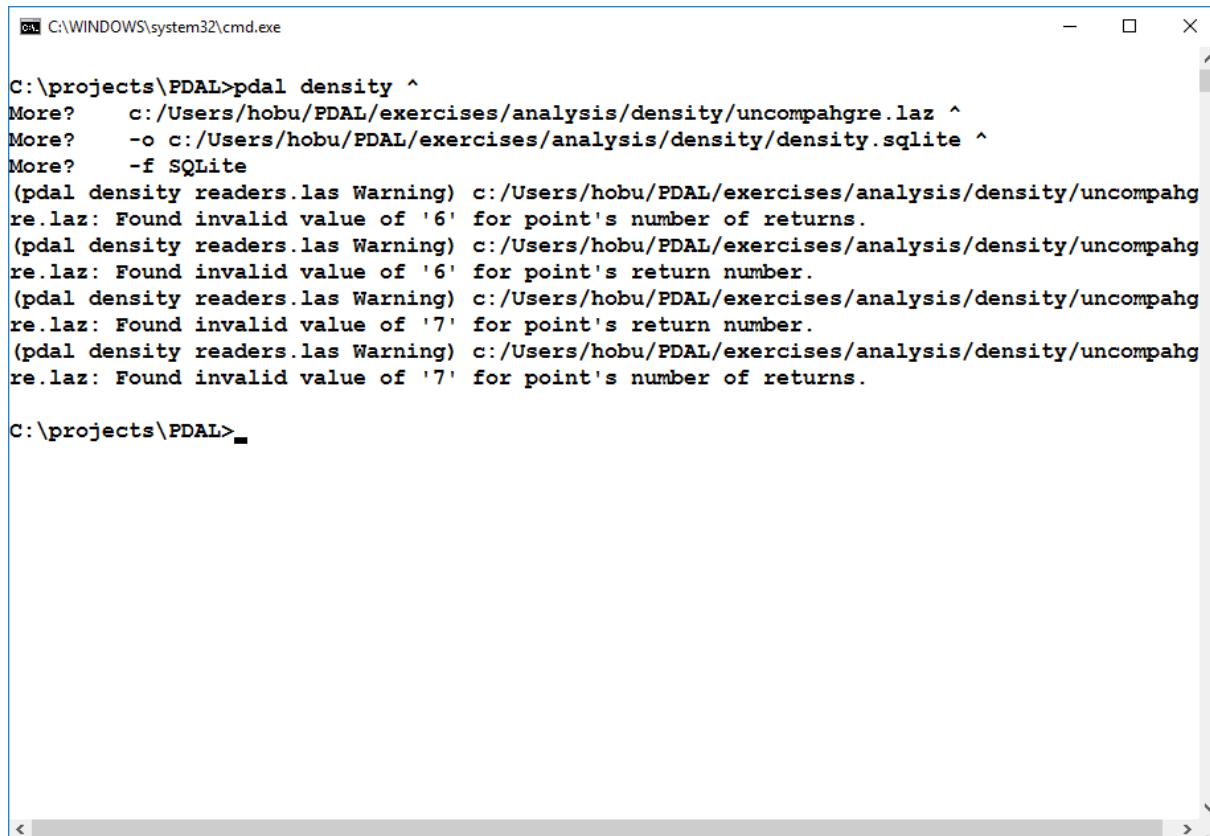
### Exercise

PDAL provides an `application` (page 27) to compute a vector field of hexagons computed with `filters.hexbin` (page 206). 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 *Anaconda Shell*:

```
1 pdal density ^
2   c:/Users/hobu/PDAL/exercises/analysis/density/uncompahgre.laz ^
3   -o c:/Users/hobu/PDAL/exercises/analysis/density/density.sqlite ^
4   -f SQLite
```



```
C:\WINDOWS\system32\cmd.exe

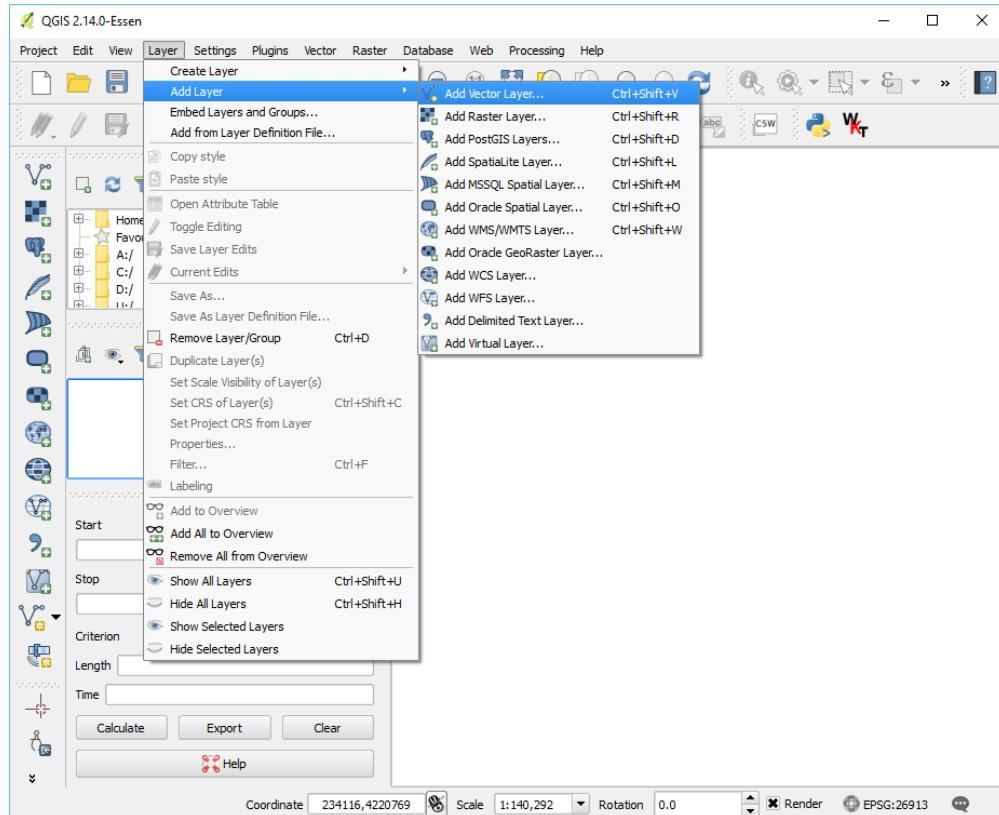
C:\projects\PDAL>pdal density ^
More?   c:/Users/hobu/PDAL/exercises/analysis/density/uncompahgre.laz ^
More?   -o c:/Users/hobu/PDAL/exercises/analysis/density/density.sqlite ^
More?   -f SQLite
(pdal density readers.las Warning) c:/Users/hobu/PDAL/exercises/analysis/density/uncompahg
re.laz: Found invalid value of '6' for point's number of returns.
(pdal density readers.las Warning) c:/Users/hobu/PDAL/exercises/analysis/density/uncompahg
re.laz: Found invalid value of '6' for point's return number.
(pdal density readers.las Warning) c:/Users/hobu/PDAL/exercises/analysis/density/uncompahg
re.laz: Found invalid value of '7' for point's return number.
(pdal density readers.las Warning) c:/Users/hobu/PDAL/exercises/analysis/density/uncompahg
re.laz: Found invalid value of '7' for point's number of returns.

C:\projects\PDAL>_
```

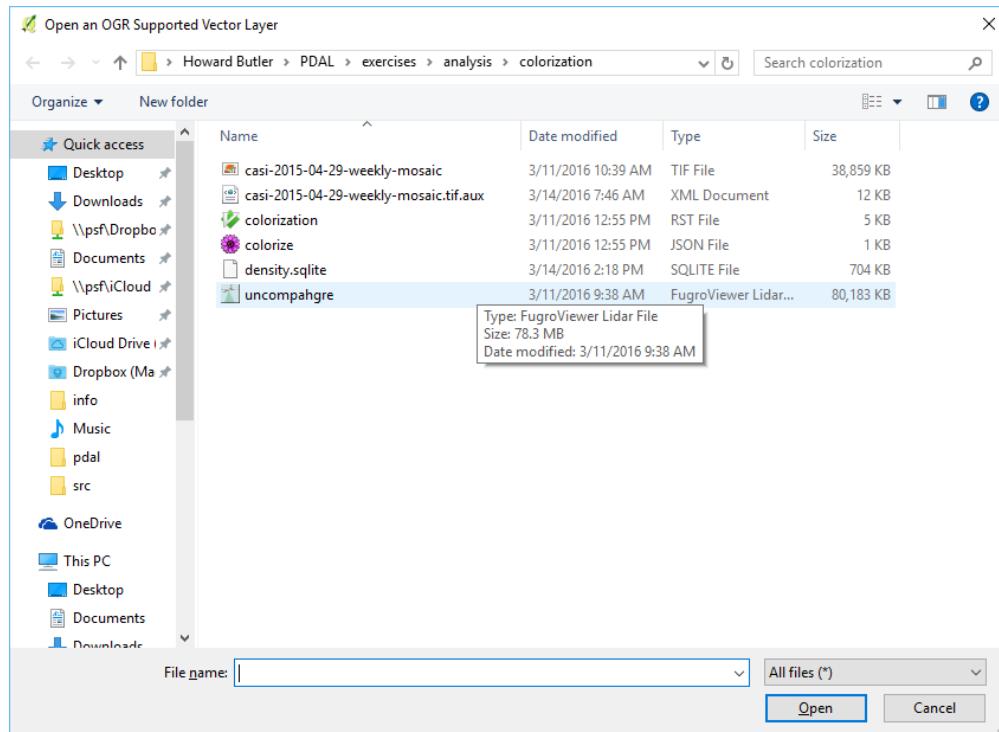
## Visualization

The command uses GDAL to output a [SQLite](http://sqlite.org) (<http://sqlite.org>) file containing hexagon polygons. We will now use [QGIS](http://qgis.org) (<http://qgis.org>) to visualize them.

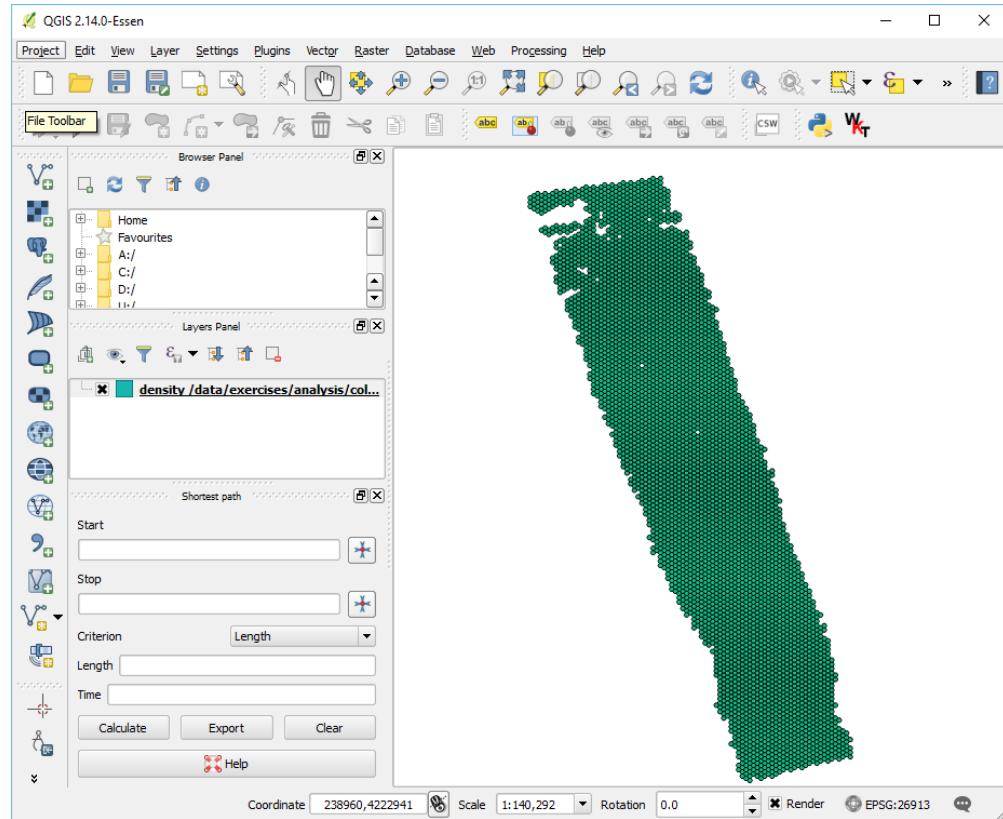
1. Add a vector layer



## 2. Navigate to the output directory



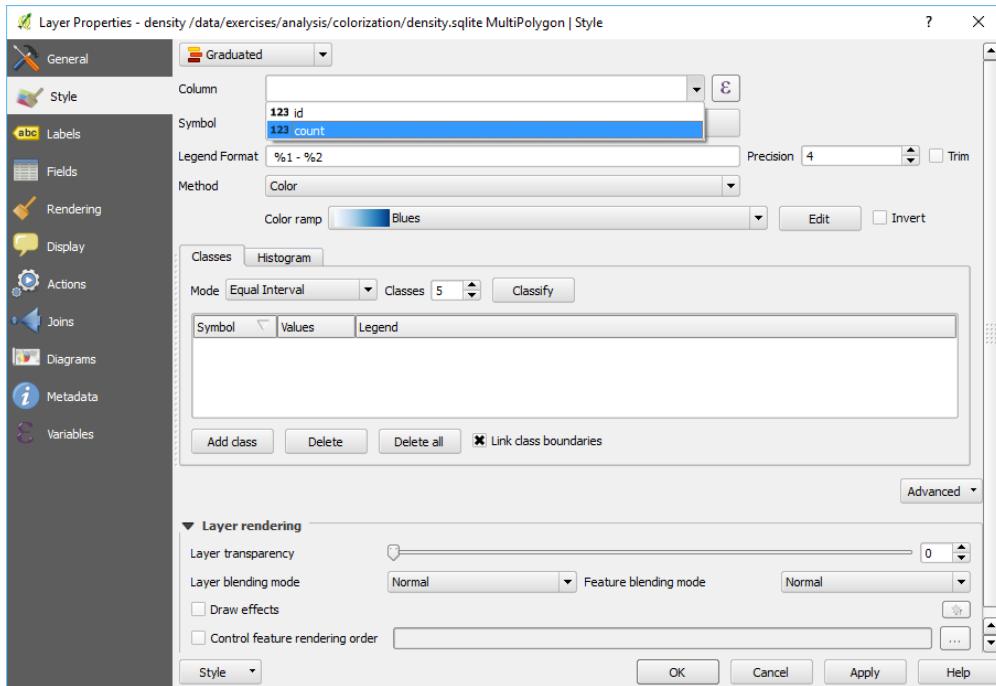
## 3. Add the density.sqlite file to the view



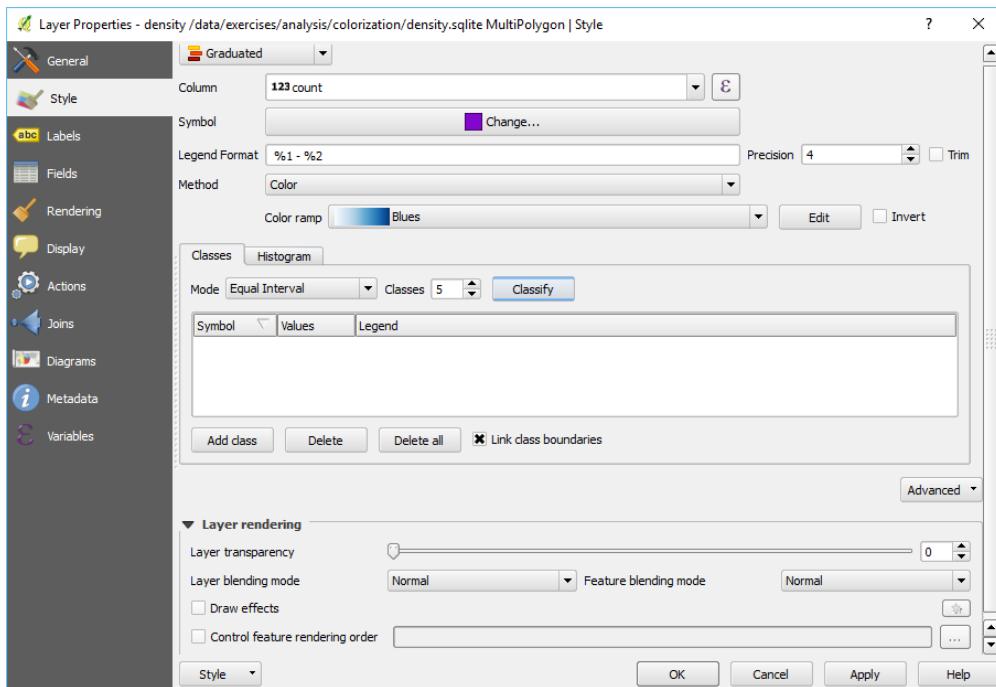
4. Right click on the `density.sqlite` layer in the *Layers* panel and then choose *Properties*.
5. Pick the *Graduated* drop down



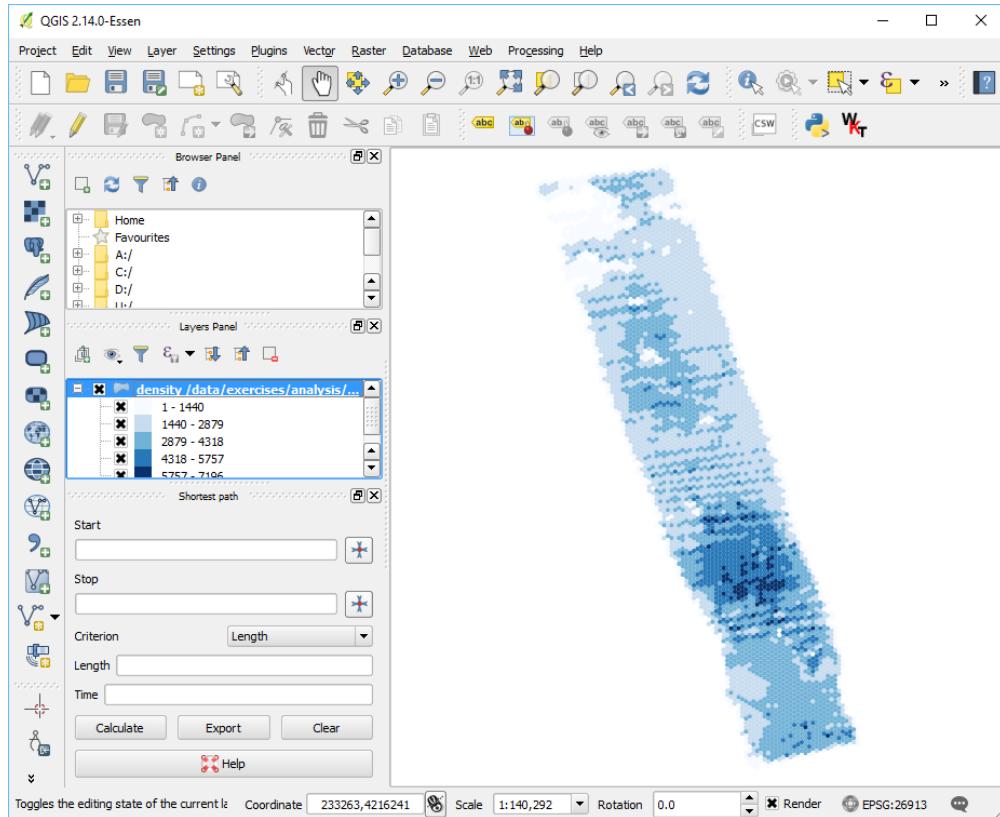
6. Choose the Count column to visualize



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 206).

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 37).

## 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 332) 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 194)
- Random using a combination of [`filters.decimation`](#) (page 183) and [`filters.randomize`](#) (page 173)
- Voxel using [`filters.voxelgrid`](#) (page 227)

In this exercise, we are going to thin with the Poisson method, but the concept should operate similarly for the [`filters.voxelgrid`](#) (page 227) approach too.

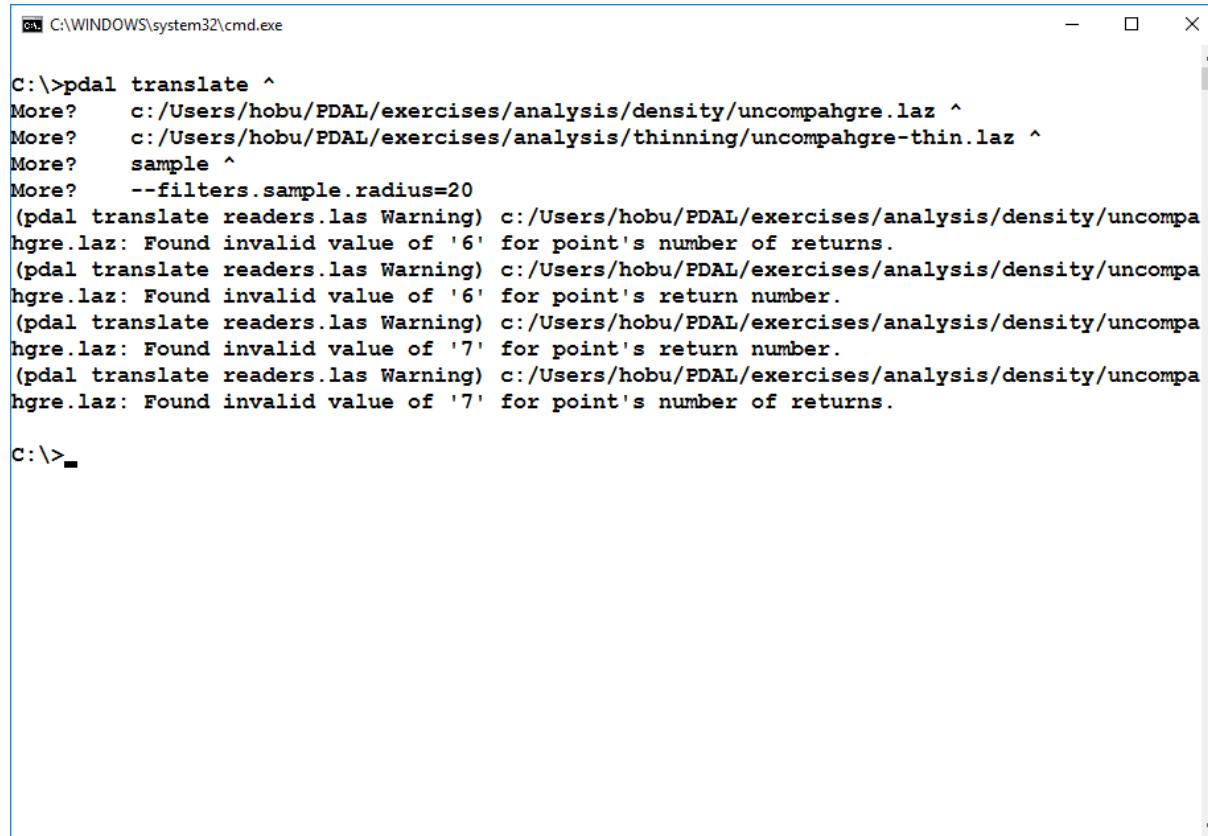
### Command

Invoke the following command, substituting accordingly, in your *Docker Quickstart Terminal*:

```
1 pdal translate ^
2   c:/Users/hobu/PDAL/exercises/analysis/density/uncompahgre.laz ^
3   c:/Users/hobu/PDAL/exercises/analysis/thinning/uncompahgre-thin.
4   ↘laz ^
5   sample ^
   --filters.sample.radius=20
```



Fig. 11.3: Thinning strategies available in PDAL



The screenshot shows a Windows Command Prompt window titled 'C:\WINDOWS\system32\cmd.exe'. The command entered is 'pdal translate ^ More? c:/Users/hobu/PDAL/exercises/analysis/density/uncompahgre.laz ^ More? c:/Users/hobu/PDAL/exercises/analysis/thinning/uncompahgre-thin.laz ^ More? sample ^ More? --filters.sample.radius=20'. The output shows several warnings from PDAL: 'Found invalid value of '6' for point's number of returns.', 'Found invalid value of '6' for point's return number.', 'Found invalid value of '7' for point's return number.', and 'Found invalid value of '7' for point's number of returns.'.

## Visualization

<http://plas.io> 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 uncompahgre-thin.laz file.

## Notes

1. Poisson sampling is non-destructive. Points that are filtered with *filters.sample* (page 194) 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 *Identifying ground returns using ProgressiveMorphologicalFilter segmentation* (page 264) tutorial on the PDAL website by Brad Chambers. You can find more detail and example invocations there.

---



Fig. 11.4: Selecting multiple data sets in <http://plas.io>

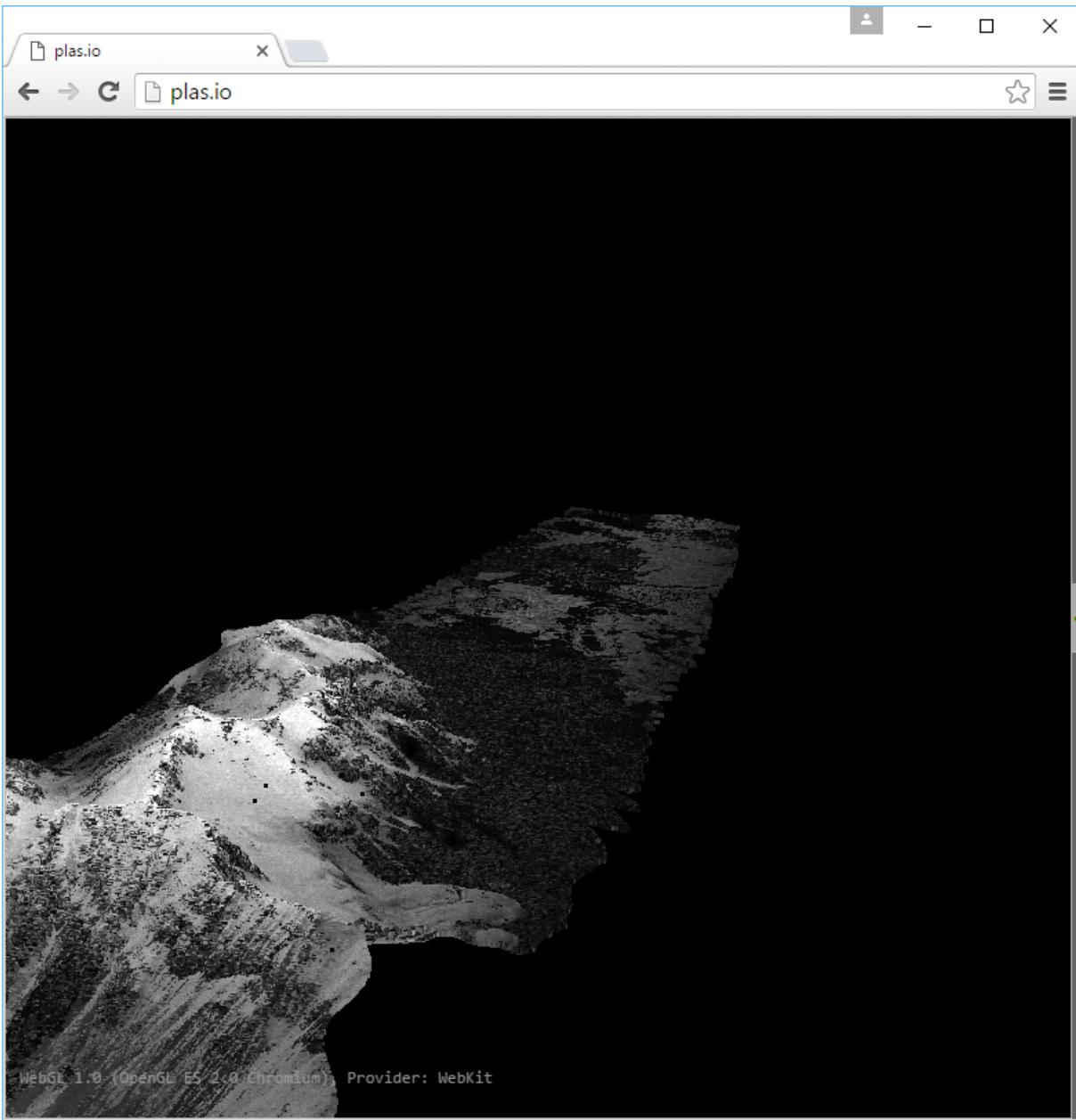


Fig. 11.5: Full resolution Uncompahgre data set

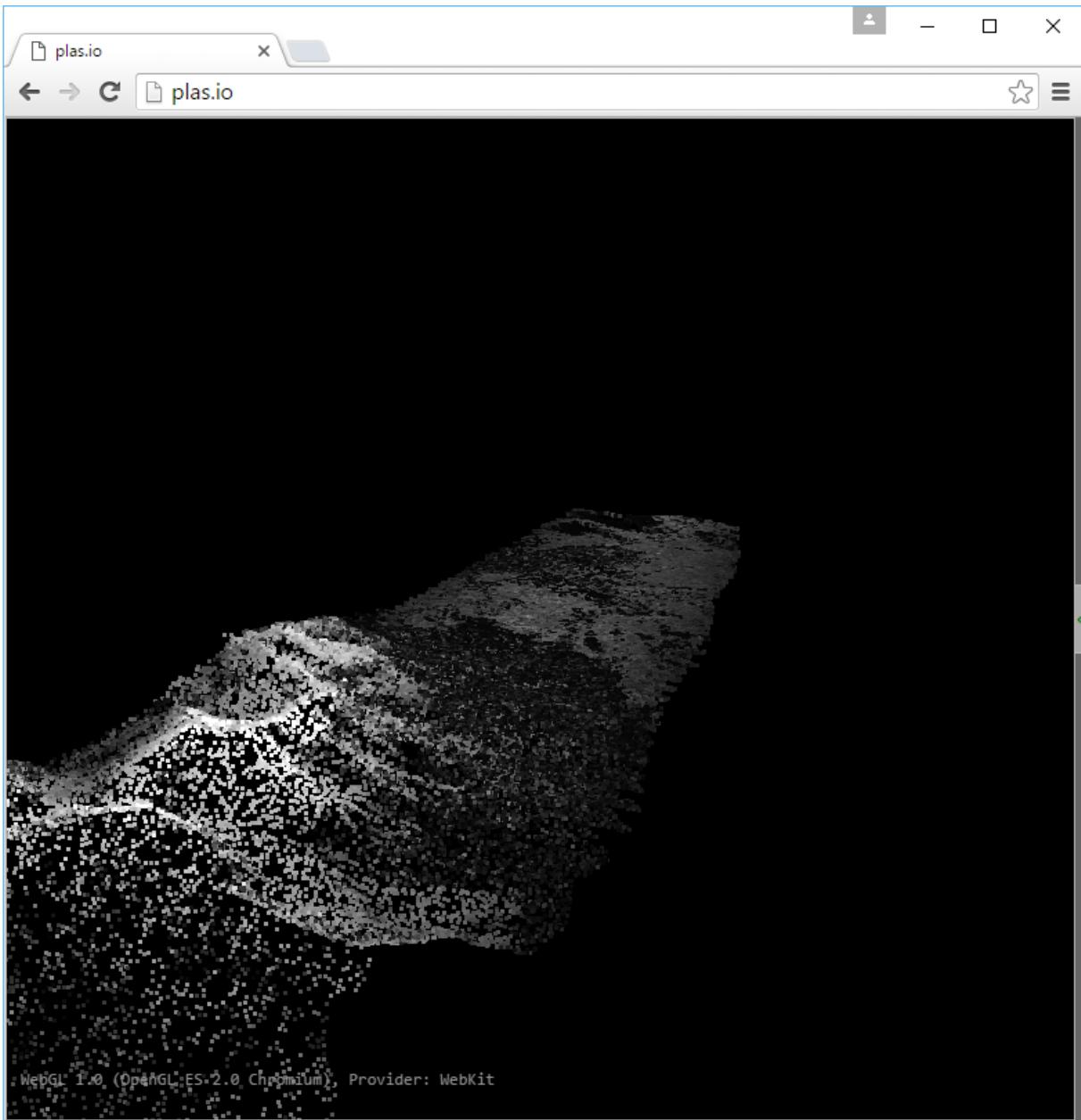


Fig. 11.6: Uncompahgre thinned at a radius of 20m

## Exercise

The primary input for Digital Terrain Model

([https://en.wikipedia.org/wiki/Digital\\_elevation\\_model](https://en.wikipedia.org/wiki/Digital_elevation_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.

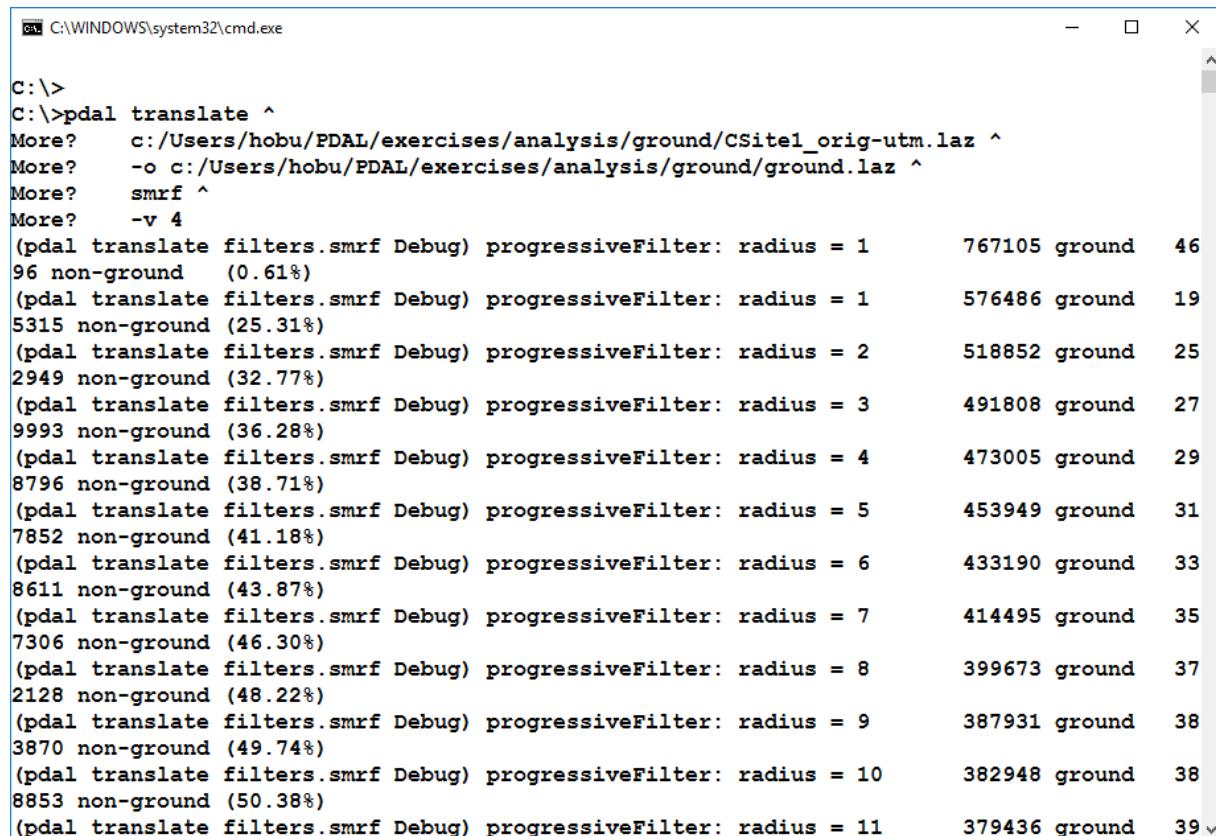
### See also:

You can read more about the specifics of the SMRF algorithm from [Pingle2013].<sup>4</sup>

## Command

Invoke the following command, substituting accordingly, in your *Anaconda Shell*:

```
1 pdal translate ^
2   c:/Users/hobu/PDAL/exercises/analysis/ground/CSite1_orig-utm.laz ^
3   -o c:/Users/hobu/PDAL/exercises/analysis/ground/ground.laz ^
4   smrf ^
5   -v 4
6
```



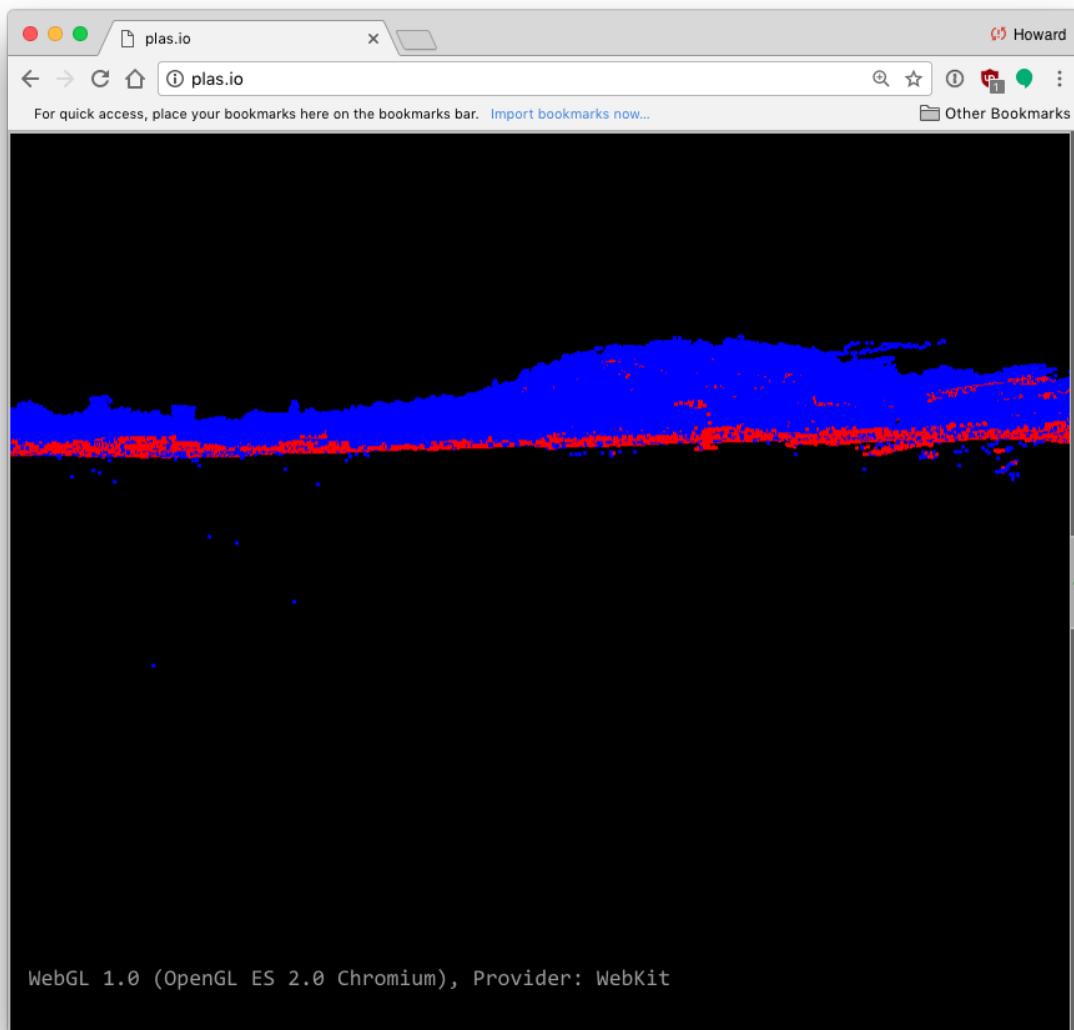
C:\>pdal translate ^
More? c:/Users/hobu/PDAL/exercises/analysis/ground/CSite1\_orig-utm.laz ^
More? -o c:/Users/hobu/PDAL/exercises/analysis/ground/ground.laz ^
More? smrf ^
More? -v 4
(pdal translate filters.smrf Debug) progressiveFilter: radius = 1 767105 ground 46
96 non-ground (0.61%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 1 576486 ground 19
5315 non-ground (25.31%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 2 518852 ground 25
2949 non-ground (32.77%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 3 491808 ground 27
9993 non-ground (36.28%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 4 473005 ground 29
8796 non-ground (38.71%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 5 453949 ground 31
7852 non-ground (41.18%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 6 433190 ground 33
8611 non-ground (43.87%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 7 414495 ground 35
7306 non-ground (46.30%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 8 399673 ground 37
2128 non-ground (48.22%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 9 387931 ground 38
3870 non-ground (49.74%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 10 382948 ground 38
8853 non-ground (50.38%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 11 379436 ground 39

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 PMF with a call to a the *filters.outlier* technique we learned about in [Removing noise](#) (page 328).

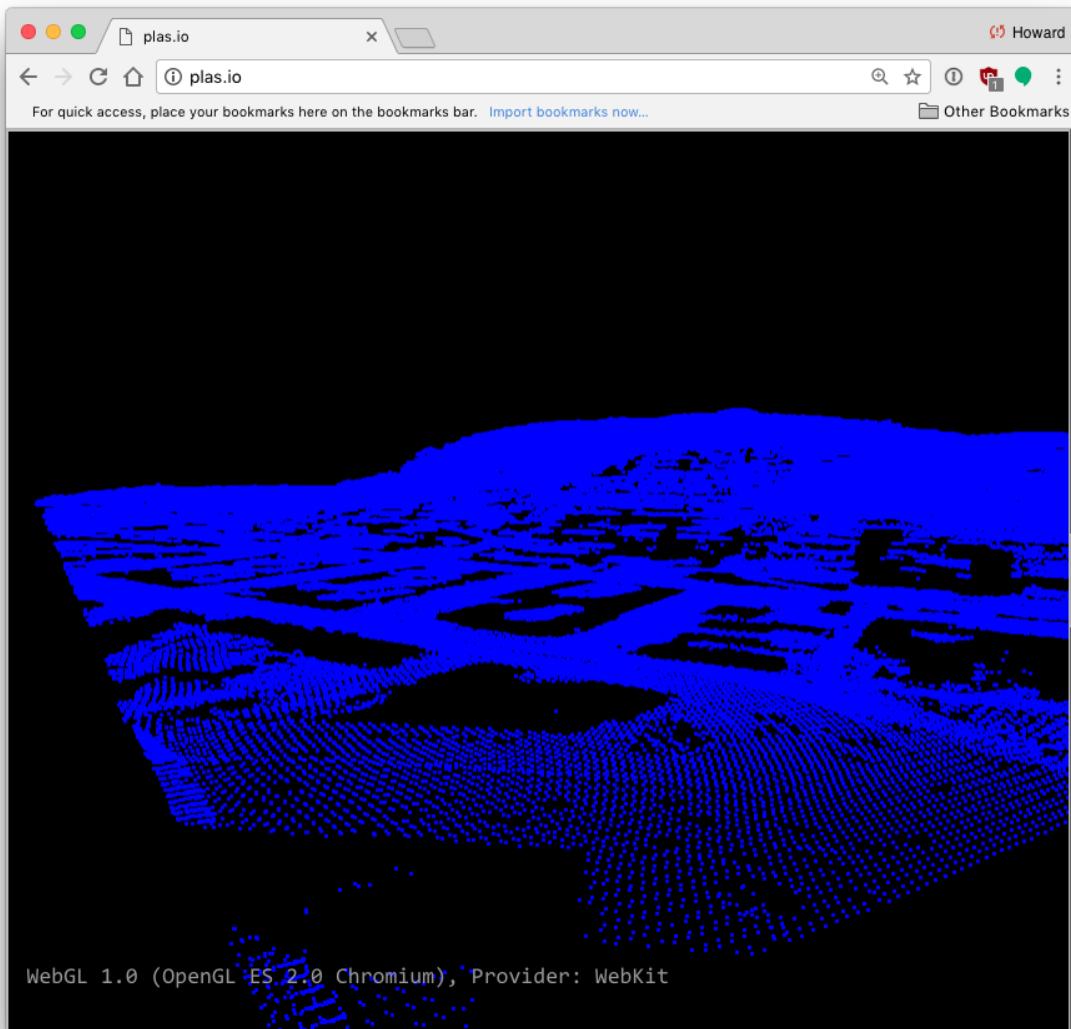
1. Let us start by removing the non-ground data:

```
1 pdal translate ^
  c:/Users/hobu/PDAL/exercises/analysis/ground/CSitel_orig-utm.laz ^
  -o c:/Users/hobu/PDAL/exercises/analysis/ground/ground.laz ^
  smrf ^
  range ^
```

```

6   --filters.range.limits="Classification[2:2]" ^
7   -v 4
8

```



2. Now we will instead use the `translate` (page 39) command to stack the `filters.outlier` (page 161) and `filters.smrf` (page 169) stages:

```

1 pdal translate ^
2   c:/Users/hobu/PDAL/exercises/analysis/ground/CSitel_orig-utm.laz ^
3   -o c:/Users/hobu/PDAL/exercises/analysis/ground/denoised-ground-
4   ↵only.laz ^
5     outlier smrf range ^
6       --filters.outlier.method="statistical" ^
7       --filters.outlier.mean_k=8 ^
8

```

```
7 --filters.outlier.multiplier=3.0 ^
8 --filters.smrf.ignore="Classification[7:7]" ^
9 --filters.range.limits="Classification[2:2]" ^
10 --writers.las.compression=true --verbose 4
```

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 PMF 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.



## Generating a DTM

This exercise uses PDAL to generate an elevation model surface using the output from the [Identifying ground](#) (page 340) exercise, PDAL's [writers.gdal](#) (page 108) 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](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 340) exercise. Please produce that file by following that exercise before starting this one.

---

### Command

Invoke the following command, substituting accordingly, in your *Anaconda Shell*:

PDAL capability to generate rasterized output is provided by the [writers.gdal](#) (page 108) stage. There is no [application](#) (page 25) to drive this stage, and we must use a pipeline.

### Pipeline breakdown

```
{  
    "pipeline": [  
        "c:/Users/hobu/PDAL/exercises/analysis/ground/denoised-  
        ↪ground-only.laz",  
        {  
            "filename": "c:/Users/hobu/PDAL/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/dtm.json` file. Make sure to edit the filenames to match your paths.

---

### 1. Reader

denoised-ground-only is the [LASzip](http://laszip.org) (<http://laszip.org>) file we will clip. You should have created this output as part of the *Identifying ground* (page 340) exercise.

### 2. writers.gdal

The [writers.gdal](#) (page 108) writer that bins the point cloud data into an elevation surface.

### Execution

```
1 pdal pipeline ^
2   c:/Users/hobu/PDAL/exercises/analysis/dtm/gdal.json
```

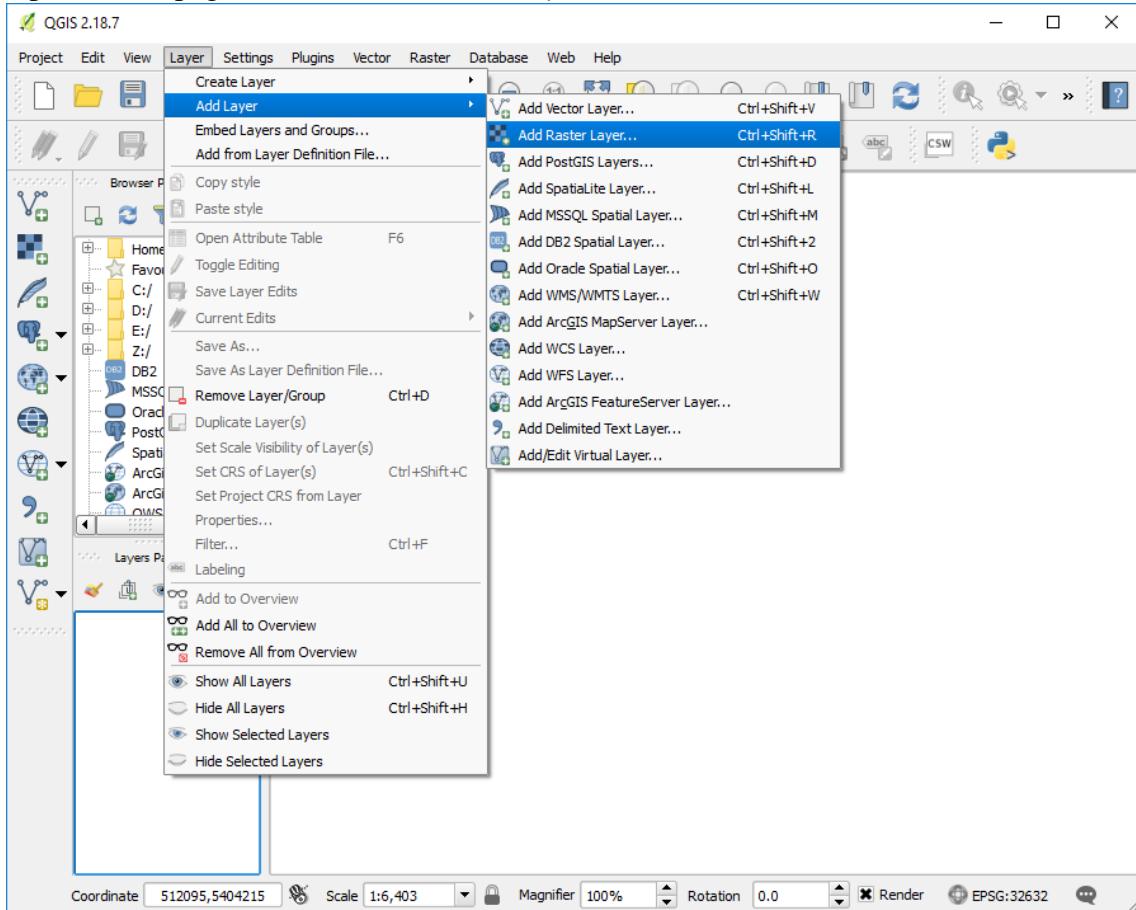


A screenshot of a Windows command prompt window titled "cmd C:\WINDOWS\system32\cmd.exe". The window shows the command "pdal pipeline ^" followed by a file path "c:/Users/hobu/PDAL/exercises/analysis/dtm/gdal.json". The command has been partially typed, with the cursor at the end of "gdal.json". The window has standard minimize, maximize, and close buttons in the top right corner.

## Visualization

Something happened, and some files were written, but we cannot really see what was produced. Let us use *QGIS* (page 292) to visualize the output.

1. Open *QGIS* (page 292) and *Add Raster Layer*:



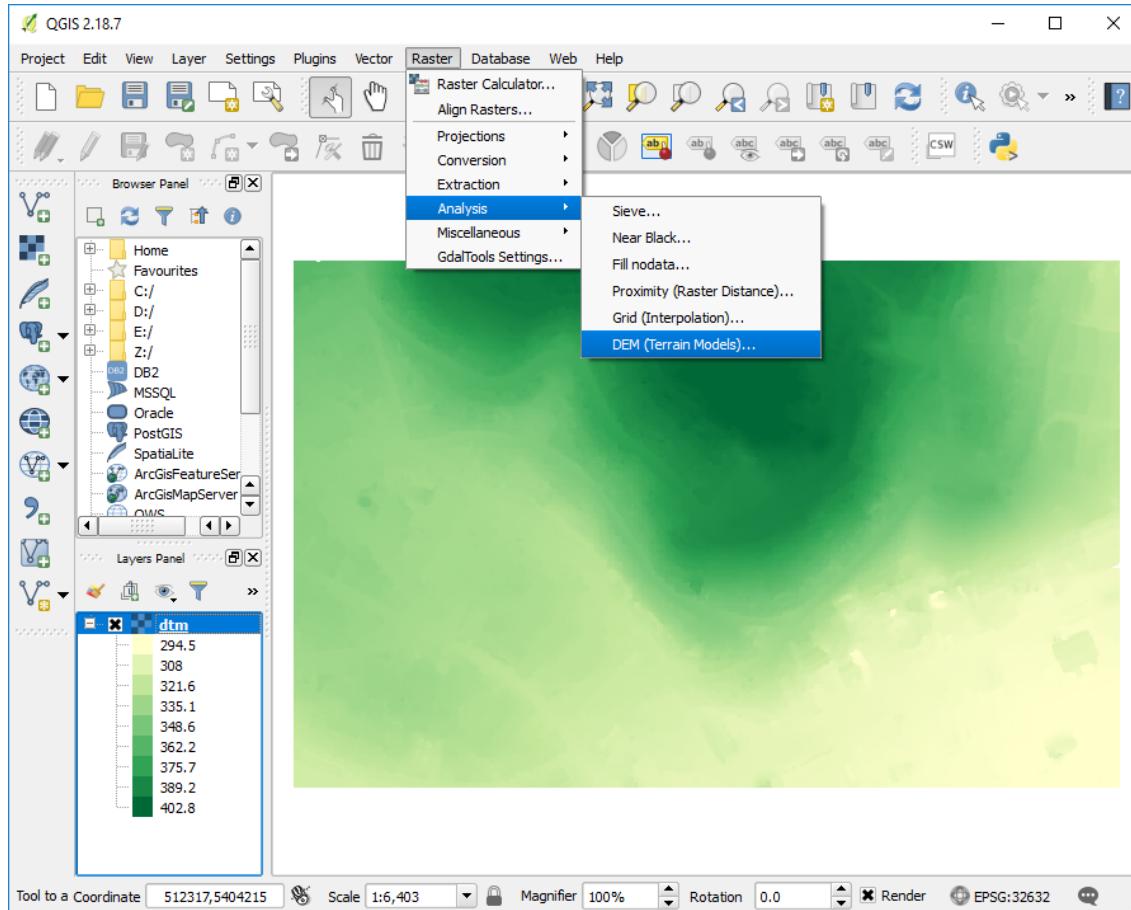
2. Add the *dtm.tif* file from your `./PDAL/exercises/analysis/dtm` directory.



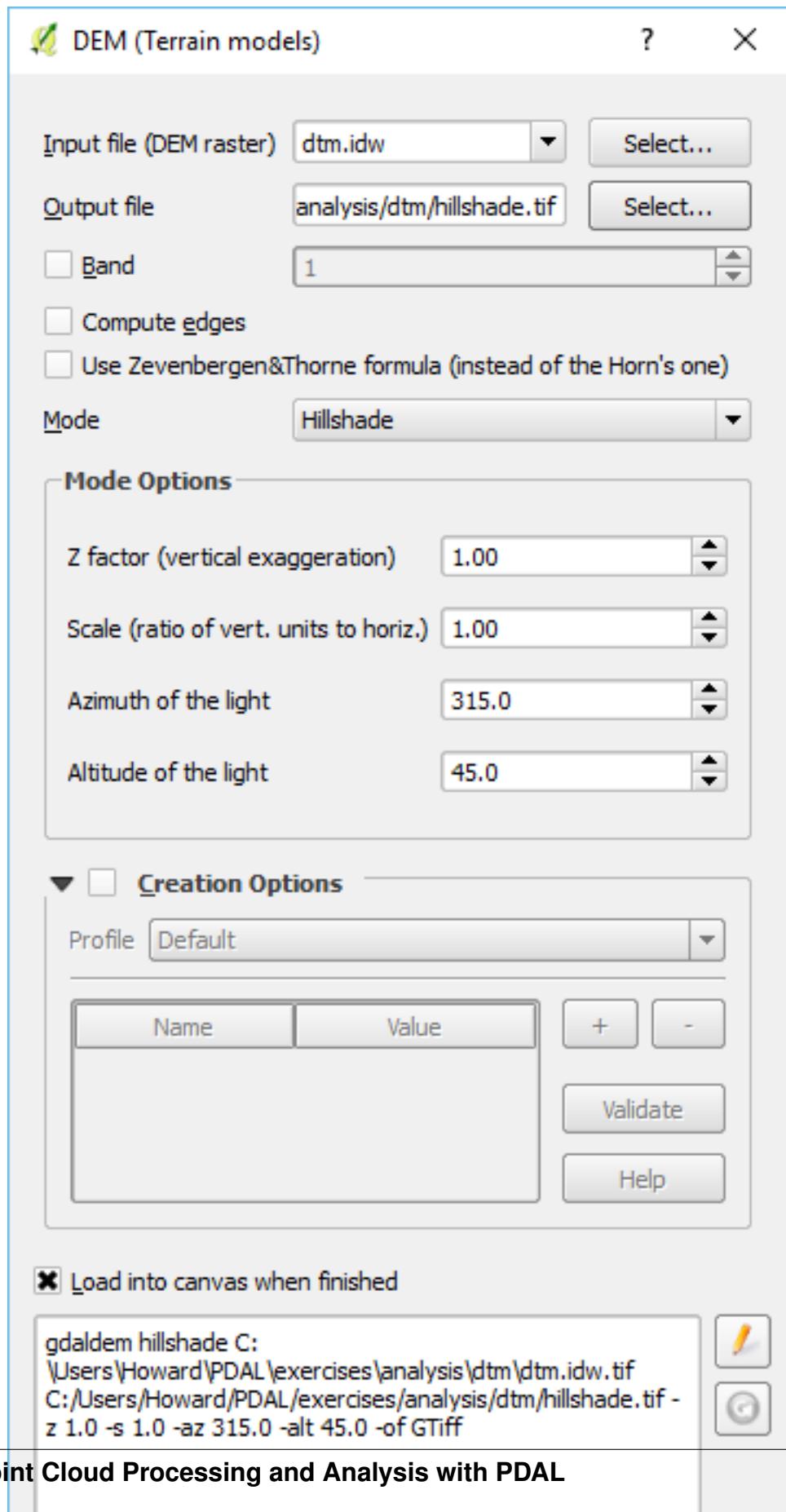
3. Classify the DTM by right-clicking on the *dtm.tif* and choosing *Properties*. Pick the pseudocolor rendering type, and then choose a color ramp and click *Classify*.



4. *QGIS* (page 292) 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->Dem*:



5. Click the window for the *Output file* and select a location to save the hillshade.tif



```
1 gdaldem hillshade ^
2     C:/Users/hobu/pdal/exercises/analysis/dtm/dtm.tif ^
3     C:/Users/hobu/pdal/exercises/analysis/dtm/hillshade.tif ^
4     -z 1.0 -s 1.0 -az 315.0 -alt 45.0 -of GTiff
```

6. 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 292) DEM tools, is a very powerful command line utility you can use for processing data.
2. `writers.gdal` (page 108) can be used for large data, but it does not interpolate a typical TIN ([https://en.wikipedia.org/wiki/Triangulated\\_irregular\\_network](https://en.wikipedia.org/wiki/Triangulated_irregular_network)) surface model.

### Rasterizing Attributes

This exercise uses PDAL to generate a raster surface using a fully classified point cloud with PDAL's `writers.gdal` (page 108).

## Exercise

---

**Note:** The exercise fetches its data from a Greyhound (<https://greyhound.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 108) stage. There is no *application* (page 25) to drive this stage, and we must use a pipeline.

### Pipeline breakdown

```
{  
  "pipeline": [  
    {  
      "type": "readers.ept",  
      "url": "http://na-c.entwine.io/dk",  
      "bounds": "([11045777.34375, 11055492.1875], [-11852109.375, -  
       ↪11842394.53125], [223441.40625, 233156.25])"  
    },  
    {  
      "type": "writers.gdal",  
      "filename": "denmark-classification.tif",  
      "dimension": "Classification",  
      "data_type": "uint16_t",  
      "output_type": "mean",  
      "resolution": 30.0  
    }  
  ]  
}
```

---

**Note:** This pipeline is available in your workshop materials in the `./exercises/analysis/dtm/dtm.json` file. Make sure to edit the filenames to match your paths.

---

## 1. Reader

```
{  
    "type": "readers.ept",  
    "url": "http://na-c.entwine.io/dk",  
    "bounds": "([11045777.34375, 11055492.1875], [-11852109.375, -  
→11842394.53125], [223441.40625, 233156.25])"  
},
```

The data is read from a readers.greyhound server that hosts the Denmark data. We're going to download a small patch of data by the Copenhagen airport that is the “full depth” of the tree.

## 2. writers.gdal

The *writers.gdal* (page 108) writer that bins the point cloud data with classification values.

```
{  
    "type": "writers.gdal",  
    "filename": "denmark-classification.tif",  
    "dimension": "Classification",  
    "data_type": "uint16_t",  
    "output_type": "mean",  
    "resolution": 30.0  
}
```

## Execution

Issue the *pipeline* (page 45) operation to execute the interpolation:

```
pdal pipeline classification.json
```

```
{  
    "pipeline": [  
        {  
            "type": "readers.ept",  
            "url": "http://na-c.entwine.io/dk",  
            "bounds": "([11045777.34375, 11055492.1875], [-11852109.375, -  
→11842394.53125], [223441.40625, 233156.25])"  
        },  
        {  
            "type": "writers.gdal",  
            "filename": "denmark-classification.tif",  
            "dimension": "Classification",  
        }  
    ]  
}
```

```
    "data_type": "uint16_t",
    "output_type": "mean",
    "resolution": 30.0
}
]
}
```



A screenshot of a Windows command prompt window titled 'cmd C:\WINDOWS\system32\cmd.exe'. The window contains the following text:  
c:\Users\hobu\PDAL\exercises\analysis\rasterization>pdal pipeline classification.json  
c:\Users\hobu\PDAL\exercises\analysis\rasterization>\_

## Visualization

Unfortunately, this doesn't 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 292) allows us to create a text file color ramp that gdaldem can consume to apply colors to the data.

```
1 # QGIS Generated Color Map Export File
2 0,255,0,0,255
```

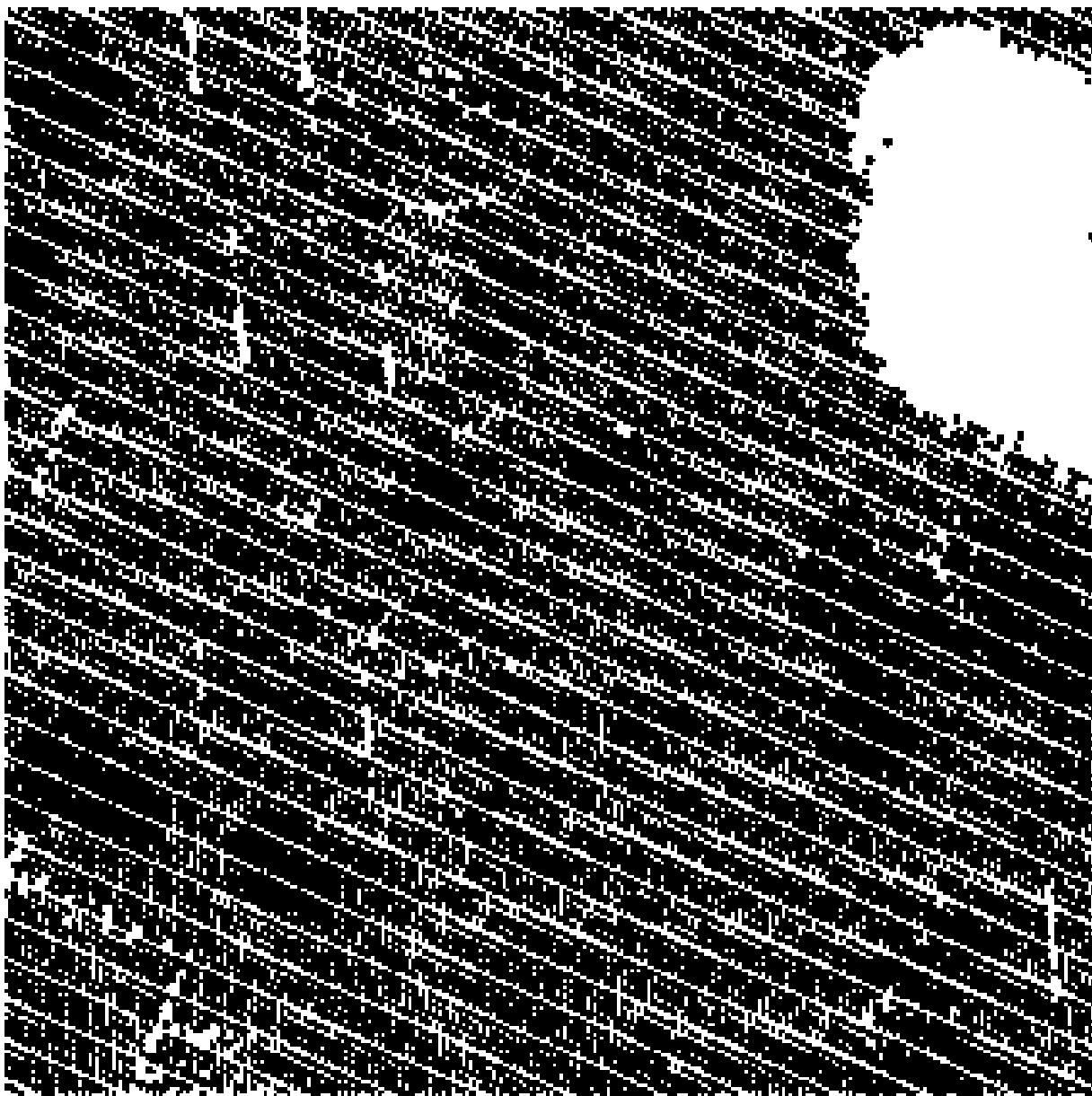


Fig. 11.7: Basic interpolation of data with [\*writers.gdal\*](#) (page 108) will output raw classification values into the resulting raster file. We will need to add a color ramp to the data for a satisfactory preview.

```

3 1,234,234,234,255
4 2,222,126,44,255
5 3,30,62,15,255
6 4,45,255,6,255
7 5,209,230,201,255
8 6,249,12,6,255
9 7,146,197,222,255
10 8,133,5,2,255
11 9,0,0,255,255
12 10,255,255,255,255

```

With the ramp, we can use `gdaldem` (<http://www.gdal.org/gdaldem.html>) to apply it to a new image:

```

1 gdaldem color-relief ^
2   demark-classification.tif ^
3   ramp.txt ^
4   classified-color.png ^
5   -exact_color_entry ^
6   -of PNG

```

## Intensity

With PDAL's ability to override pipeline via commands, we can generate a relative intensity image:

```

1 pdal pipeline classification.json ^
2   --writers.gdal.dimension="Intensity" ^
3   --writers.gdal.data_type="float" ^
4   --writers.gdal.filename="intensity.tif"
5
6 gdal_translate intensity.tif intensity.png -of PNG

```

## Notes

1. `writers.gdal` (page 108) 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 45) contains more information about overrides and organizing complex pipelines.

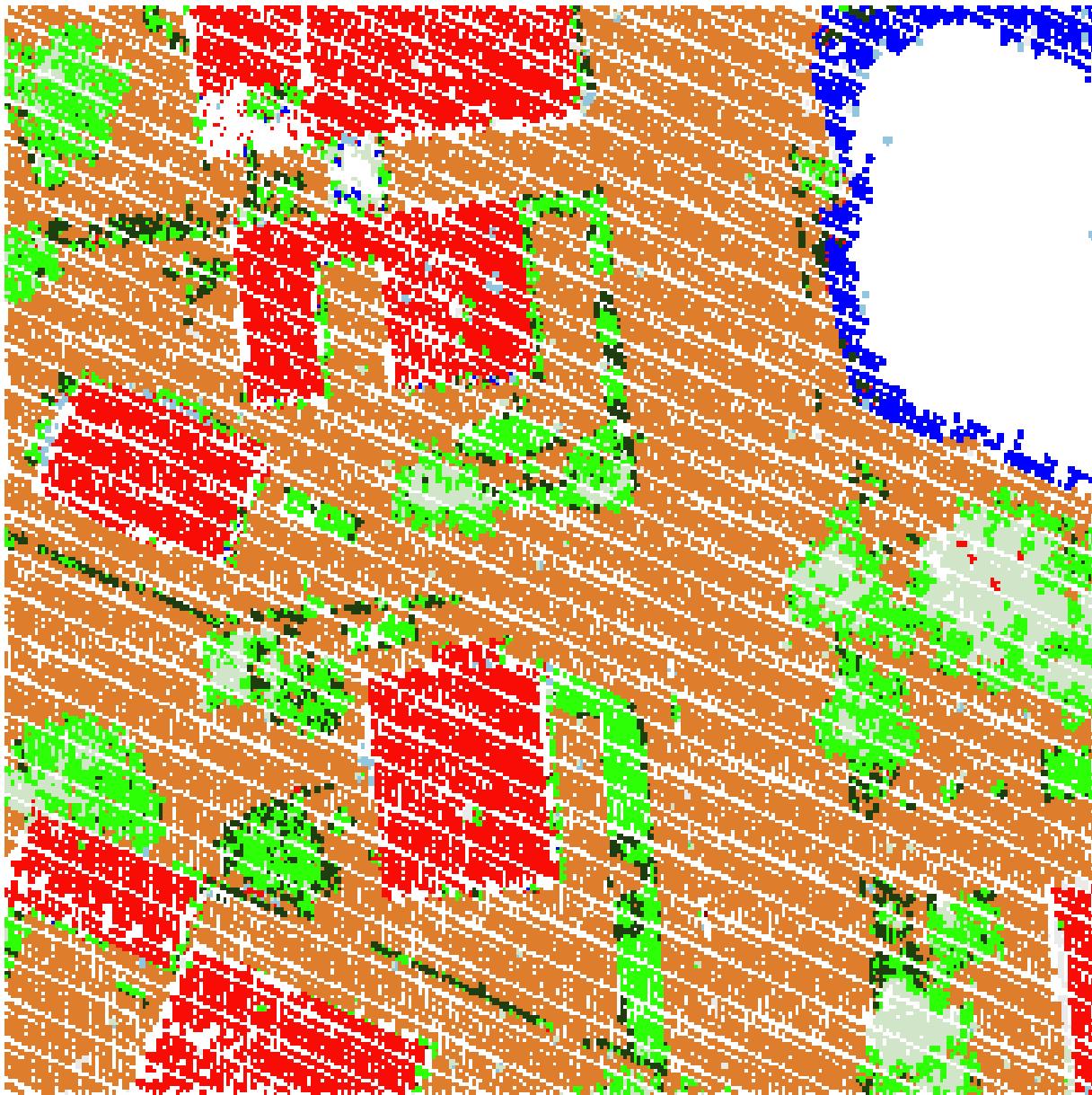


Fig. 11.8: The use of `-exact_color_entry` for gdaldem ensures that specific classification values are given the requested color. For categorical data such as a classification surface, interpolated output would look poor.



Fig. 11.9: 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.

### Python

#### 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 233) bindings and [filters.python](#) (page 221) 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 233) 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 32).

---

**Note:** Python allows you to enhance and build functionality that you can use in the context of other [Pipeline](#) (page 45) operations.

---

### PDAL Pipeline

We're going to create a PDAL [Pipeline](#) (page 45) to tell PDAL to run our Python script in a [filters.python](#) (page 221) stage.

```
1 {
2     "pipeline": [
3         {
4             "filename": "c:/Users/hobu/PDAL/exercises/
5             ↪python/athletic-fields.laz"
6             },
7             {
8                 "type": "filters.programmable",
9                 "function": "make_plot",
10                "module": "anything",
11                "pdalargs": "{\"filename\": \"histogram.png\"}"
12            },
13            {
14                "script": "c:/Users/hobu/PDAL/exercises/python/
15                ↪histogram.py"
16            },
17            {
18                "type": "filters.python",
19                "function": "plot",
20                "module": "anything",
21                "pdalargs": "[\"histogram.png\"]"
22            }
23        ]
24    }
```

```
14             "type": "writers.null"
15         }
16     ]
17 }
```

---

**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/) (<https://matplotlib.org/>). Store it as `histogram.py` next to the `histogram.json Pipeline` (page 45) 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.

---

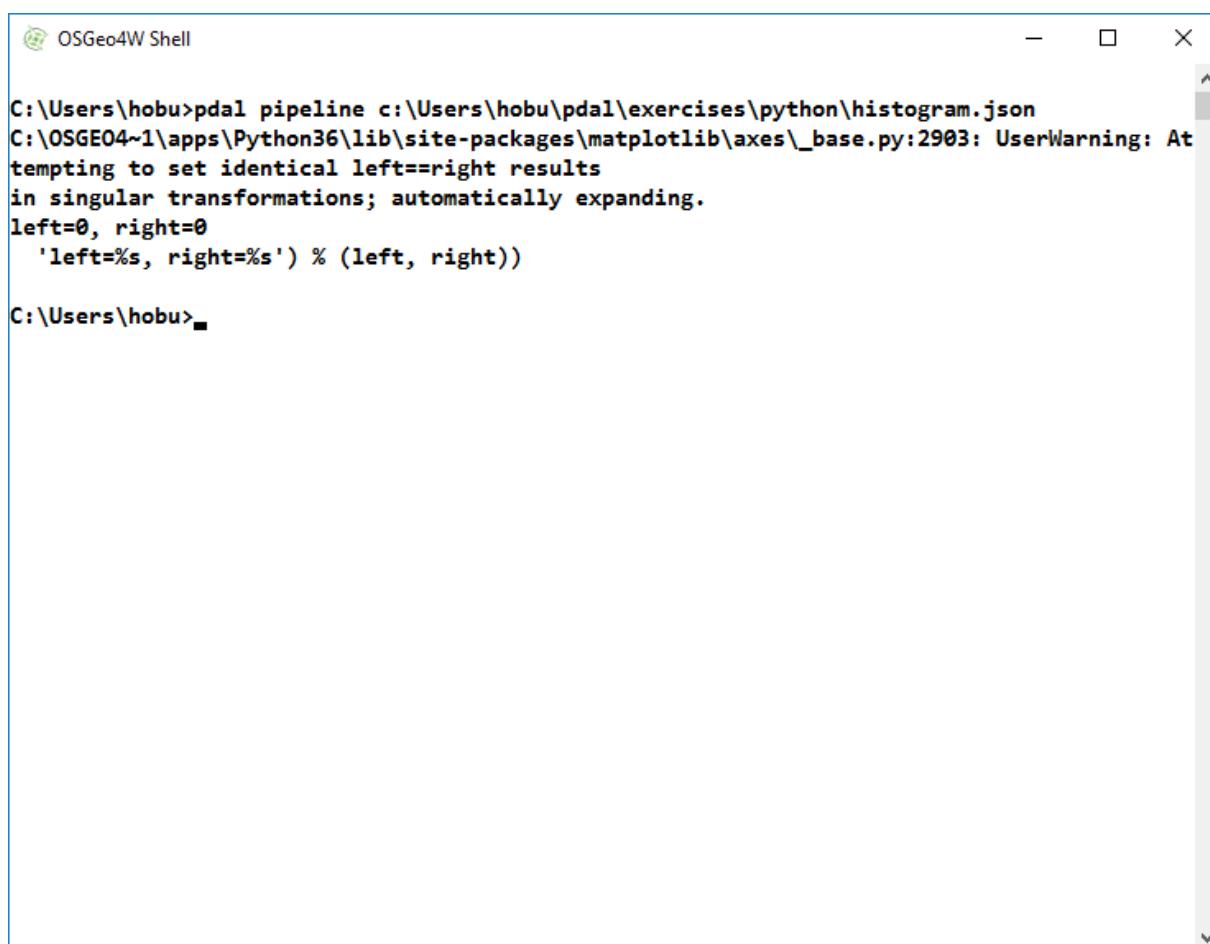
```
1 # import numpy
2 import numpy as np
3
4 # import matplotlib stuff and make sure to use the
5 # AGG renderer.
6 import matplotlib
7 matplotlib.use('Agg')
8 import matplotlib.pyplot as plt
9 import matplotlib.mlab as mlab
10
11 # This only works for Python 3. Use
12 # StringIO for Python 2.
13 from io import BytesIO
14
15 # The make_plot function will do all of our work. The
16 # filters.programmable filter expects a function name in the
17 # module that has at least two arguments -- "ins" which
18 # are numpy arrays for each dimension, and the "outs" which
19 # the script can alter/set/adjust to have them updated for
20 # further processing.
21 def make_plot(ins, outs):
```

```
23 # figure position and row will increment
24 figure_position = 1
25 row = 1
26
27 fig = plt.figure(figure_position, figsize=(6, 8.5), dpi=300)
28
29 for key in ins:
30     dimension = ins[key]
31     ax = fig.add_subplot(len(ins.keys()), 1, row)
32
33     # histogram the current dimension with 30 bins
34     n, bins, patches = ax.hist(dimension, 30,
35                                normed=0,
36                                facecolor='grey',
37                                alpha=0.75,
38                                align='mid',
39                                histtype='stepfilled',
40                                linewidth=None)
41
42     # Set plot particulars
43     ax.set_ylabel(key, size=10, rotation='horizontal')
44     ax.get_xaxis().set_visible(False)
45     ax.set_yticklabels('')
46     ax.set_yticks(())
47     ax.set_xlim(min(dimension), max(dimension))
48     ax.set_ylim(min(n), max(n))
49
50     # increment plot position
51     row = row + 1
52     figure_position = figure_position + 1
53
54 # We will save the PNG bytes to a BytesIO instance
55 # and the nwrite that to a file.
56 output = BytesIO()
57 plt.savefig(output, format="PNG")
58
59 # a module global variable, called 'pdalargs' is available
60 # to filters.programmable and filters.predicate modules that
61 # contains
62 # a dictionary of arguments that can be explicitly passed into
63 # the module by the user. We passed in a filename arg in our
64 # `pdal pipeline` call
65 if 'filename' in pdalargs:
66     filename = pdalargs['filename']
67 else:
68     filename = 'histogram.png'
```

```
68 # open up the filename and write out the
69 # bytes of the PNG stored in the BytesIO instance
70 o = open(filename, 'wb')
71 o.write(output.getvalue())
72 o.close()
73
74
75 # filters.programmable scripts need to
76 # return True to tell the filter it was successful.
77 return True
78
79
80
```

## Run pdal pipeline

```
1 pdal pipeline c:/Users/hobu/PDAL/exercises/python/histogram.json
```



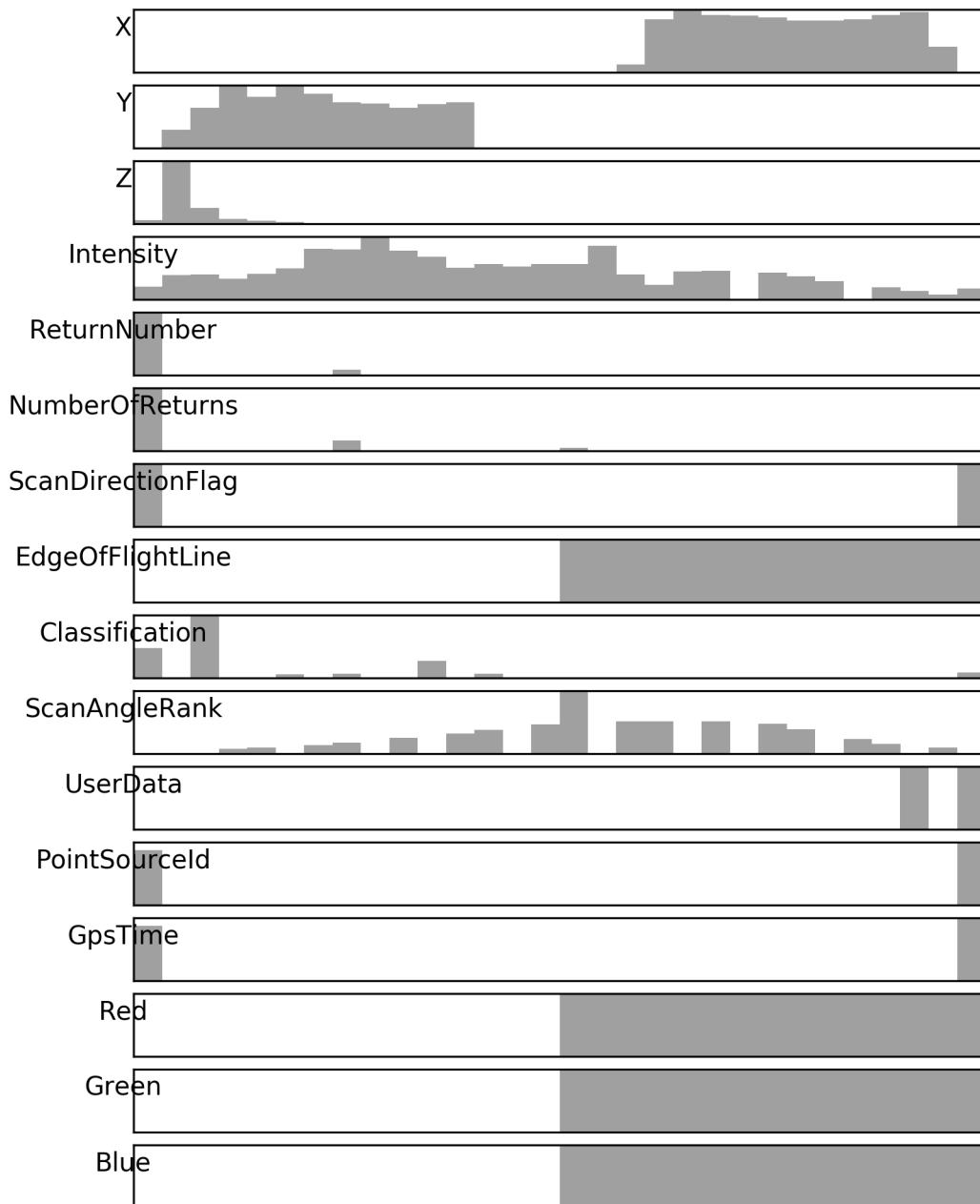
The screenshot shows a terminal window titled "OSGeo4W Shell". The command "pdal pipeline c:/Users/hobu/PDAL/exercises/python/histogram.json" is entered and executed. The output includes a UserWarning message from matplotlib about singular transformations.

```
C:\Users\hobu>pdal pipeline c:/Users/hobu/PDAL/exercises/python/histogram.json
C:\OSGEO4~1\apps\Python36\lib\site-packages\matplotlib\axes\_base.py:2903: UserWarning: At
tempting to set identical left==right results
in singular transformations; automatically expanding.
left=0, right=0
'left=%s, right=%s') % (left, right))

C:\Users\hobu>
```



## Output



### Notes

1. `writers.null` (page 121) 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

### Georeferencing

As discussed [\*in the introduction\*](#) (page 288), 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](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](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.range](#) (page 191) PDAL filter to drop all points with very high intensity values.

---

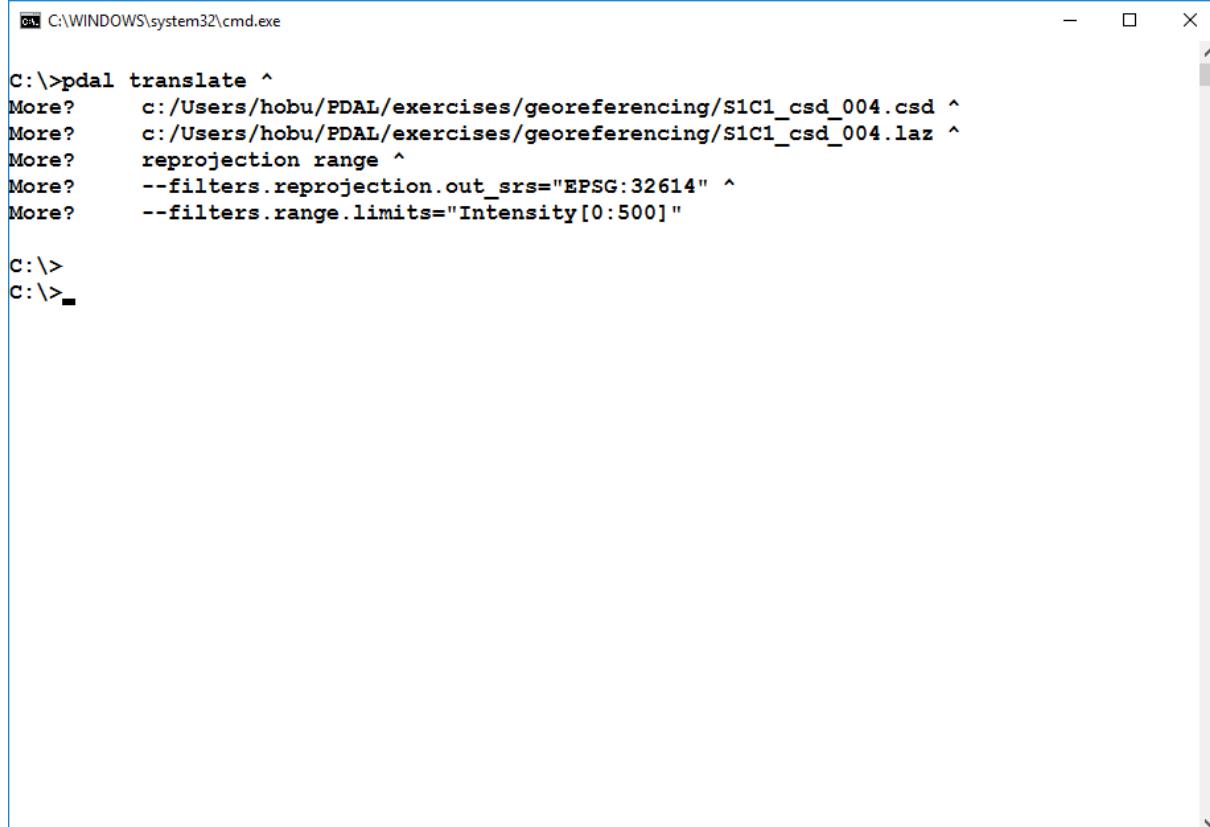
**Note:** These data were provided by Dr. Craig Glennie and were collected by [NCALM](#) (<http://ncalm.cive.uh.edu/>), the National Center for Airborne Laser Mapping. The collect area is southwest of Austin, TX.

---

## Command

Invoke the following command, substituting accordingly, into your *Anaconda Shell*:

```
pdal translate ^
  c:/Users/hobu/PDAL/exercises/georeferencing/S1C1_csd_004.csd ^
  c:/Users/hobu/PDAL/exercises/georeferencing/S1C1_csd_004.laz ^
  reprojection range ^
  --filters.reprojection.out_srs="EPSG:32614" ^
  --filters.range.limits="Intensity[0:500]"
```



```
C:\>pdal translate ^
More?   c:/Users/hobu/PDAL/exercises/georeferencing/S1C1_csd_004.csd ^
More?   c:/Users/hobu/PDAL/exercises/georeferencing/S1C1_csd_004.laz ^
More?   reprojection range ^
More?   --filters.reprojection.out_srs="EPSG:32614" ^
More?   --filters.range.limits="Intensity[0:500]"

C:\>
C:\>
```

### Visualization

View your georeferenced point cloud in <http://plas.io>.

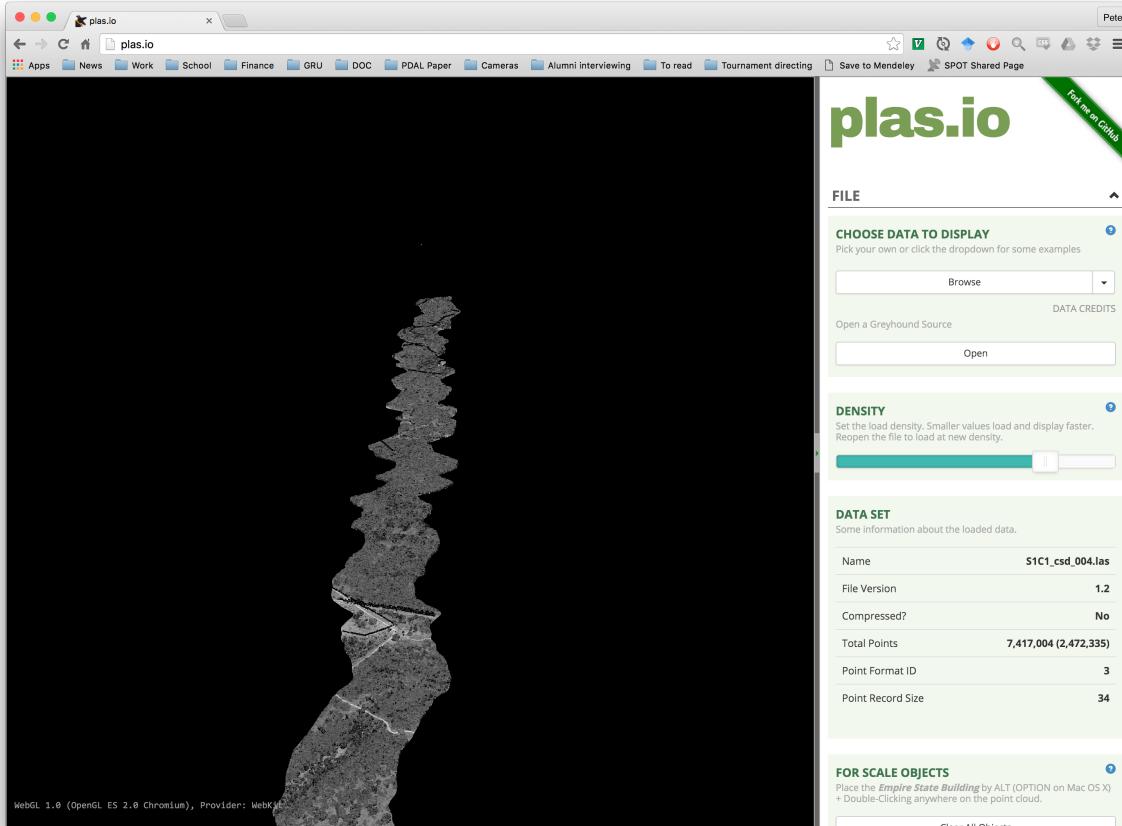


Fig. 11.10: Our airborne laser point cloud after georeferencing, reprojection, and intensity filtering.

### 11.1.5 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": [  
    {
```

```

    "type": "readers.greyhound",
    "url": "data.greyhound.io",
    "resource": "dublin",
    "threads": 8,
    "depth_end": 14,
    "bounds": "([-697041.0, -696241.0], [7045398.0, 7046086.
    ↪ 0], [-40, 400])"

  },
  {
    "type": "writers.las",
    "compression": "true",
    "minor_version": "2",
    "dataformat_id": "0",
    "filename": "st-stephens.laz"
  }
]
}

```

- Read data from a [Greyhound](#) (<http://greyhound.io/>) server using `readers.greyhound` (page 63) (See [Greyhound](#) (page 310))
- Thin it by 1.0 meter spacing using `filters.sample` (page 194) (See [Thinning](#) (page 337))
- Filter out noise using `filters.outlier` (page 161) (See [Removing noise](#) (page 328))
- Classify ground points using `filters.smrf` (page 169) (See [Identifying ground](#) (page 340))
- Compute height above ground using `filters.hag` (page 150)
- Generate a digital terrain model (DTM) using `writers.gdal` (page 108) (See [Generating a DTM](#) (page 349))
- Generate a average vegetative height model using `writers.gdal` (page 108)

---

**Note:** You should review specific [Exercises](#) (page 297) for specifics how to achieve each task.

---

### 11.1.6 Notes

#### Notes

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## Notes

## Notes

## Notes

## Notes

## Notes



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CHAPTER  
TWELVE

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## DEVELOPMENT

### 12.1 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 25) and users looking to use the PDAL API in their own applications should look [here](#) (page 453).

---

#### 12.1.1 PDAL Architecture Overview

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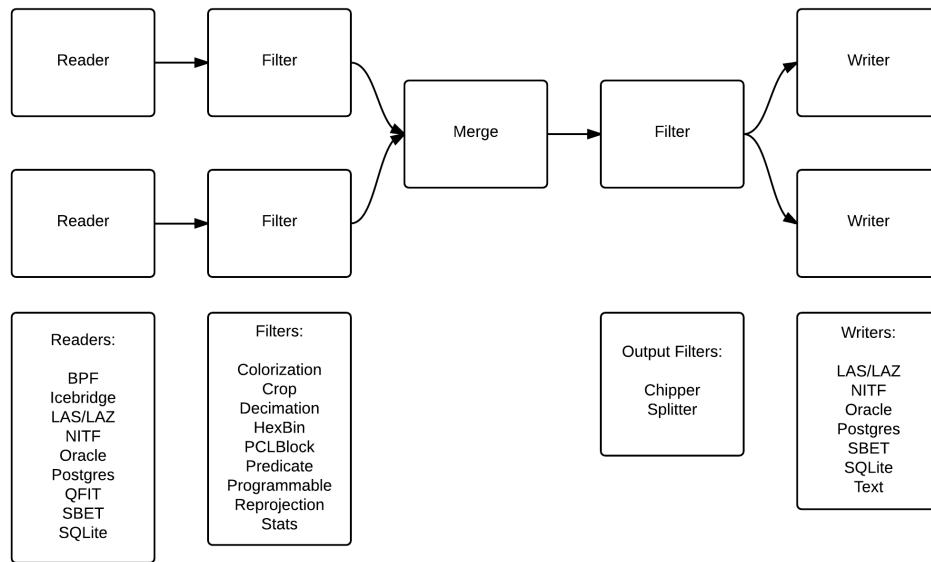
**Date** 5/15/2016

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 StreamingPointTable exists to allow a pipeline to run without loading all points in memory. A StreamingPointTable 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.

## 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 judgement 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.

```
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.

```
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, read(), that will place the data from the input source into the provided point view:

```
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 a 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 size() function of the point view. read() should return the number of points read by during the function call.

```
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--)
    {
        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);

        // Set X, Y and Z into the pointView.
        view->setField(Dimension::Id::X, nextId, x);
        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);

        transform(x, y, z);

        view->setField(Dimension::Id::X, id, x);
        view->setField(Dimension::Id::Y, id, y);
        view->setField(Dimension::Id::Z, id, z);
    }
}
```

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:

```
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().

```

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);  
}
```

### 12.1.2 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).

#### Dependencies

Building PDAL successfully depends on having other libraries configured and installed. These [dependencies](#) (page 399) 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 ..
-- Could NOT find JSONCPP (missing: JSONCPP_LIBRARY JSONCPP_INCLUDE_
    ↪DIR) (Required is at least version "1.6.2")
-- 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:

* PostgreSQLPointCloud plugin, read/write PostgreSQLPointCloud_
    ↪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:

* 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":
{
  "bbox":
  {
    "EPSG:4326":
    {
      "bbox":
      {
        "maxx": -123.0689038,
        "maxy": 44.0515451,
        "maxz": 158.651448,
        "minx": -123.0734481,
        "miny": 44.04990077,
        "minz": 123.828048
      },
      ...
    }
  }
}

```

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 [red]
→ 0.23 sec
  Start 2: pdal_filters_icp_test
2/97 Test #2: pdal_filters_icp_test ..... Passed [red]
→ 0.12 sec
  Start 3: pdal_filters_python_test
3/97 Test #3: pdal_filters_python_test ..... Passed [red]
→ 3.52 sec
  Start 4: pdal_io_numpy_test
4/97 Test #4: pdal_io_numpy_test ..... Passed [red]
→ 0.31 sec
  ...
93/96 Test #93: pdal_io_ilvis2_metadata_test ..... Passed [red]
→ 0.03 sec
  Start 94: pdal_io_ilvis2_reader_metadata_test
94/96 Test #94: pdal_io_ilvis2_reader_metadata_test .... Passed [red]
→ 0.05 sec
  Start 95: xml_schema_test
95/96 Test #95: xml_schema_test ..... Passed [red]
→ 0.04 sec
  Start 96: pdal_io_ilvis2_test
96/96 Test #96: pdal_io_ilvis2_test ..... Passed [red]
→ 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

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**Date** 03/20/2019

---

**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 AppVeyor 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/appveyor.yml> and <https://github.com/PDAL/PDAL/tree/master/scripts/appveyor> for inspiration.

---

## Required Compiler

PDAL is known to compile on [Visual Studio 2015](https://www.visualstudio.com/vs/older-downloads/) (<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 [AppVeyor](https://ci.appveyor.com/project/hobu/pdal/history) (<https://ci.appveyor.com/project/hobu/pdal/history>) 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 AppVeyor configuration at <https://github.com/PDAL/PDAL/blob/master/appveyor.yml>. The most interesting bits are the `install` section, the `config.cmd`, and the `build.cmd` scripts. The AppVeyor configuration already has Miniconda installed, and the `config.cmd` script installs all of PDAL's prerequisites via the command line.

```
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/appveyor/test/build.cmd` file in PDAL's source tree.

---

## Fetching the Source

Get the source code for PDAL. Presumably you have [GitHub for Windows](https://desktop.github.com/) (<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) (<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. There are two places in the source tree for inspiration on this topic.

1. The AppVeyor build configuration  
<https://github.com/PDAL/PDAL/blob/master/scripts/appveyor/config.cmd#L26>
2. Howard Butler's example build configuration  
<https://github.com/PDAL/PDAL/blob/master/scripts/conda/wind64.bat>

---

**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

PDAL depends on a number of libraries to do its work. You should make sure those dependencies are installed on your system before installing PDAL or use a packaging system that will automatically ensure that prerequisites are satisfied. 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 (2.2+)

PDAL uses GDAL for spatial reference system description manipulation, and image reading supporting for the NITF driver, and *writers.oci* (page 122) support. 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>

Conda: <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) (<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) (<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) (<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.

---

## Optional Dependencies

### LASzip (Latest package/source recommended)

LASzip (<http://laszip.org>) is a library with a *CMake*-based build system that provides periodic compression of [ASPRS LAS](#) (<http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html>) data. It is used by the *writers.las* (page 113) and *readers.las* (page 69) to provide compressed LAS support.:

```
Source: https://github.com/LASzip/LASzip
Conda: https://anaconda.org/conda-forge/laszip
```

### laz-perf (Latest package/source recommended)

laz-perf provides an alternative LAS compression/decompression engine that may be slightly faster in some circumstances. laz-perf supports fewer LAS point types and versions than does LASzip. It is also used as a compression type for *writers.oci* (page 122) and *writers.sqlite* (page 130):

```
Source: https://github.com/verma/laz-perf/
Conda: https://anaconda.org/conda-forge/laz-perf
```

### libxml2 (2.7+)

libxml2 (<http://xmlsoft.org>) is used to serialize PDAL dimension descriptions into XML for the database drivers such as *writers.oci* (page 122), *readers.sqlite* (page 95), or *readers.pgpointcloud* (page 82).:

```
Source: http://www.xmlsoft.org/
Conda: https://anaconda.org/conda-forge/libxml2
```

## 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.

## OCI (10g+)

Obtain the [Oracle Instant Client](#)

(<http://www.oracle.com/technology/tech/oci/instantclient/index.html>) and install in a location on your system. Be sure to install both the “Basic” and the “SDK” modules. Set your ORACLE\_HOME environment variable system- or user-wide to point to this location so the CMake configuration can find your install. OCI is used by both [\*writers.oci\*](#) (page 122) and [\*readers.oci\*](#) (page 79) for Oracle Point Cloud read/write support. In order to obtain the OCI libraries you must register with Oracle.:

```
Libraries: https://www.oracle.com/technetwork/database/database-technologies/instant-client/downloads/index.html
```

## Nitro (Requires specific source package)

Nitro is a library that provides [NITF](#)

([http://en.wikipedia.org/wiki/National\\_Imagery\\_Transmission\\_Format](http://en.wikipedia.org/wiki/National_Imagery_Transmission_Format)) support for PDAL to write LAS-in-NITF files for [\*writers.nitf\*](#) (page 119). You must use the specific version of Nitro referenced below for licensing and compatibility reasons.:

```
Source: http://github.com/hobu/nitro
```

## PCL (1.7.2+)

The [Point Cloud Library \(PCL\)](#) (<http://pointclouds.org>) is used by the [\*pcl\*](#) (page 32), [\*writers.pcd\*](#) (page 126), [\*readers.pcd\*](#) (page 81), and [\*filterspclblock\*](#) (page 219) to provide support for various PCL-related operations.:

```
Source: https://github.com/PointCloudLibrary/pcl
Conda: https://anaconda.org/conda-forge/pcl
```

## TileDB (1.4.1+)

[TileDB](https://www.tiledb.io) (<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 [\*readers.tiledb\*](#) (page 133) and [\*readers.tiledb\*](#) (page 100).:

Source: <https://github.com/TileDB-Inc/TileDB>  
Conda: <https://anaconda.org/conda-forge/tiledb>

### 12.1.3 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.

### 12.1.4 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 32) and `pdal translate` (page 39) 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:

```
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("nulluidnode", 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:

```
{  
    "writers.test":  
    {  
        "intlist":  
        [  
            45,  
            55  
        ],  
        "nodename": "Some string data",  
        "parent":  
        {  
            "nulluidnode": "00000000-0000-0000-0000-000000000000",  
            "num_in_list":  
            [  
                66  
            ]  
        }  
    }  
}
```

### 12.1.5 Writing with PDAL

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**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 55) that conforms to PDAL's [pdal::Stage](#) (page 487), you can implement a simple read-filter-write pipeline using [Pipeline](#) (page 45) and not have to code anything explicit yourself.

---

#### Includes

First, our code.

```
#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);
    }
}

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;

// Set second argument to 'true' to let factory take ownership of
// stage and facilitate clean up.
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.

```
#include <pdal/PointView.hpp>
#include <pdal/PointTable.hpp>
#include <pdal/Dimension.hpp>
#include <pdal/Options.hpp>
#include <pdal/StageFactory.hpp>

#include <io/BufferReader.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 BufferedReader and sends it to a writer.

```

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);

    BufferedReader reader;
    reader.addView(view);

    StageFactory factory;

    // Set second argument to 'true' to let factory take ownership of
// stage and facilitate clean up.
    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 392) 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.

```
cmake_minimum_required(VERSION 3.6)
project(WritingTutorial)

find_package(PDAL 1.6.0 REQUIRED CONFIG)

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 433) 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
```

## 12.1.6 Writing a filter

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**Date** 11/02/2017

PDAL can be extended through the development of filter functions.

### See also:

For more on filters and their role in PDAL, please refer to [PDAL Architecture Overview](#) (page 381).

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 148), 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.pmf](#) (page 167), 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.

```
1 // MyFilter.hpp
2
3 #pragma once
4
5 #include <pdal/Filter.hpp>
6 #include <pdal/Stage.hpp>
7
8 #include <memory>
9
10 namespace pdal
11 {
12
13 class Options;
14 class PointLayout;
15 class PointView;
16
17 class PDAL_DLL MyFilter : public Filter
18 {
19 public:
20     MyFilter() : Filter()
```

```
21 { }
22 std::string getName() const;
23
24 private:
25     double m_value;
26     Dimension::Id m_myDimension;
27
28     virtual void addDimensions(PointLayoutPtr layout);
29     virtual void addArgs(ProgramArgs& args);
30     virtual PointViewSet run(PointViewPtr view);
31
32     MyFilter& operator=(const MyFilter&); // not implemented
33     MyFilter(const MyFilter&); // not implemented
34 }
35
36 } // namespace pdal
```

This header should be relatively straightforward, but we will point out three methods that must be declared for the plugin interface to be satisfied.

```
private:
    double m_value;
```

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.

```
1 // MyFilter.cpp
2
3 #include "MyFilter.hpp"
4
5 #include <pdal/Options.hpp>
6 #include <pdal/PointTable.hpp>
7 #include <pdal/PointView.hpp>
8 #include <pdal/util/ProgramArgs.hpp>
9
10 namespace pdal
11 {
12
13     static PluginInfo const s_info =
14         PluginInfo("filters.name", "My awesome filter",
15                     "http://link/to/documentation");
```

```

16
17 CREATE_SHARED_PLUGIN(1, 0, MyFilter, Filter, s_info)
18
19 std::string MyFilter::getName() const
20 {
21     return s_info.name;
22 }
23
24 void MyFilter::addArgs(ProgramArgs& args)
25 {
26     args.add("param", "Some parameter", m_value, 1.0);
27 }
28
29 void MyFilter::addDimensions(PointLayoutPtr layout)
30 {
31     layout->registerDim(Dimension::Id::Intensity);
32     m_myDimension = layout->registerOrAssignDim("MyDimension",
33                                                 Dimension::Type::Unsigned8);
34 }
35
36 PointViewSet MyFilter::run(PointViewPtr input)
37 {
38     PointViewSet viewSet;
39     viewSet.insert(input);
40     return viewSet;
41 }
42
43 } // namespace pdal

```

For your filter to be available to PDAL at runtime, it must adhere to the PDAL plugin interface. As a convenience, we provide the macros in `pdal_macros.hpp` to do just this.

We begin by creating a `PluginInfo` struct containing three identifying elements - the filter name, description, and a link to documentation.

```

1     "http://link/to/documentation");
2
3 CREATE_SHARED_PLUGIN(1, 0, MyFilter, Filter, s_info)

```

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`).

Next, we pass the following to the `CREATE_STATIC_STAGE` macro, passing in the name of the stage and the `PluginInfo` struct.

```
std::string MyFilter::getName() const
```

To create a shared stage, we simply change `CREATE_STATIC_STAGE` to `CREATE_SHARED_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.

```
1     return s_info.name;
2 }
3
4 void MyFilter::addArgs(ProgramArgs& args)
```

Now that the filter has implemented the proper plugin interface, we will begin to implement some methods that actually implement the filter. First, `getDefaults()` is used to advertise those options that the filter provides. Within PDAL, this is primarily used as a means of displaying options via the PDAL CLI with the `--options` argument. It provides the user with the option names, descriptions, and default values.

```
1     args.add("param", "Some parameter", m_value, 1.0);
2 }
3
4 void MyFilter::addDimensions(PointLayoutPtr layout)
```

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`.

```
1     layout->registerDim(Dimension::Id::Intensity);
2     m_myDimension = layout->registerOrAssignDim("MyDimension",
3                                         Dimension::Type::Unsigned8);
4 }
5
6 PointViewSet MyFilter::run(PointViewPtr input)
```

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()`.

```
1     PointViewSet viewSet;
2     viewSet.insert(input);
3     return viewSet;
4 }
5
6 } // namespace pdal
```

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:

```
1 cmake_minimum_required(VERSION 2.8.12)
2 project(FilterTutorial)
3
4 find_package(PDAL 1.6.0 REQUIRED CONFIG)
5
6 add_library(pdal_plugin_filter_myfilter SHARED MyFilter.cpp)
7 target_link_libraries(pdal_plugin_filter_myfilter PRIVATE ${PDAL_
    ↴LIBRARIES})
8 target_include_directories(pdal_plugin_filter_myfilter PRIVATE
    ${PDAL_INCLUDE_DIRS})
```

### 12.1.7 Writing a kernel

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**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.

```
1 // MyKernel.hpp
2
3 #pragma once
4
5 #include <pdal/Kernel.hpp>
6
7 #include <string>
8
9 namespace pdal
10 {
```

```
11
12 class PDAL_DLL MyKernel : public Kernel
13 {
14 public:
15     MyKernel();
16
17     std::string getName() const;
18     int execute(); // override
19
20 private:
21     void addSwitches(ProgramArgs& args);
22
23     std::string m_input_file;
24     std::string m_output_file;
25 };
26
27 } // namespace pdal
```

As with other plugins, the MyKernel class needs to return a name.

```
std::string getName() const;
```

## The source

Again, we start with a full listing of the kernel source.

```
1 // MyKernel.cpp
2
3 #include "MyKernel.hpp"
4
5 #include <pdal/Filter.hpp>
6 #include <pdal/Kernel.hpp>
7 #include <pdal/Options.hpp>
8 #include <pdal/PointTable.hpp>
9
10 #include <memory>
11 #include <string>
12
13
14 namespace pdal {
15
16     static PluginInfo const s_info
17     {
18         "kernels.mykernel",
19         "MyKernel",
20         "http://link/to/documentation"
```

```

21    } ;
22
23    CREATE_SHARED_KERNEL(MyKernel, s_info) ;
24    std::string MyKernel::getName() const { return s_info.name; }
25
26    MyKernel::MyKernel() : Kernel()
27    {}
28
29    void MyKernel::addSwitches(ProgramArgs& args)
30    {
31        args.add("input,i", "Input filename", m_input_file).
32        setPositional();
32        args.add("output,o", "Output filename", m_output_file).
33        setPositional();
33    }
34
35    int MyKernel::execute()
36    {
37        PointTable table;
38
39        Stage& reader = makeReader(m_input_file, "readers.las");
40
41        // Options should be added in the call to makeFilter, makeReader,
42        // or makeWriter so that the system can override them with those
43        // provided on the command line when applicable.
44        Options filterOptions;
45        filterOptions.add("step", 10);
46        Stage& filter = makeFilter("filters.decimation", reader,
47        filterOptions);
48
49        Stage& writer = makeWriter(m_output_file, filter, "writers.text"
50        );
51        writer.prepare(table);
52        writer.execute(table);
53
54        return 0;
55    }
55} // namespace pdal

```

In your kernel implementation, you will use a macro defined in `pdal_macros`. This macro registers the plugin with the `PluginManager`.

```
CREATE_SHARED_KERNEL(MyKernel, s_info);
```

To build up a processing pipeline in this example, we need to create two objects: the `pdal::PointTable` (page 479).

```
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:

```
1 cmake_minimum_required(VERSION 2.8.12)
2 project(KernelTutorial)
3
4 find_package(PDAL 1.6.0 REQUIRED CONFIG)
5
```

```

6 add_library(pdal_plugin_kernel_mykernel SHARED MyKernel.cpp)
7 target_link_libraries(pdal_plugin_kernel_mykernel PRIVATE ${PDAL_
8   ↪LIBRARIES})
9 target_include_directories(pdal_plugin_kernel_mykernel PRIVATE
                           ${PDAL_INCLUDE_DIRS})

```

## 12.1.8 Writing a reader

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**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.

```

1 // MyReader.hpp
2
3 #pragma once
4
5 #include <pdal/PointView.hpp>
6 #include <pdal/Reader.hpp>
7 #include <pdal/util/IStream.hpp>
8
9 namespace pdal
10 {
11     class MyReader : public Reader
12     {
13     public:
14         MyReader() : Reader() {};
15         std::string getName() const;
16
17     private:
18         std::unique_ptr<ILeStream> m_stream;
19         point_count_t m_index;
20         double m_scale_z;
21
22         virtual void addDimensions(PointLayoutPtr layout);
23         virtual void addArgs(ProgramArgs& args);
24         virtual void ready(PointTableRef table);

```

```
25     virtual point_count_t read(PointViewPtr view, point_count_t _  
26         ↪count);  
27     virtual void done(PointTableRef table);  
28 }
```

```
1     std::unique_ptr<ILeStream> m_stream;  
2     point_count_t m_index;  
3     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.

```
1     virtual void addDimensions(PointLayoutPtr layout);  
2     virtual void addArgs(ProgramArgs& args);  
3     virtual void ready(PointTableRef table);  
4     virtual point_count_t read(PointViewPtr view, point_count_t _  
5         ↪count);  
6     virtual void done(PointTableRef table);
```

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.

```
1 // MyReader.cpp  
2  
3 #include "MyReader.hpp"  
4 #include <pdal/util/ProgramArgs.hpp>  
5  
6 namespace pdal  
7 {  
8     static PluginInfo const s_info  
9     {  
10         "readers.myreader",  
11         "My Awesome Reader",  
12         "http://link/to/documentation"  
13     };  
14 }
```

```

15    CREATE_SHARED_STAGE(MyReader, s_info)
16
17    std::string MyReader::getName() const { return s_info.name; }
18
19    void MyReader::addArgs(ProgramArgs& args)
20    {
21        args.add("z_scale", "Z Scaling", m_scale_z, 1.0);
22    }
23
24    void MyReader::addDimensions(PointLayoutPtr layout)
25    {
26        layout->registerDim(Dimension::Id::X);
27        layout->registerDim(Dimension::Id::Y);
28        layout->registerDim(Dimension::Id::Z);
29        layout->registerOrAssignDim("MyData", ↵
30            Dimension::Type::Unsigned64);
31    }
32
33    void MyReader::ready(PointTableRef)
34    {
35        SpatialReference ref("EPSG:4385");
36        setSpatialReference(ref);
37    }
38
39    template <typename T>
40    T convert(const StringList& s, const std::string& name, size_t ↵
41        fieldno)
42    {
43        T output;
44        bool bConverted = Utils::fromString(s[fieldno], output);
45        if (!bConverted)
46        {
47            std::stringstream oss;
48            oss << "Unable to convert " << name << ", " << s[fieldno] <↵
49            ", to double";
50            throw pdal_error(oss.str());
51        }
52
53        return output;
54    }
55
56    point_count_t MyReader::read(PointViewPtr view, point_count_t ↵
57        count)
58    {
59        PointLayoutPtr layout = view->layout();

```

```

58     PointId nextId = view->size();
59     PointId idx = m_index;
60     point_count_t numRead = 0;
61
62     m_stream.reset(new ILeStream(m_filename));
63
64     size_t HEADERSIZE(1);
65     size_t skip_lines((std::max)(HEADERSIZE, (size_t)m_index));
66     size_t line_no(1);
67     for (std::string line; std::getline(*m_stream->stream(), line); line_no++)
68     {
69         if (line_no <= skip_lines)
70         {
71             continue;
72         }
73
74         // MyReader format: X::Y::Z::Data
75         StringList s = Utils::split2(line, ':');
76
77         unsigned long u64(0);
78         if (s.size() != 4)
79         {
80             std::stringstream oss;
81             oss << "Unable to split proper number of fields. Expected 4,
82             got "
83             << s.size();
84             throw pdal_error(oss.str());
85         }
86
87         std::string name("X");
88         view->setField(Dimension::Id::X, nextId, convert<double>(s,
89         name, 0));
90
91         name = "Y";
92         view->setField(Dimension::Id::Y, nextId, convert<double>(s,
93         name, 1));
94
95         name = "Z";
96         double z = convert<double>(s, name, 2) * m_scale_z;
97         view->setField(Dimension::Id::Z, nextId, z);
98
99         name = "MyData";
100        view->setField(layout->findProprietaryDim(name),
101                      nextId,
102                      convert<unsigned int>(s, name, 3));

```

```

101     nextId++;
102     if (m_cb)
103         m_cb(*view, nextId);
104     }
105     m_index = nextId;
106     numRead = nextId;
107
108     return numRead;
109 }
110
111 void MyReader::done(PointTableRef)
112 {
113     m_stream.reset();
114 }
115
116 } //namespace pdal

```

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.

```

1 static PluginInfo const s_info
2 {
3     "readers.myreader",
4     "My Awesome Reader",
5     "http://link/to/documentation"
6 };
7
8 CREATE_SHARED_STAGE(MyReader, s_info)

```

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.

```

1 void MyReader::addArgs(ProgramArgs& args)
2 {
3     args.add("z_scale", "Z Scaling", m_scale_z, 1.0);
4 }

```

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.

```

1 void MyReader::addDimensions(PointLayoutPtr layout)
2 {
3     layout->registerDim(Dimension::Id::X);
4     layout->registerDim(Dimension::Id::Y);
5     layout->registerDim(Dimension::Id::Z);
6     layout->registerOrAssignDim("MyData", ↴
7         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.

```

1 void MyReader::ready(PointTableRef)
2 {
3     SpatialReference ref("EPSG:4385");
4     setSpatialReference(ref);
5 }
```

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.

```

1 template <typename T>
2 T convert(const StringList& s, const std::string& name, size_t ↴
3 fieldno)
4 {
5     T output;
6     bool bConverted = Utils::fromString(s[fieldno], output);
7     if (!bConverted)
8     {
9         std::stringstream oss;
10        oss << "Unable to convert " << name << ", " << s[fieldno] < ↴
11        ", to double";
12        throw pdal_error(oss.str());
13    }
14
15    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.

```

1 PointLayoutPtr layout = view->layout();
2 PointId nextId = view->size();
3 PointId idx = m_index;
4 point_count_t numRead = 0;
5
6 m_stream.reset(new ILeStream(m_filename));

```

In preparation for reading the file, we prepare to skip some header lines. In our case, the header is only a single line.

```

1 size_t HEADERSIZE(1);
2 size_t skip_lines((std::max)(HEADERSIZE, (size_t)m_index));
3 size_t line_no(1);

```

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.

```

1     for (std::string line; std::getline(*m_stream->stream(), line); ↳line_no++)
2     {
3         if (line_no <= skip_lines)
4         {
5             continue;
6         }

```

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.

```

1     StringList s = Utils::split2(line, ':');
2
3     unsigned long u64(0);
4     if (s.size() != 4)
5     {
6         std::stringstream oss;
7         oss << "Unable to split proper number of fields. Expected 4,  

↳ got "
8             << s.size();
9         throw pdal_error(oss.str());
10    }

```

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.

```

1     std::string name("X");
2     view->setField(Dimension::Id::X, nextId, convert<double>(s,
3         ↵name, 0));
4
5     name = "Y";
6     view->setField(Dimension::Id::Y, nextId, convert<double>(s,
7         ↵name, 1));
8
9     name = "Z";
10    double z = convert<double>(s, name, 2) * m_scale_z;
11    view->setField(Dimension::Id::Z, nextId, z);
12
13    name = "MyData";
14    view->setField(layout->findProprietaryDim(name),
15                    nextId,
16                    convert<unsigned int>(s, name, 3));

```

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.

```

1     nextId++;
2     if (m_cb)
3         m_cb(*view, nextId);
4     }
5     m_index = nextId;
6     numRead = nextId;
7
8     return numRead;

```

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.

```

1     void MyReader::done(PointTableRef)
2     {
3         m_stream.reset();
4     }

```

## 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:

```
1 cmake_minimum_required(VERSION 2.8.12)
2 project(ReaderTutorial)
3
4 find_package(PDAL 1.6.0 REQUIRED CONFIG)
5
6 add_library(pdal_plugin_reader_myreader SHARED MyReader.cpp)
7 target_link_libraries(pdal_plugin_reader_myreader PRIVATE ${PDAL_
    ↴LIBRARIES})
8 target_include_directories(pdal_plugin_reader_myreader PRIVATE
    ${PDAL_INCLUDE_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.

Please download the [pipeline-myreader.json](#) (<https://github.com/PDAL/PDAL/blob/master/examples/writing-reader/pipeline-myreader.json?raw=true>) and [test-reader-input.txt](#) (<https://github.com/PDAL/PDAL/blob/master/examples/writing-reader/test-reader-input.txt?raw=true>) files.

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.

### 12.1.9 Writing a writer

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**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.

```
1 // MyWriter.hpp
2
3 #pragma once
4
5 #include <pdal/Writer.hpp>
6
7 #include <string>
8
9 namespace pdal{
10
11     typedef std::shared_ptr<std::ostream> FileStreamPtr;
12
13     class MyWriter : public Writer
14     {
15         public:
16             MyWriter()
17             { }
18
19             std::string getName() const;
20
21         private:
22             virtual void addArgs(ProgramArgs& args);
23             virtual void initialize();
24             virtual void ready(PointTableRef table);
25             virtual void write(const PointViewPtr view);
26             virtual void done(PointTableRef table);
27
28             std::string m_filename;
29             std::string m_newline;
30             std::string m_datafield;
31             int m_precision;
32
33             FileStreamPtr m_stream;
34             Dimension::Id m_dataDim;
35     };
36
37 } // namespace pdal
```

In your MyWriter class, you will declare the necessary methods and variables needed to make the writer work and meet the plugin specifications.

```
1     typedef std::shared_ptr<std::ostream> FileStreamPtr;
```

FileStreamPtr is defined to make the declaration of the stream easier to manage later on.

```
std::string getName() const;
```

Every stage must return a unique name.

```
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.

```
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.

```
1 // MyWriter.cpp
2
3 #include "MyWriter.hpp"
4 #include <pdal/util/FileUtils.hpp>
5 #include <pdal/util/ProgramArgs.hpp>
6
7 namespace pdal
8 {
9     static PluginInfo const s_info
10    {
11        "writers.mywriter",
12        "My Awesome Writer",
13        "http://path/to/documentation"
14    };
}
```

```
15 CREATE_SHARED_STAGE(MyWriter, s_info);
16
17 std::string MyWriter::getName() const { return s_info.name; }
18
19
20 struct FileStreamDeleter
21 {
22     template <typename T>
23     void operator() (T* ptr)
24     {
25         if (ptr)
26         {
27             ptr->flush();
28             FileUtils::closeFile(ptr);
29         }
30     }
31 };
32
33 void MyWriter::addArgs(ProgramArgs& args)
34 {
35     // setPositional() Makes the argument required.
36     args.add("filename", "Output filename", m_filename).
37     ↪ setPositional();
37     args.add("newline", "Line terminator", m_newline, "\n");
38     args.add("datafield", "Data field", m_datafield, "UserData");
39     args.add("precision", "Precision", m_precision, 3);
40 }
41
42 void MyWriter::initialize()
43 {
44     m_stream = FileStreamPtr(FileUtils::createFile(m_filename, true),
45         FileStreamDeleter());
46     if (!m_stream)
47     {
48         std::stringstream out;
49         out << "writers.mywriter couldn't open '" << m_filename <<
50         "' for output.";
51         throw pdal_error(out.str());
52     }
53 }
54
55
56 void MyWriter::ready(PointTableRef table)
57 {
58     m_stream->precision(m_precision);
59     *m_stream << std::fixed;
```

```

61     Dimension::Id d = table.layout()->findDim(m_datafield);
62     if (d == Dimension::Id::Unknown)
63     {
64         std::ostringstream oss;
65         oss << "Dimension not found with name '" << m_datafield << "'";
66         throw pdal_error(oss.str());
67     }
68
69     m_dataDim = d;
70
71     *m_stream << "#X:Y:Z:MyData" << m_newline;
72 }
73
74
75 void MyWriter::write(PointViewPtr view)
76 {
77     for (PointId idx = 0; idx < view->size(); ++idx)
78     {
79         double x = view->getFieldAs<double>(Dimension::Id::X, idx);
80         double y = view->getFieldAs<double>(Dimension::Id::Y, idx);
81         double z = view->getFieldAs<double>(Dimension::Id::Z, idx);
82         unsigned int myData = 0;
83
84         if (!m_datafield.empty())
85             myData = (int)(view->getFieldAs<double>(m_dataDim, idx) +_
86             ↵0.5);
87
88         *m_stream << x << ":" << y << ":" << z << ":"
89         << myData << m_newline;
90     }
91 }
92
93
94 void MyWriter::done(PointTableRef)
95 {
96     m_stream.reset();
97 }
98 }
```

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.

```

1  struct FileStreamDeleter
2  {
3      template <typename T>
4      void operator() (T* ptr)
5      {
6          if (ptr)
7          {
8              ptr->flush();
9              FileUtils::closeFile(ptr);
10         }
11     }
12 };

```

This struct is used for helping with the FileStreamPtr for cleanup.

```

1  void MyWriter::addArgs(ProgramArgs& args)
2  {
3      // setPositional() Makes the argument required.
4      args.add("filename", "Output filename", m_filename).
5      ↳setPositional();
6      args.add("newline", "Line terminator", m_newline, "\n");
7      args.add("datafield", "Data field", m_datafield, "UserData");
8      args.add("precision", "Precision", m_precision, 3);
}

```

This method defines the arguments the writer provides and binds them to private variables.

```

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.

```

1  void MyWriter::ready(PointTableRef table)
2  {
3      m_stream->precision(m_precision);
4      *m_stream << std::fixed;
5
6      Dimension::Id d = table.layout()->findDim(m_datafield);
7      if (d == Dimension::Id::Unknown)
8      {
9          std::ostringstream oss;
10         oss << "Dimension not found with name '" << m_datafield << "'";
11         throw pdal_error(oss.str());
12     }
13
14     m_dataDim = d;
15
16     *m_stream << "#X:Y:Z:MyData" << m_newline;
17 }
```

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.

```

1  void MyWriter::write(PointViewPtr view)
2  {
3      for (PointId idx = 0; idx < view->size(); ++idx)
4      {
5          double x = view->getFieldAs<double>(Dimension::Id::X, idx);
6          double y = view->getFieldAs<double>(Dimension::Id::Y, idx);
7          double z = view->getFieldAs<double>(Dimension::Id::Z, idx);
8          unsigned int myData = 0;
9
10         if (!m_datafield.empty())
11             myData = (int)(view->getFieldAs<double>(m_dataDim, idx) +_
12             0.5);
13
14         *m_stream << x << ":" << y << ":" << z << ":"
15             << myData << m_newline;
16     }
17 }
```

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.

```
1 void MyWriter::done(PointTableRef)
2 {
3     m_stream.reset();
4 }
```

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:

```
1 cmake_minimum_required(VERSION 2.8.12)
2 project(WriterTutorial)
3
4 find_package(PDAL 1.6.0 REQUIRED CONFIG)
5
6 add_library(pdal_plugin_writer_mywriter SHARED MyWriter.cpp)
7 target_link_libraries(pdal_plugin_writer_mywriter PRIVATE ${PDAL_
    ↴LIBRARIES})
8 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 convert it to our output format. For this example, use `interesting.las` (<https://github.com/PDAL/PDAL/blob/master/test/data/interesting.las?raw=true>), and run it through `pipeline-mywriter.json`

(<https://github.com/PDAL/PDAL/blob/master/examples/writing-writer/pipeline-mywriter.json?raw=true>).

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.

## 12.1.10 CMake

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**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 404).

---

**Note:** We assume you have either *built or installed* (page 392) PDAL.

---

### Basic CMake configuration

Begin by creating a file named `CMakeLists.txt` that contains:

```
cmake_minimum_required(VERSION 2.8)
project(MY_PDAL_PROJECT)
find_package(PDAL 1.0.0 REQUIRED CONFIG)
include_directories(${PDAL_INCLUDE_DIRS})
link_directories(${PDAL_LIBRARY_DIRS})
add_definitions(${PDAL_DEFINITIONS})
set(CMAKE_CXX_FLAGS "-std=c++11")
add_executable(tutorial tutorial.cpp)
target_link_libraries(tutorial PRIVATE ${PDAL_LIBRARIES})
```

### CMakeLists explained

```
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.

```
project(MY_PDAL_PROJECT)
```

The CMake *project* command names your project and sets a number of useful CMake variables.

```
find_package(PDAL 1.0.0 REQUIRED CONFIG)
```

We next ask CMake to locate the PDAL package, requiring version 1.0.0 or higher.

```
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

```
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.

```
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*.

```
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:

```
$ cd /PATH/TO/MY/PDAL/PROJECT  
$ mkdir build
```

Run cmake from within the build directory:

```
$ cd build  
$ cmake ..
```

Now, build the project:

```
$ make
```

The project is now built and ready to run:

```
$ ./tutorial
```

## 12.2 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.

### 12.2.1 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:

```
#pragma once
```

### 12.2.2 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



(<http://hobu.co>) **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) (<https://github.com/hobu>) founded the project, and he provides project leadership and software development. [Andrew Bell](https://github.com/abellgithub) (<https://github.com/abellgithub>) has contributed design, refactoring, and new feature development of PDAL over the past couple of years.

[Michael Gerlek](https://github.com/mpgerlek) ([http://github.com/mpgerlek](https://github.com/mpgerlek)) helped bootstrap PDAL by providing its first design, basic primitive objects, and first stage implementations.



(<http://radiantsolutions.com>) Bradley Chambers (<https://github.com/chambbj>) from [RadiantSolutions](http://radiantsolutions.com/) (<http://radiantsolutions.com/>) has contributed numerous features and capabilities to the PDAL project, including *Poisson sampling* (page 194) and *Progressive Morphological Filters* (page 264). He is also a prolific *Tutorials* (page 237) writer.

## Funding Contributors



(<http://www.erdc.usace.army.mil/Locations/CRREL.aspx>) The US Army Corps of Engineers Remote Sensing / GIS Center of Expertise at [CRREL](http://www.erdc.usace.army.mil/Locations/CRREL.aspx) (<http://www.erdc.usace.army.mil/Locations/CRREL.aspx>) sponsors development of PDAL for its use in point cloud data management systems. [CRREL](http://www.erdc.usace.army.mil/Locations/CRREL.aspx) (<http://www.erdc.usace.army.mil/Locations/CRREL.aspx>)'s [GRiD](http://lidar.io/about.html) (<http://lidar.io/about.html>) project manages LiDAR and point cloud data for a multitude of U.S. Army Corps missions. Find out more about GRiD in this [LiDAR Magazine article](http://www.lidarmag.com/content/view/11343/198/)



(<http://www.lidarmag.com/content/view/11343/198/>).



(<http://www.nsf.gov>)

(<http://www.uh.edu>) **NSF**

(<http://www.nsf.gov>), in collaboration with **Dr. Craig Glennie**

(<http://www.cive.uh.edu/faculty/glennie>) at the **University of Houston** (<http://www.uh.edu>)

supports PDAL with funding support to develop and enhance statistical methods, transformation operations, tutorial and example development, and **PCL** (<http://pointclouds.org>) integration.

### 12.2.3 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>)
- **Doxxygen** (<http://www.stack.nl/~dimitri/doxygen/>)
- **Latex** (<https://en.wikipedia.org/wiki/LaTeX>)
- **dvipng** (<https://en.wikipedia.org/wiki/Dvipng>)

#### 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/) (<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) (<http://www.stack.nl/~dimitri/doxygen/download.html>). If you are on Max OS X and use [homebrew](http://mxcl.github.io/homebrew/) (<http://mxcl.github.io/homebrew/>), you can install doxygen with a simple `brew install doxygen`.

## Latex

[Latex](https://en.wikipedia.org/wiki/LaTeX) (<https://en.wikipedia.org/wiki/LaTeX>) and [pdflatex](https://www.tug.org/applications/pdftex/) (<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) (<https://en.wikipedia.org/wiki/Dvipng>) to turn [Latex](https://en.wikipedia.org/wiki/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) (<https://github.com/michaeljones/breathe>) and [Sphinx](http://sphinx-doc.org/) (<http://sphinx-doc.org/>).

---

**Note:** For a full build of the [C++ API](#) (page 453) documentation, you need to make doxygen to have it build its XML output which is consumed by [Breathe](https://github.com/michaeljones/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 [Travis](#) (page 452). 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/>).

---

**Note:** The website is regenerated and pushed only on the `after_success` [Travis](#) (page 452) call. If the tests aren't passing, the website won't be updated.

---

### 12.2.4 Building Docker Containers for PDAL

PDAL's [repository](#) (page 14) is linked to [DockerHub](https://hub.docker.com/r/pdal/pdal/) (<https://hub.docker.com/r/pdal/pdal/>) for automatic building of [Docker](https://www.docker.com/) (<https://www.docker.com/>) containers. PDAL keeps three Docker containers current.

- `pdal/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 441) container, but the [Dependencies](#) (page 441) container is not pinned to specific Xenial 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 452) testing by Travis. It is built using the Dockerfile at <https://github.com/PDAL/PDAL/blob/master/scripts/docker/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/) (<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 Xenial](#)

(<http://releases.ubuntu.com/16.04/>). 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

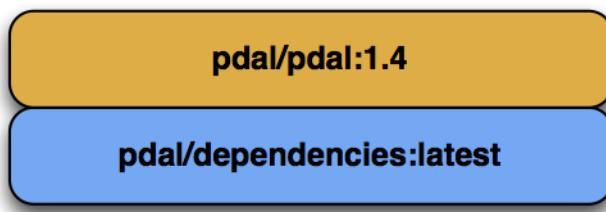


Fig. 12.1: Docker containers on maintenance branch correspond to major PDAL releases.

### 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 442) Docker container for any production-oriented operations. Only use the latest one to test or prototype a latest, unreleased feature.

```
$ git tag -f docker-master  
$ git push origin refs/tags/docker-master -f
```

### 12.2.5 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.



Fig. 12.2: The `pdal/pdal:latest` branch is current relative to the `docker-master` branch in GitHub.

## 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](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.

## 12.2.6 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 25) and known plugins.
- We use the [Google C++ Test Framework](https://code.google.com/p/googletest/) (<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 sec
    Start 5: pdal_kdindex_test
```

```

5/61 Test #5: pdal_kdindex_test ..... Passed 0.
↳ 03 sec
    Start 6: pdal_log_test
6/61 Test #6: pdal_log_test ..... Passed 0.
↳ 03 sec
    Start 7: pdal_metadata_test
7/61 Test #7: pdal_metadata_test ..... Passed 0.
↳ 02 sec
    Start 8: pdal_options_test
8/61 Test #8: pdal_options_test ..... Passed 0.
↳ 02 sec
    Start 9: pdal_pdalutils_test
9/61 Test #9: pdal_pdalutils_test ..... Passed 0.
↳ 02 sec
    Start 10: pdal_pipeline_manager_test
10/61 Test #10: pdal_pipeline_manager_test ..... Passed 0.
↳ 03 sec
    Start 11: pdal_point_view_test
11/61 Test #11: pdal_point_view_test ..... Passed 2.
↳ 03 sec
    Start 12: pdal_point_table_test
12/61 Test #12: pdal_point_table_test ..... Passed 0.
↳ 03 sec
    Start 13: pdal_spatial_reference_test
13/61 Test #13: pdal_spatial_reference_test ..... Passed 0.
↳ 07 sec
    Start 14: pdal_support_test
14/61 Test #14: pdal_support_test ..... Passed 0.
↳ 02 sec
    Start 15: pdal_user_callback_test
15/61 Test #15: pdal_user_callback_test ..... Passed 0.
↳ 02 sec
    Start 16: pdal_utils_test
16/61 Test #16: pdal_utils_test ..... Passed 0.
↳ 02 sec
    Start 17: pdal_lazperf_test
17/61 Test #17: pdal_lazperf_test ..... Passed 0.
↳ 04 sec
    Start 18: pdal_io_bpf_test
18/61 Test #18: pdal_io_bpf_test ..... Passed 0.
↳ 20 sec
    Start 19: pdal_io_buffer_test
19/61 Test #19: pdal_io_buffer_test ..... Passed 0.
↳ 02 sec
    Start 20: pdal_io_faux_test
20/61 Test #20: pdal_io_faux_test ..... Passed 0.
↳ 04 sec

```

```
    Start 21: pdal_io_ilvis2_test
21/61 Test #21: pdal_io_ilvis2_test ..... Passed 0.
↳ 06 sec
    Start 22: pdal_io_las_reader_test
22/61 Test #22: pdal_io_las_reader_test ..... Passed 0.
↳ 49 sec
    Start 23: pdal_io_las_writer_test
23/61 Test #23: pdal_io_las_writer_test ..... Passed 2.
↳ 27 sec
    Start 24: pdal_io_optech_test
24/61 Test #24: pdal_io_optech_test ..... Passed 0.
↳ 03 sec
    Start 25: pdal_io_ply_reader_test
25/61 Test #25: pdal_io_ply_reader_test ..... Passed 0.
↳ 03 sec
    Start 26: pdal_io_ply_writer_test
26/61 Test #26: pdal_io_ply_writer_test ..... Passed 0.
↳ 02 sec
    Start 27: pdal_io_qfit_test
27/61 Test #27: pdal_io_qfit_test ..... Passed 0.
↳ 03 sec
    Start 28: pdal_io_sbet_reader_test
28/61 Test #28: pdal_io_sbet_reader_test ..... Passed 0.
↳ 04 sec
    Start 29: pdal_io_sbet_writer_test
29/61 Test #29: pdal_io_sbet_writer_test ..... Passed 0.
↳ 03 sec
    Start 30: pdal_io_terrasonic_test
30/61 Test #30: pdal_io_terrasonic_test ..... Passed 0.
↳ 03 sec
    Start 31: pdal_filters_chipper_test
31/61 Test #31: pdal_filters_chipper_test ..... Passed 0.
↳ 03 sec
    Start 32: pdal_filters_colorization_test
32/61 Test #32: pdal_filters_colorization_test ..... Passed 11.
↳ 40 sec
    Start 33: pdal_filters_crop_test
33/61 Test #33: pdal_filters_crop_test ..... Passed 0.
↳ 04 sec
    Start 34: pdal_filters_decimation_test
34/61 Test #34: pdal_filters_decimation_test ..... Passed 0.
↳ 02 sec
    Start 35: pdal_filters_divider_test
35/61 Test #35: pdal_filters_divider_test ..... Passed 0.
↳ 03 sec
    Start 36: pdal_filters_ferry_test
36/61 Test #36: pdal_filters_ferry_test ..... Passed 0.
↳ 04 sec
```

```

        Start 37: pdal_filters_merge_test
37/61 Test #37: pdal_filters_merge_test ..... Passed 0.
↪03 sec
        Start 38: pdal_filters_reprojection_test
38/61 Test #38: pdal_filters_reprojection_test ..... Passed 0.
↪03 sec
        Start 39: pdal_filters_range_test
39/61 Test #39: pdal_filters_range_test ..... Passed 0.
↪05 sec
        Start 40: pdal_filters_randomize_test
40/61 Test #40: pdal_filters_randomize_test ..... Passed 0.
↪02 sec
        Start 41: pdal_filters_sort_test
41/61 Test #41: pdal_filters_sort_test ..... Passed 0.
↪39 sec
        Start 42: pdal_filters_splitter_test
42/61 Test #42: pdal_filters_splitter_test ..... Passed 0.
↪03 sec
        Start 43: pdal_filters_stats_test
43/61 Test #43: pdal_filters_stats_test ..... Passed 0.
↪03 sec
        Start 44: pdal_filters_transformation_test
44/61 Test #44: pdal_filters_transformation_test ... Passed 0.
↪03 sec
        Start 45: pdal_merge_test
45/61 Test #45: pdal_merge_test ..... Passed 0.
↪07 sec
        Start 46: pc2pc_test
46/61 Test #46: pc2pc_test ..... Passed 0.
↪15 sec
        Start 47: xml_schema_test
47/61 Test #47: xml_schema_test ..... Passed 0.
↪02 sec
        Start 48: pdal_filters_attribute_test
48/61 Test #48: pdal_filters_attribute_test ..... Passed 0.
↪09 sec
        Start 49: pdal_plugins_cpd_kernel_test
49/61 Test #49: pdal_plugins_cpd_kernel_test ..... ***Exception: ↵
↪Other 0.08 sec
        Start 50: hexbintest
50/61 Test #50: hexbintest ..... Passed 0.
↪03 sec
        Start 51: icetest
51/61 Test #51: icetest ..... Passed 0.
↪04 sec
        Start 52: mrsidtest
52/61 Test #52: mrsidtest ..... Passed 0.
↪06 sec

```

```
Start 53: pdal_io_nitf_writer_test
53/61 Test #53: pdal_io_nitf_writer_test ..... Passed 0.
↳ 08 sec
    Start 54: pdal_io_nitf_reader_test
54/61 Test #54: pdal_io_nitf_reader_test ..... Passed 0.
↳ 04 sec
    Start 55: ocitest
55/61 Test #55: ocitest ..... ***Failed 0.
↳ 06 sec
    Start 56: pcltest
56/61 Test #56: pcltest ..... Passed 0.
↳ 28 sec
    Start 57: pgpointcloudtest
57/61 Test #57: pgpointcloudtest ..... Passed 1.
↳ 66 sec
    Start 58: plangtest
58/61 Test #58: plangtest ..... Passed 0.
↳ 14 sec
    Start 59: python_predicate_test
59/61 Test #59: python_predicate_test ..... Passed 0.
↳ 16 sec
    Start 60: python_programmable_test
60/61 Test #60: python_programmable_test ..... Passed 0.
↳ 15 sec
    Start 61: sqlitetest
61/61 Test #61: sqlitetest ..... Passed 0.
↳ 55 sec

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:

```
$ 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)
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)
[ RUN      ] BPFTest.flex
[ OK      ] BPFTest.flex (8 ms)
[ RUN      ] BPFTest.flex2
[ OK      ] BPFTest.flex2 (7 ms)
[ RUN      ] BPFTest.outputdims
[ OK      ] BPFTest.outputdims (14 ms)
[-----] 20 tests from BPFTest (185 ms total)

[-----] Global test environment tear-down
[=====] 20 tests from 1 test case ran. (185 ms total)
[ PASSED ] 20 tests.
```

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 PostgreSQLPointCloud 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-envvars.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).

### 12.2.7 Continuous Integration

PDAL *regression tests* (page 444) are run on a per-commit basis by at least two continuous integration platforms.

#### Status



#### Travis

The Travis continuous integration platform runs the PDAL test suite on Alpine Linux. The build status and other supporting information can be found at <https://travis-ci.org/PDAL/PDAL>. Its configuration can be found at <https://github.com/PDAL/PDAL/blob/master/.travis.yml>. All administrators of the GitHub *PDAL* group have rights to modify the Travis configuration.

It uses the `alpine:edge` Docker image found at [https://hub.docker.com/\\_/alpine/](https://hub.docker.com/_/alpine/) as a base platform. If you want to add new functionality based on a dependency, you will need to ensure that the dependency is available in <https://pkgs.alpinelinux.org/packages> and update the Travis configuration YAML accordingly.

#### AppVeyor

PDAL uses the AppVeyor continuous integration platform to run the PDAL compilation and test suite on Windows. The build status and other supporting information can be found at <https://ci.appveyor.com/project/hobu/pdal>. Its configuration can be found at <https://github.com/PDAL/PDAL/blob/master/appveyor.yml>. All administrators of the GitHub *PDAL* group have rights to modify the AppVeyor configuration.

Howard Butler (<http://github.com/hobu>) currently pays the bill to run in the AppVeyor upper performance processing tier. The AppVeyor configuration depends on *Conda* (page 16) for

dependencies. If you want to add new test functionality based on a dependency, you will need to update [Conda](#) (page 16) with a new package to do so.

## 12.3 API

PDAL is a C++ library, and its primary API is in that language. There is also a *Python* (page 233) 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 25) and users looking for documentation on how to contribute to PDAL should look [here](#) (page 381).

---

### 12.3.1 C++ API

`pdal::BOX2D`

`class pdal::BOX2D`

*BOX2D* (page 453) represents a two-dimensional box with double-precision bounds.

Subclassed by *pdal::BOX3D* (page 457)

#### Public Functions

`BOX2D()`

Construct an “empty” bounds box.

`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.

**Return** Whether the bounds box is empty.

**bool valid() const**

Determine whether a bounds box has had any bounds set.

**Return** Whether the bounds box is valid.

**void clear()**

Clear the bounds box to an empty state.

*BOX2D* (page 453) &**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 453) &**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.

**bool contains** (double *x*, double *y*) **const**

Determine if a bounds box contains a point.

**Return** Whether both dimensions are equal to or less than the maximum box values and equal to or more than the minimum box values.

#### Parameters

- *x*: X dimension value.
- *y*: Y dimension value.

**bool equal** (**const** *BOX2D* (page 453) &*other*) **const**

Determine if the bounds of this box are the same as that of another box.

Empty bounds boxes are always equal.

**Return** `true` if the provided box has equal limits to this box, `false` otherwise.

#### Parameters

- *other*: Bounds box to check for equality.

bool **operator==** (*BOX2D* (page 453) **const** &*other*) **const**

Determine if the bounds of this box are the same as that of another box.

Empty bounds boxes are always equal.

**Return** `true` if the provided box has equal limits to this box, `false` otherwise.

#### Parameters

- *other*: Bounds box to check for equality.

bool **operator!=** (*BOX2D* (page 453) **const** &*other*) **const**

Determine if the bounds of this box are different from that of another box.

Empty bounds boxes are never unequal.

**Return** `true` if the provided box has limits different from this box, `false` otherwise.

#### Parameters

- *other*: Bounds box to check for inequality.

*BOX2D* (page 453) **&grow** (**const** *BOX2D* (page 453) &*other*)

Expand this box to contain another box.

#### Parameters

- *other*: Box that this box should contain.

void **clip** (**const** *BOX2D* (page 453) &*other*)

Clip this bounds box by another so it will be contained by the other box.

#### Parameters

- *other*: Clipping box for this box.

bool **contains** (**const** *BOX2D* (page 453) &*other*) **const**

Determine if another bounds box is contained in this bounds box.

Equal limits are considered to be contained.

**Return** `true` if the provided box is contained in this box, `false` otherwise.

#### Parameters

- *other*: Bounds box to check for containment.

`bool overlaps (const BOX2D (page 453) &other) const`  
Determine if another box overlaps this box.

**Return** Whether the provided box overlaps this box.

#### Parameters

- *other*: Box to test for overlap.

`std::string toBox (uint32_t precision = 8) const`  
Convert this box to a string suitable for use in SQLite.

**Return** String format of this box.

#### Parameters

- *precision*: Precision for output [default: 8]

`std::string toWKT (uint32_t precision = 8) const`  
Convert this box to a well-known text string.

**Return** String format of this box.

#### Parameters

- *precision*: Precision for output [default: 8]

`std::string toGeoJSON (uint32_t precision = 8) const`  
Convert this box to a GeoJSON text string.

**Return** String format of this box.

#### Parameters

- *precision*: Precision for output [default: 8]

### Public Members

`double minx`  
Minimum X value.

`double maxx`  
Maximum X value.

`double miny`  
Minimum Y value.

`double maxy`  
Maximum Y value.

## Public Static Functions

**const** *BOX2D* (page 453) **&getDefaultSpatialExtent()**

Return a statically-allocated Bounds extent that represents infinity.

**Return** A bounds box with infinite bounds,

**class** *pdal::BOX3D*

*BOX3D* (page 457) represents a three-dimensional box with double-precision bounds.

Inherits from *pdal::BOX2D* (page 453)

## Public Functions

**BOX3D ()**

Clear the bounds box to an empty state.

**BOX3D (const *BOX3D* (page 457) &*box*)**

**BOX3D (const *BOX2D* (page 453) &*box*)**

**BOX3D (double *minx*, double *miny*, double *minz*, double *maxx*, double *maxy*, double *maxz*)**

Construct and initialize a bounds box.

### Parameters

- *minx*: Minimum X value.
- *miny*: Minimum Y value.
- *minz*: Minimum Z value.
- *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).

**Return** Whether the bounds box is empty.

**bool *valid () const***

Determine whether a bounds box has had any bounds set.

**Return** if the bounds box is not empty

`BOX3D` (page 457) &`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.

`bool contains(double x, double y, double z) const`

Determine if a bounds box contains a point.

**Return** Whether both dimensions are equal to or less than the maximum box values and equal to or more than the minimum box values.

### Parameters

- *x*: X dimension value.
- *y*: Y dimension value.
- *z*: Z dimension value.

`bool contains(const BOX3D (page 457) &other) const`

Determine if another bounds box is contained in this bounds box.

Equal limits are considered to be contained.

**Return** `true` if the provided box is contained in this box, `false` otherwise.

### Parameters

- *other*: Bounds box to check for containment.

`bool equal (const BOX3D (page 457) &other) const`

Determine if the bounds of this box are the same as that of another box.

Empty bounds boxes are always equal.

**Return** `true` if the provided box has equal limits to this box, `false` otherwise.

#### Parameters

- `other`: Bounds box to check for equality.

`bool operator==(BOX3D (page 457) const &rhs) const`

Determine if the bounds of this box are the same as that of another box.

Empty bounds boxes are always equal.

**Return** `true` if the provided box has equal limits to this box, `false` otherwise.

#### Parameters

- `other`: Bounds box to check for equality.

`bool operator!=(BOX3D (page 457) const &rhs) const`

Determine if the bounds of this box are different from that of another box.

Empty bounds boxes are never unequal.

**Return** `true` if the provided box has limits different from this box, `false` otherwise.

#### Parameters

- `other`: Bounds box to check for inequality.

`BOX3D (page 457) &grow(const BOX3D (page 457) &other)`

Expand this box to contain another box.

#### Parameters

- `other`: Box that this box should contain.

`BOX3D (page 457) &grow(double dist)`

Expand this box by a specified amount.

#### Parameters

- `dist`: Distance by which box should be expanded.

`void clip(const BOX3D (page 457) &other)`

Clip this bounds box by another so it will be contained by the other box.

#### Parameters

- `other`: Clipping box for this box.

`bool overlaps (const BOX3D (page 457) &other) const`  
Determine if another box overlaps this box.

**Return** Whether the provided box overlaps this box.

#### Parameters

- *other*: Box to test for overlap.

*BOX2D* (page 453) `to2d () const`  
Convert this box to 2-dimensional bounding box.

**Return** Bounding box with Z dimension stripped.

`std::string toBox (uint32_t precision = 8) const`  
Convert this box to a string suitable for use in SQLite.

**Return** String format of this box.

#### Parameters

- *precision*: Precision for output [default: 8]

`std::string toWKT (uint32_t precision = 8) const`  
Convert this box to a well-known text string.

**Return** String format of this box.

#### Parameters

- *precision*: Precision for output [default: 8]

### Public Members

`double minz`  
Minimum Z value.

`double maxz`  
Maximum Z value.

### Public Static Functions

`const BOX3D (page 457) &getDefaultSpatialExtent ()`  
Return a statically-allocated Bounds extent that represents infinity.

**Return** A bounds box with infinite bounds,

**pdal::Charbuf****class pdal::Charbuf**

Allow a data buffer to be used at a std::streambuf.

Inherits from streambuf

**Public Functions****PDAL\_DLL Charbuf()**

Construct an empty *Charbuf* (page 461).

**PDAL\_DLL Charbuf(std::vector<char> &v, pos\_type bufOffset = 0)**

Construct a *Charbuf* (page 461) that wraps a byte vector.

**Parameters**

- v: Byte vector to back streambuf.
- bufOffset: Offset in vector (ignore bytes before offset).

**PDAL\_DLL Charbuf(char \*buf, size\_t count, pos\_type bufOffset = 0)**

Construct a *Charbuf* (page 461) 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 461).

**Parameters**

- buf: Buffer to back streambuf.
- count: Size of buffer.
- bufOffset: Offset in vector (ignore bytes before offset).

**pdal::Dimension****namespace pdal::Dimension**

## Typedefs

```
typedef std::vector<Detail> DetailList
```

## Enums

```
enum BaseType
```

*Values:*

```
None = 0x000
```

```
Signed = 0x100
```

```
Unsigned = 0x200
```

```
Floating = 0x400
```

```
enum Type
```

*Values:*

```
None = 0
```

```
Unsigned8 = unsigned(BaseType::Unsigned) | 1
```

```
Signed8 = unsigned(BaseType::Signed) | 1
```

```
Unsigned16 = unsigned(BaseType::Unsigned) | 2
```

```
Signed16 = unsigned(BaseType::Signed) | 2
```

```
Unsigned32 = unsigned(BaseType::Unsigned) | 4
```

```
Signed32 = unsigned(BaseType::Signed) | 4
```

```
Unsigned64 = unsigned(BaseType::Unsigned) | 8
```

```
Signed64 = unsigned(BaseType::Signed) | 8
```

```
Float = unsigned(BaseType::Floating) | 4
```

```
Double = unsigned(BaseType::Floating) | 8
```

## Functions

*BaseType* (page 462) **fromName** (std::string *name*)

std::string **toName** (*BaseType* (page 462) *b*)

std::size\_t **size** (*Type* (page 462) *t*)

*BaseType* (page 462) **base** (*Type* (page 462) *t*)

`std::string interpretationName (Type (page 462) dimtype)`

Get a string representation of a datatype.

**Return** String representation of dimension type.

#### Parameters

- *dimtype*: *Dimension* (page 461) type.

*Type* (page 462) **type** (`std::string s`)

Get the type corresponding to a type name.

**Return** Corresponding type enumeration value.

#### Parameters

- *s*: Name of type.

`std::size_t extractName (const std::string &s, std::string::size_type p)`

Extract a dimension name of a string.

*Dimension* (page 461) names start with an alpha and continue with numbers or underscores.

**Return** Number of characters in the extracted name.

#### Parameters

- *s*: String from which to extract dimension name.
- *p*: Position at which to start extracting.

`std::istream &operator>> (std::istream &in, Dimension (page 461)::Type (page 462) &type)`

`std::ostream &operator<< (std::ostream &out, const Dimension (page 461)::Type (page 462) &type)`

## Variables

`const int COUNT = (std::numeric_limits<uint16_t>::max)()`

`const int PROPRIETARY = 0xF000`

## `pdal::Extractor`

`class pdal::Extractor`

Buffer wrapper for input of binary data from a buffer.

Subclassed by pdal::BeExtractor, pdal::LeExtractor, pdal::SwitchableExtractor

## Public Functions

**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.

**operator bool ()**

Determine if the buffer is good.

**Return** Whether the buffer is good.

**void seek (std::size\_t pos)**

Seek to a position in the buffer.

### Parameters

- pos: Position to seek in buffer.

**void skip (std::size\_t cnt)**

Advance buffer position.

### Parameters

- cnt: Number of bytes to skip in buffer.

**size\_t position () const**

Return the get position of buffer.

**Return** Get position.

**bool good () const**

Determine whether the extractor is good (the get pointer is in the buffer).

**Return** Whether the get pointer is valid.

```
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.

```
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.

```
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.

```
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.

```
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 463) &**operator>>** (uint8\_t &*v*) = 0

```
virtual Extractor (page 463) &operator>> (int8_t &v) = 0
virtual Extractor (page 463) &operator>> (uint16_t &v) = 0
virtual Extractor (page 463) &operator>> (int16_t &v) = 0
virtual Extractor (page 463) &operator>> (uint32_t &v) = 0
virtual Extractor (page 463) &operator>> (int32_t &v) = 0
virtual Extractor (page 463) &operator>> (uint64_t &v) = 0
virtual Extractor (page 463) &operator>> (int64_t &v) = 0
virtual Extractor (page 463) &operator>> (float &v) = 0
virtual Extractor (page 463) &operator>> (double &v) = 0
```

**pdal::FileUtils**

```
namespace pdal::FileUtils
```

## Functions

**PDAL\_DLL std::istream \* pdal::FileUtils::openFile(std::string const & f)**  
Open an existing file for reading.

**Return** Pointer to opened stream.

### Parameters

- filename: Filename.
- asBinary: Read as binary file (don't convert /r/n to /n)

**PDAL\_DLL std::ostream \* pdal::FileUtils::createFile(std::string const & f)**  
Create a file and open for writing.

**Return** Pointer to opened stream.

### Parameters

- filename: Filename.
- asBinary: Write as binary file (don't convert /n to /r/n)

**PDAL\_DLL bool pdal::FileUtils::directoryExists(const std::string & dirname)**  
Determine if a directory exists.

**Return** Whether a directory exists.

**Parameters**

- dirname: Name of directory.

**PDAL\_DLL bool pdal::FileUtils::createDirectory(const std::string & dirname)**  
Create a directory.

**Return** Whether the directory was created.

**Parameters**

- dirname: Directory name.

**PDAL\_DLL bool pdal::FileUtils::createDirectories(const std::string & path)**  
Create all directories in the provided path.

**Return** on failure

**Parameters**

- dirname: Path name.

**PDAL\_DLL void pdal::FileUtils::deleteDirectory(const std::string & dirname)**  
Delete a directory and its contents.

**Parameters**

- dirname: Directory name.

**PDAL\_DLL std::vector< std::string > pdal::FileUtils::directoryList(const std::string & dirname)**  
List the contents of a directory.

**Return** List of entries in the directory.

**Parameters**

- dirname: Name of directory to list.

**PDAL\_DLL void pdal::FileUtils::closeFile(std::ostream \* ofs)**  
Close a file created with createFile.

**Parameters**

- ofs: Pointer to stream to close.

**PDAL\_DLL void pdal::FileUtils::closeFile(std::istream \* ifs)**  
Close a file created with openFile.

**Parameters**

- ifs: Pointer to stream to close.

```
PDAL_DLL bool pdal::FileUtils::deleteFile(const std::string & filename)
Delete a file.
```

**Return** true if successful, false otherwise

#### Parameters

- filename: Name of file to delete.

```
PDAL_DLL void pdal::FileUtils::renameFile(const std::string & dest, const std::string & src)
Rename a file.
```

#### Parameters

- dest: Desired filename.
- src: Source filename.

```
PDAL_DLL bool pdal::FileUtils::fileExists(const std::string & filename)
Determine if a file exists.
```

**Return** Whether the file exists.

#### Parameters

- filename.:

```
PDAL_DLL uintmax_t pdal::FileUtils::fileSize(const std::string & filename)
Get the size of a file.
```

**Return** Size of file.

#### Parameters

- filename: Filename.

```
PDAL_DLL std::string pdal::FileUtils::readFileToString(const std::string & filename)
Read a file into a string.
```

**Return** File contents as a string

#### Parameters

- filename: Filename.

```
PDAL_DLL std::string pdal::FileUtils::getcwd()
Get the current working directory with trailing separator.
```

**Return** The current working directory.

```
PDAL_DLL std::string pdal::FileUtils::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.
```

**Return** Absolute version of provided filename.

**Parameters**

- `filename`: Name of file to convert to absolute path.

**PDAL\_DLL std::string pdal::FileUtils::toAbsolutePath(const std::string &**

If the filename is an absolute path, just return it otherwise, make it absolute (relative to base dir) and return that.

**Return** Absolute version of provided filename relative to base.

**Parameters**

- `filename`: Name of file to convert to absolute path.
- `base`: Base name to use.

**PDAL\_DLL std::string pdal::FileUtils::getFilename(const std::string &**

Return the file component of the given path, e.g.

“d:/foo/bar/a.c” -> “a.c”

**Return** File part of path.

**Parameters**

- `path`: Path from which to extract file component.

**PDAL\_DLL std::string pdal::FileUtils::getDirectory(const std::string &**

Return the directory component of the given path, e.g.

“d:/foo/bar/a.c” -> “d:/foo/bar/”

**Return** Directory part of path.

**Parameters**

- `path`: Path from which to extract directory component.

**PDAL\_DLL std::string pdal::FileUtils::stem(const std::string & path)**

Return the filename stripped of the extension.

. and .. are returned unchanged.

**Return** Stem of filename.

**Parameters**

- `path`: File path from which to extract file stem.

**PDAL\_DLL bool pdal::FileUtils::isDirectory(const std::string & path)**

Determine if path is a directory.

**Return** Whether the path represents a directory.

**Parameters**

- path: Directory to check.

**PDAL\_DLL bool pdal::FileUtils::isAbsolutePath(const std::string & path)**

Determine if the path is an absolute path.

**Return** Whether the path is absolute.

**Parameters**

- path: Path to test.

**PDAL\_DLL void pdal::FileUtils::fileTimes(const std::string & filename,**

Get the file creation and modification times.

**Parameters**

- filename: Filename.
- createTime: Pointer to creation time structure.
- modTime: Pointer to modification time structure.

**PDAL\_DLL std::string pdal::FileUtils::extension(const std::string & path)**

Return the extension of the filename, including the separator (.)�

**Return** Extension of filename.

**Parameters**

- path: File path from which to extract extension.

**PDAL\_DLL std::vector< std::string > pdal::FileUtils::glob(std::string f)**

Expand a filespec to a list of files.

**Return** List of files that correspond to provided file specification.

**Parameters**

- filespec: File specification to expand.

## **pdal::Filter**

**class pdal::Filter**

Inherits from [pdal::Stage](#) (page 487)

Subclassed by pdal::ApproximateCoplanarFilter, pdal::AssignFilter, pdal::ChipperFilter, pdal::ClusterFilter, pdal::ColorinterpFilter, pdal::ColorizationFilter, pdal::CpdFilter, pdal::CropFilter, pdal::DecimationFilter, pdal::DelaunayFilter, pdal::DEMFilter,

pdal::DividerFilter, pdal::EigenvaluesFilter, pdal::ELMFilter, pdal::EstimateRankFilter,  
pdal::FerryFilter, pdal::GreedyProjection, pdal::GridProjectionFilter,  
pdal::GroupByFilter, pdal::HAGFilter, pdal::HeadFilter, pdal::HexBin, pdal::IcpFilter,  
pdal::InfoFilter, pdal::IQRFilter, pdal::KDistanceFilter, pdal::LocateFilter,  
pdal::LOFFilter, pdal::MADFitter, pdal::MatlabFilter, pdal::MergeFilter,  
pdal::MongoExpressionFilter, pdal::MongusFilter, pdal::MortonOrderFilter,  
pdal::MovingLeastSquaresFilter, pdal::NeighborClassifierFilter, pdal::NNDistanceFilter,  
pdal::NormalFilter, pdal::OutlierFilter, pdal::OverlayFilter, pdal::PCLBlock,  
pdal::PMFFilter, pdal::PoissonFilter, pdal::PythonFilter, pdal::RadialDensityFilter,  
pdal::RandomizeFilter, pdal::RangeFilter, pdal::ReprojectionFilter, pdal::ReturnsFilter,  
pdal::SampleFilter, pdal::SMRFilter, pdal::SortFilter, pdal::SplitterFilter,  
pdal::StatsFilter, pdal::StreamCallbackFilter, pdal::TailFilter, pdal::TransformationFilter,  
pdal::VoxelCenterNearestNeighborFilter, pdal::VoxelCentroidNearestNeighborFilter,  
pdal::VoxelGridFilter, SplitFilter

## Public Functions

### **Filter()**

**pdal::IStream**

**class pdal::IStream**

Stream wrapper for input of binary data.

Subclassed by pdal::IBeStream, pdal::ILeStream, pdal::ISwitchableStream

## Public Functions

### **PDAL\_DLL IStream()**

Default constructor.

### **PDAL\_DLL IStream(**const std::string &filename**)**

Construct an *IStream* (page 471) from a filename.

#### Parameters

- **filename:** File from which to read.

### **PDAL\_DLL IStream(**std::istream \*stream**)**

Construct an *IStream* (page 471) from an input stream pointer.

#### Parameters

- stream: Stream from which to read.

**PDAL\_DLL ~IStream()**

**PDAL\_DLL int pdal::IStream::open(const std::string & filename)**  
Open a file to extract.

**Return** -1 if a stream is already assigned, 0 otherwise.

#### Parameters

- filename: Filename.

**PDAL\_DLL void pdal::IStream::close()**

Close the underlying stream.

**PDAL\_DLL operator bool()**

Return the state of the stream.

**Return** The state of the underlying stream.

**PDAL\_DLL void pdal::IStream::seek(std::streampos pos)**

Seek to a position in the underlying stream.

#### Parameters

- pos: Position to seek to,

**PDAL\_DLL void pdal::IStream::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)

**PDAL\_DLL void pdal::IStream::skip(std::streamoff offset)**

Skip relative to the current position.

#### Parameters

- offset: Offset from the current position.

**PDAL\_DLL std::streampos pdal::IStream::position() const**

Determine the position of the get pointer.

**Return** Current get position.

**PDAL\_DLL bool pdal::IStream::good() const**

Determine if the underlying stream is good.

**Return** Whether the underlying stream is good.

**PDAL\_DLL std::istream\* pdal::IStream::stream()**

Fetch a pointer to the underlying stream.

**Return** Pointer to the underlying stream.

**PDAL\_DLL void pdal::IStream::pushStream(std::istream \* strm)**

Temporarily push a stream to read from.

### Parameters

- *strm*: New stream to read from.

**PDAL\_DLL std::istream\* pdal::IStream::popStream()**

Pop the current stream and return it.

The last stream on the stack cannot be popped.

**Return** Pointer to the popped stream.

**PDAL\_DLL void pdal::IStream::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.

**PDAL\_DLL void pdal::IStream::get(std::vector< char > & buf)**

Fetch data from the stream into a vector of char.

### Parameters

- *buf*: Buffer to fill.

**PDAL\_DLL void pdal::IStream::get(std::vector< unsigned char > & buf)**

Fetch data from the stream into a vector of unsigned char.

### Parameters

- *buf*: Buffer to fill.

**PDAL\_DLL void pdal::IStream::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.

**PDAL\_DLL void pdal::IStream::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 pdal::Log**

*pdal::Log* (page 474) is a logging object that is provided by *pdal::Stage* (page 487) to facilitate logging operations.

### 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

**LogLevel `getLevel()`**

Return the logging level of the *pdal::Log* (page 474) instance

**void `setLevel(LogLevel v)`**

Sets the logging level of the *pdal::Log* (page 474) instance.

### Parameters

- `v`: logging level to use for *get()* (page 475) comparison operations

**void `setLeader(const std::string &leader)`**

Set the leader string (deprecated).

### Parameters

- `leader`: Leader string.

```
void pushLeader (const std::string &leader)
```

Push the leader string onto the stack.

#### Parameters

- *leader*: Leader string

```
std::string leader () const
```

Get the leader string.

**Return** The current leader string.

```
void popLeader ()
```

Pop the current leader string.

```
std::string getLogLevelString (LogLevel v) const
```

**Return** A string representing the LogLevel

### Log stream operations

```
std::ostream *getLogStream ()
```

**Return** 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 475) is less than the logging level of the *pdal::Log* (page 474) instance

```
void floatPrecision (int level)
```

Sets the floating point precision.

```
void clearFloat ()
```

Clears the floating point precision settings of the streams.

## Public Functions

**Log** (std::string **const** &*leaderString*, std::string **const** &*outputName*, bool *timing* = false)  
Constructs a *pdal::Log* (page 474) instance.

### Parameters

- *leaderString*: A string to presage all log entries with
- *outputName*: A filename or one of ‘stdout’, ‘stdlog’, or ‘stderr’ to use for outputting log information.
- *timing*: Set to true to get timing output with log messages.

**Log** (std::string **const** &*leaderString*, std::ostream \**v*, bool *timing* = false)  
Constructs a *pdal::Log* (page 474) instance.

### Parameters

- *leaderString*: A string to presage all log entries with
- *v*: An existing std::ostream to use for logging (instead of the the instance creating its own)
- *timing*: Set to true to get timing output with log messages.

## **pdal::Metadata**

### **class pdal::Metadata**

## Public Functions

**Metadata()**

**Metadata** (**const** std::string &*name*)

*MetadataNode* (page 476) **getNode()** **const**

## Public Static Functions

std::string **inferType** (**const** std::string &*val*)

### **class pdal::MetadataNode**

## Public Functions

**MetadataNode ()**

**MetadataNode (const std::string &name)**

*MetadataNode* (page 476) **add (const std::string &name)**

*MetadataNode* (page 476) **addList (const std::string &name)**

*MetadataNode* (page 476) **clone (const std::string &name) const**

*MetadataNode* (page 476) **add (MetadataNode (page 476) node)**

*MetadataNode* (page 476) **addList (MetadataNode (page 476) node)**

*MetadataNode* (page 476) **addEncoded (const std::string &name, const unsigned char \*buf, size\_t size, const std::string &descrip = std::string())**

*MetadataNode* (page 476) **addListEncoded (const std::string &name, const unsigned char \*buf, size\_t size, const std::string &descrip = std::string())**

*MetadataNode* (page 476) **addWithType (const std::string &name, const std::string &value, const std::string &type, const std::string &descrip)**

*MetadataNode* (page 476) **add (const std::string &name, const double &value, const std::string &descrip = std::string(), size\_t precision = 10)**

**template <typename T>**

*MetadataNode* (page 476) **add (const std::string &name, const T &value, const std::string &descrip = std::string())**

**template <typename T>**

*MetadataNode* (page 476) **addList (const std::string &name, const T &value, const std::string &descrip = std::string())**

**template <typename T>**

*MetadataNode* (page 476) **addOrUpdate (const std::string &lname, const T &value)**

**template <typename T>**

*MetadataNode* (page 476) **addOrUpdate (const std::string &lname, const T &value, const std::string &descrip)**

*MetadataNode* (page 476) **addOrUpdate (MetadataNode (page 476) n)**

**std::string type () const**

```
MetadataType kind() const
std::string name() const
template <typename T>
T value() const

std::string value() const
std::string jsonValue() const
std::string description() const

MetadataNodeList children() const
MetadataNodeList children(const std::string &name) const
bool hasChildren() const
std::vector<std::string> childNames() const

operator bool() const
bool operator!()
bool valid() const
bool empty() const
template <typename PREDICATE>
MetadataNode (page 476) find(PREDICATE p) const
template <typename PREDICATE>
MetadataNodeList findChildren(PREDICATE p)
template <typename PREDICATE>
MetadataNode (page 476) findChild(PREDICATE p) const
MetadataNode (page 476) findChild(const char *s) const
MetadataNode (page 476) findChild(std::string s) const

pdal::Options
```

**class pdal::Options**

## Public Functions

**Options()**

**Options(const Option &opt)**

```
void add(const Option &option)
void add(const Options (page 478) &options)
void addConditional(const Option &option)
void addConditional(const Options (page 478) &option)
void remove(const Option &option)
void replace(const Option &option)
void toMetadata (MetadataNode (page 476) &parent) const
template <typename T>
void add(const std::string &name, T value)
void add(const std::string &name, const std::string &value)
void add(const std::string &name, const bool &value)
template <typename T>
void replace(const std::string &name, T value)
void replace(const std::string &name, const std::string &value)
void replace(const std::string &name, const bool &value)
StringList getValues(const std::string &name) const
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 483).
```

**Return** List of options as argument strings.

## Public Static Functions

*Options* (page 478) **fromFile** (**const** std::string &filename, bool *throwOnOpenError* = true)

**pdal::PointTable**

```
class pdal::PointTable
    Inherits from pdal::SimplePointTable
```

## Public Functions

```
PointTable()
~PointTable()
virtual bool supportsView() const
```

`pdal::PointView`

```
class pdal::PointView
Inherits from pdal::PointContainer
```

## Public Functions

`PointView(const PointView (page 480)&)`

`PointView (page 480) &operator=(const PointView (page 480)&)`

`PointView(PointTableRef pointTable)`

`PointView(PointTableRef pointTable, const SpatialReference &srs)`

`~PointView()`

`PointViewIter begin()`

`PointViewIter end()`

`int id() const`

`point_count_t size() const`

`bool empty() const`

`void appendPoint (const PointView (page 480) &buffer, PointId id)`

`void append (const PointView (page 480) &buf)`

`PointViewPtr makeNew() const`

Return a new point view with the same point table as this point buffer.

`PointRef point (PointId id)`

`template <class T>`

`T getFieldAs (Dimension (page 461)::Id dim, PointId pointIndex) const`

```
void getField(char *pos, Dimension (page 461)::Id d, Dimension
               (page 461)::Type (page 462) type, PointId id) const
template <typename T>
void setField(Dimension (page 461)::Id dim, PointId idx, T val)
void setField(Dimension (page 461)::Id dim, Dimension (page 461)::Type
               (page 462) type, PointId idx, const void *val)
template <typename T>
bool compare(Dimension (page 461)::Id dim, PointId id1, PointId id2)
bool compare(Dimension (page 461)::Id dim, PointId id1, PointId id2)
void getRawField(Dimension (page 461)::Id dim, PointId idx, void *buf)
const
void calculateBounds(BOX2D (page 453) &box) const
```

**Return** a cumulated bounds of all points in the *PointView* (page 480).

---

**Note:** This method requires that an *X*, *Y*, and *Z* dimension be available, and that it can be casted into a *double* data type using the `pdal::Dimension::applyScaling()` method. Otherwise, an exception will be thrown.

---

```
void calculateBounds(BOX3D (page 457) &box) const
void dump(std::ostream &ostr) const
bool hasDim(Dimension (page 461)::Id id) const
std::string dimName(Dimension (page 461)::Id id) const
Dimension (page 461)::IdList dims() const
std::size_t pointSize() const
std::size_t dimSize(Dimension (page 461)::Id id) const
Dimension (page 461)::Type (page 462) dimType(Dimension (page 461)::Id id)
const
DimTypeList dimTypes() const
PointLayoutPtr layout() const
PointTableRef table() const
SpatialReference spatialReference() const
```

```
void getPackedPoint (const DimTypeList &dims, PointId idx, char *buf)
```

**const**  
Fill a buffer with point data specified by the dimension list.

#### Parameters

- dims: List of dimensions/types to retrieve.
- idx: Index of point to get.
- buf: Pointer to buffer to fill.

```
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: Dimension/types of data in packed order
- idx: Index of point to write.
- buf: Packed data buffer.

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.

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.

void **clearTemps** ()

*MetadataNode* (page 476) **toMetadata** () **const**

void **invalidateProducts** ()

TriangularMesh \***createMesh** (**const** std::string &name)

Creates a mesh with the specified name.

**Return** Pointer to the new mesh. Null is returned if the mesh already exists.

#### Parameters

- name: Name of the mesh.

TriangularMesh \***mesh** (**const** std::string &*name* = "")  
Get a pointer to a mesh.

**Return** New mesh. Null is returned if the mesh already exists.

#### Parameters

- *name*: Name of the mesh.

KD3Index &**build3dIndex** ()

KD2Index &**build2dIndex** ()

#### Friends

**friend** pdal::PointView::plang::Invocation

**pdal::ProgramArgs**

**class** pdal::ProgramArgs

Parses command lines, provides validation and stores found values in bound variables.

Add arguments with [add](#) (page 483). When all arguments have been added, use [parse](#) (page 485) to validate command line and assign values to variables bound with [add](#) (page 483).

#### Public Functions

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.

**Return** Reference to the new 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.
- *def*: Default value of argument.

```
Arg &add(const std::string &name, const std::string &description,  
         std::vector<std::string> &var)  
Add a list-based (vector) string argument.
```

**Return** Reference to the new 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.

```
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>
```

```
Arg &add(const std::string &name, const std::string &description,  
         std::vector<T> &var)  
Add a list-based (vector) argument.
```

**Return** Reference to the new 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.

```
template <typename T>
```

```
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.
```

**Return** Reference to the new 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.

```
template <typename T>
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.

**Return** Reference to the new 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.
- def: Default value of argument.

```
template <typename T>
Arg &add(const std::string &name, const std::string description, T &var)
```

Add an argument to the list of arguments.

**Return** Reference to the new 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.

```
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.

```
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.

**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.

**void reset ()**

Reset the state of all arguments and bound variables as if no parsing had occurred.

**std::string commandLine () const**

Return a string suitable for use in a “usage” line for display to users as help.

**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.

**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.

**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 487) 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 pdal::Reader`**

Inherits from *pdal::Stage* (page 487)

Subclassed by `pdal::BpfReader`, `pdal::BufferReader`, `pdal::DbReader`, `pdal::EptReader`, `pdal::EsriReader`, `pdal::FauxReader`, `pdal::GDALReader`, `pdal::GeoWaveReader`, `pdal::GreyhoundReader`, `pdal::IcebridgeReader`, `pdal::Ilvis2Reader`, `pdal::LasReader`, `pdal::MatlabReader`, `pdal::MbReader`, `pdal::MrsidReader`, `pdal::NumpyReader`, `pdal::OptechReader`, `pdal::OSGReader`, `pdal::PcdReader`, `pdal::PlyReader`, `pdal::PtsReader`, `pdal::QfitReader`, `pdal::RdbReader`, `pdal::RxpReader`, `pdal::SbetReader`, `pdal::TerrasolidReader`, `pdal::TextReader`, `pdal::TileDBReader`, `pdal::TIndexReader`

## **`pdal::Stage`**

*pdal::Stage* (page 487) is the base class of *pdal::Filter* (page 470), *pdal::Reader* (page 487), and `pdal::MultiFilter` classes that implement the reading API in a PDAL pipeline.

### **`class pdal::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 488) into a pipeline. The pipeline is run with by calling in sequence `prepare()` (page 488) and `execute()` (page 488) 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 470), *pdal::Reader* (page 487), `pdal::Streamable`, *pdal::Writer* (page 513)

## Public Functions

**Stage ()**

**virtual ~Stage ()**

**void setInput (*Stage* (page 487) &*input*)**

Add a stage to the input list of this stage.

### Parameters

- *input*: *Stage* (page 487) to use as input.

**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 488) can be called. Prepare recurses through all input stages.

### Parameters

- *table*: *PointTable* (page 479) being used for stage pipeline.

**PointViewSet 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 488) function.

**virtual** void **execute** (StreamPointTable &*table*)

**virtual** bool **pipelineStreamable** () **const**

Determine if a pipeline with this stage as a sink is streamable.

**Return** Whether the pipeline is streamable.

**virtual const Stage** (page 487) \***findNonstreamable** () **const**

Return a pointer to a pipeline's first non-streamable stage, if one exists.

**Return** 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 480) 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 487) 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.

**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 480) 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.

**Return** The stage's spatial reference.

void **setOptions** (*Options* (page 478) *options*)

Set a stage's options.

Set the options on a stage, clearing all previously set options.

### Parameters

- *options*: *Options* (page 478) to set.

**void addConditionalOptions (const *Options* (page 478) &*opts*)**

Add options if an option with the same name doesn't already exist on the stage.

### Parameters

- *opts*: *Options* (page 478) to add.

**void addAllArgs (*ProgramArgs* (page 483) &*args*)**

Add a stage's options to a *ProgramArgs* (page 483) set.

### Parameters

- *args*: *ProgramArgs* (page 483) to add to.

**void addOptions (const *Options* (page 478) &*opts*)**

Add options to the existing option set.

### Parameters

- *opts*: *Options* (page 478) to add.

**void removeOptions (const *Options* (page 478) &*opts*)**

Remove options from a stage's option set.

### Parameters

- *opts*: *Options* (page 478) to remove.

**void setLog (LogPtr &*log*)**

Set the stage's log.

### Parameters

- *log*: *Log* (page 474) pointer.

**virtual LogPtr log () const**

Return the stage's log pointer.

**Return** *Log* (page 474) pointer.

**void startLogging () const**

Push the stage's leader into the log.

**void stopLogging () const**

Pop the stage's leader from the log.

**bool `isDebug()` const**

Determine whether the stage is in debug mode or not.

**Return** The stage's debug state.

**virtual std::string `getName()` const = 0**

Return the name of a stage.

**Return** The stage's name.

**void `setTag(const std::string &tag)`**

Set a specific tag name.

**virtual std::string `tag()` const**

Return the tag name of a stage.

**Return** The tag name.

**std::vector<*Stage* (page 487) \*> `&getInputs()`**

Return a list of the stage's inputs.

**Return** A vector pointers to input stages.

***MetadataNode* (page 476) `getMetadata()` const**

Get the stage's metadata node.

**Return** *Stage* (page 487)'s metadata.

**void `serialize(MetadataNode (page 476) root, PipelineWriter::TagMap &tags) const`**

Serialize a stage by inserting appropriate data into the provided *MetadataNode* (page 476).

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

**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.

**Return** Whether the parsed name is a valid stage name.

#### Parameters

- *o*: Input string to parse.
- *pos*: Parsing start/end position.

**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.

**Return** Whether the parsed name is a valid tag name.

#### Parameters

- *o*: Input string to parse.
- *pos*: Parsing start/end position.
- *tag*: Parsed tag name.

## **pdal::StageFactory**

**class pdal::StageFactory**

This class provides a mechanism for creating *Stage* (page 487) 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()* (page 493) if desired.

**Note** *Stage* (page 487) creation is thread-safe.

### Public Functions

**StageFactory** (bool *ignored* = true)

Create a stage factory.

#### Parameters

- *ignored*: Ignored argument.

*Stage* (page 487) \***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.

**Return** Pointer to created stage.

#### Parameters

- `stage_name`: Type of stage to be created.

void **destroyStage** (*Stage* (page 487) \**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

`std::string inferReaderDriver (const std::string &filename)`

Infer the reader to use based on a filename.

Find the default reader for a file.

**Return** Driver name or empty string if no reader can be inferred from the filename.

**Return** Name of the reader driver associated with the file.

#### Parameters

- `filename`: Filename that should be analyzed to determine a driver.

#### Parameters

- `filename`: Filename for which to infer a reader.

`std::string inferWriterDriver (const std::string &filename)`

Infer the writer to use based on filename extension.

Find the default writer for a file.

**Return** Driver name or empty string if no writer can be inferred from the filename.

**Return** Name of the writer driver associated with the file.

#### Parameters

- `filename`: Filename for which to infer a writer.

### `pdal::Utils`

`:cpp:namespace:‘pdal::Utils’` is a set of utility functions.

```
namespace pdal::Utils
```

#### TypeDefs

```
using pdal::Utils::BacktraceEntries = typedef std::deque<BacktraceEntry>
```

#### Functions

```
template <>
template<>
bool fromString<Eigen::MatrixXd> (const std::string &s, Eigen::MatrixXd
&matrix)

std::string PDAL_DLL pdal::Utils::toJSON(const MetadataNode &m)

void PDAL_DLL pdal::Utils::toJSON(const MetadataNode &m, std::ostream&

std::ostream PDAL_DLL * pdal::Utils::createFile(const std::string & path,
Create a file (may be on a supported remote filesystem).
```

**Return** Pointer to the created stream, or NULL.

#### Parameters

- `path`: Path to file to create.
- `asBinary`: Whether the file should be written in binary mode.

```
std::istream PDAL_DLL * pdal::Utils::openFile(const std::string & path,
Open a file (potentially on a remote filesystem).
```

**Return** Pointer to stream opened for input.

#### Parameters

- `path`: Path (potentially remote) of file to open.
- `asBinary`: Whether the file should be opened binary.

```
void PDAL_DLL pdal::Utils::closeFile(std::ostream * out)
Close an output stream.
```

#### Parameters

- `out`: Stream to close.

```
void PDAL_DLL pdal::Utils::closeFile(std::istream * in)
    Close an input stream.
```

#### Parameters

- `out`: Stream to close.

```
bool PDAL_DLL pdal::Utils::fileExists(const std::string & path)
    Check to see if a file exists.
```

**Return** Whether the file exists or not.

#### Parameters

- `path`: Path to file.

```
double PDAL_DLL pdal::Utils::computeHausdorff(PointViewPtr srcView, Po
```

```
void printError(const std::string &s)
```

```
double toDouble(const Everything &e, Dimension (page 461)::Type
    (page 462) type)
```

```
template <typename INPUT>
Everything extractDim(INPUT &ext, Dimension (page 461)::Type (page 462)
    type)
```

```
template <typename OUTPUT>
```

```
void insertDim(OUTPUT &ins, Dimension (page 461)::Type (page 462) type,
    const Everything &e)
```

```
MetadataNode (page 476) toMetadata (const BOX2D (page 453) &bounds)
```

```
MetadataNode (page 476) toMetadata (const BOX3D (page 457) &bounds)
```

```
int openProgress (const std::string &filename)
```

```
void closeProgress (int fd)
```

```
void writeProgress (int fd, const std::string &type, const std::string &text)
```

```
std::vector<std::string> PDAL_DLL pdal::Utils::maybeGlob (const std::st
```

```
template <typename CONTAINER, typename VALUE>
```

```
bool contains (const CONTAINER &cont, const VALUE &val)
```

Determine if a container contains a value.

**Return** `true` if the value is in the container, `false` otherwise.

#### Parameters

- `cont`: Container.

- val: Value.

```
template <typename KEY, typename VALUE>
bool contains (const std::map<KEY, VALUE> &c, const KEY &v)
Determine if a map contains a key.
```

**Return** true if the value is in the container, false otherwise.

#### Parameters

- c: Map.
- v: Key value.

```
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 &cont, PREDICATE p)
Remove all instances matching a unary predicate from a container.
```

#### Parameters

- cont: Container.
- p: Predicate indicating whether a value should be removed.

```
PDAL_DLL std::vector< std::string > pdal::Utils::backtrace()
Generate a backtrace as a list of strings.
```

**Return** List of functions at the point of the call.

*Utils* (page 494)::BacktraceEntries **backtraceImpl()**

```
template <class T>
PDAL_DLL const T& pdal::Utils::clamp(const T & t, const T & minimum, const T & 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.

**Return** the value clamped to the given bounds.

#### Parameters

- $t$ : the input value.
- $\min$ : the lower bound.
- $\max$ : the upper bound.

`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.

`double uniform(const double &minimum, const double &maximum, uint32_t seed)`  
Generate values in a uniform distribution in the range [minimum, maximum] using the provided seed value.

#### Parameters

- `double`: Lower value of range for random number generation.
- `double`: Upper value of range for random number generation.
- `seed`: Seed value for random number generation.

`double normal(const double &mean, const double &sigma, uint32_t seed)`  
Generate values in a normal distribution in the range [minimum, maximum] using the provided seed value.

#### Parameters

- `double`: Lower value of range for random number generation.
- `double`: Upper value of range for random number generation.
- `seed`: Seed value for random number generation.

`PDAL_DLL bool pdal::Utils::compare_approx(double v1, double v2, double`  
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`

`double sround(double r)`

Round double value to nearest integral value.

**Return** Rounded value

### Parameters

- `r`: Value to round

`std::string tolower(const std::string &s)`

Convert a string to lowercase.

**Return** Converted string.

`std::string toupper(const std::string &s)`

Convert a string to uppercase.

**Return** Converted string.

`bool iequals(const std::string &s, const std::string &s2)`

Compare strings in a case-insensitive manner.

**Return** Whether the strings are equal.

### Parameters

- `s`: First string to compare.
- `s2`: Second string to compare.

`bool startsWith(const std::string &s, const std::string &prefix)`

Determine if a string starts with a particular prefix.

**Return** Whether the string begins with the prefix.

### Parameters

- `s`: String to check for prefix.
- `prefix`: Prefix to search for.

bool **endsWith**(**const** std::string &*s*, **const** std::string &*postfix*)

Determine if a string ends with a particular postfix.

**Return** Whether the string ends with the postfix.

#### Parameters

- *s*: String to check for postfix.
- *postfix*: Postfix to search for.

int **cksum**(char \**buf*, size\_t *size*)

Generate a checksum that is the integer sum of the values of the bytes in a buffer.

**Return** Generated checksum.

#### Parameters

- *buf*: Pointer to buffer.
- *size*: Size of buffer.

int **getenv**(std::string **const** &*name*, std::string &*val*)

Fetch the value of an environment variable.

**Return** 0 on success, -1 on failure

#### Parameters

- *name*: Name of environment variable.
- *name*: Value of the environment variable if it exists, empty otherwise.

int **setenv**(**const** std::string &*env*, **const** std::string &*val*)

Set the value of an environment variable.

**Return** 0 on success, -1 on failure

#### Parameters

- *env*: Name of environment variable.
- *val*: Value of environment variable.

int **unsetenv**(**const** std::string &*env*)

Clear the value of an environment variable.

**Return** 0 on success, -1 on failure

#### Parameters

- `env`: Name of the environment variable to clear.

`void eatwhitespace (std::istream &s)`  
Skip stream input until a non-space character is found.

#### Parameters

- `s`: Stream to process.

`void trimLeading (std::string &s)`  
Remove whitespace from the beginning of a string.

#### Parameters

- `s`: String to be trimmed.

`void trimTrailing (std::string &s)`  
Remove whitespace from the end of a string.

#### Parameters

- `s`: String to be trimmed.

`void trim (std::string &s)`  
Remove whitespace from the beginning and end of a string.

#### Parameters

- `s`: String to be trimmed.

`bool eatcharacter (std::istream &s, char x)`  
If specified character is at the current stream position, advance the stream position by 1.

**Return** `true` if the character is at the current stream position, `false` otherwise.

#### Parameters

- `s`: Stream to inspect.
- `x`: Character to check for.

`std::string base64_encode (const unsigned char *buf, size_t size)`  
Convert a buffer to a string using base64 encoding.

**Return** Encoded buffer.

## Parameters

- `buf`: Pointer to buffer to encode.
- `size`: Size of buffer.

```
std::string base64_encode(std::vector<uint8_t> const &bytes)  
Convert a buffer to a string using base64 encoding.
```

**Return** Encoded buffer.

## Parameters

- `bytes`: Pointer to buffer to encode.

```
std::vector<uint8_t> base64_decode(std::string const &input)  
Decode a base64-encoded string into a buffer.
```

**Return** Buffer containing decoded string.

## Parameters

- `input`: String to decode.

```
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.

**Return** Pointer to FILE for input/output from the subprocess.

## Parameters

- `command`: Command to run in subprocess. Either ‘r’, ‘w’ or ‘r+’ to specify if the pipe should be opened as read-only, write-only or read-write.

```
int portable_pclose(FILE *fp)
```

Close file opened with [\*portable\\_popen\*](#) (page 501).

**Return** 0 on success, -1 on failure.

## Parameters

- `fp`: Pointer to file to close.

```
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.

**Return** Modified version of input string.

### Parameters

- input: Input string to modify.
- replaceWhat: Token to locate in input string.
- replaceWithWhat: Replacement for found tokens.

```
StringList 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.

**Return** List of substrings generated from the input string.

### 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.

```
StringList 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.

**Return** List of substrings generated from the input string.

### 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`.

`std::string escapeJSON (const std::string &s)`

Add escape characters or otherwise transform an input string so as to be a valid JSON string.

**Return** Valid JSON version of input string.

#### Parameters

- `s`: Input string.

`std::string demangle (const std::string &s)`

Demangle a C++ symbol into readable form.

Demangle strings using the compiler-provided demangle function.

**Return** Demangled symbol.

**Return** Demangled string

#### Parameters

- `s`: String to demangle.

#### Parameters

- `s`: String to be demangled.

`int screenWidth ()`

Return the screen width of an associated tty.

**Return** 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 () as necessary.

**Return** Copy of input string with non-printing characters converted to printable notation.

#### Parameters

- *s*: String to modify.

```
double normalizeLongitude (double longitude)
    Normalize longitude so that it's between (-180, 180].
```

**Return** Normalized longitude.

#### Parameters

- *longitude*: Longitude to normalize.

```
std::string hexDump (const char *buf, size_t count)
```

Convert an input buffer to a hexadecimal string representation similar to the output of the UNIX command ‘od’.

This is mostly used as an occasional debugging aid.

**Return** Buffer converted to hex string.

#### Parameters

- *buf*: Point to buffer to dump.
- *count*: Size of buffer.

```
template <typename PREDICATE>
```

```
PDAL_DLL std::string::size_type pdal::Utils::extract(const std::string &
```

Count the number of characters in a string that meet a predicate.

**Return** Then number of characters matching the 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.

```
PDAL_DLL std::string::size_type pdal::Utils::extractSpaces(const std::string &
```

Count the number of characters spaces in a string at a position.

**Return** Then number of space-y characters matching the predicate.

#### Parameters

- *s*: String in which to start counting characters.
- *p*: Position in input string at which to start counting.

```
template <typename PREDICATE>
```

```
PDAL_DLL std::vector<std::string> pdal::Utils::split(const std::string
```

Split a string into substrings based on a predicate.

Characters matching the predicate are discarded.

**Return** Substrings.

#### Parameters

- s: String to split.
- p: Unary predicate that returns true to indicate that a character is a split location.

```
template <typename PREDICATE>
```

```
PDAL_DLL std::vector<std::string> pdal::Utils::split2(const std::string
```

Split a string into substrings.

Characters matching the predicate are discarded, as are empty strings otherwise produced by [split\(\)](#) (page 505).

**Return** Vector of substrings.

#### Parameters

- s: String to split.
- p: Predicate returns true if a char in a string is a split location.

```
PDAL_DLL std::vector<std::string> pdal::Utils::split(const std::string
```

Split a string into substrings based a splitting character.

The splitting characters are discarded.

**Return** Substrings.

#### Parameters

- s: String to split.
- p: Character indicating split positions.

```
PDAL_DLL std::vector<std::string> pdal::Utils::split2(const std::string
```

Split a string into substrings based a splitting character.

The splitting characters are discarded as are empty strings otherwise produced by [split\(\)](#) (page 505).

**Return** Substrings.

#### Parameters

- s: String to split.

- p: Character indicating split positions.

```
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.

**Return** List of arguments.

#### Parameters

- s: Input string to parse.

```
template <typename T>  
std::string typeidName ()
```

Return a string representation of a type specified by the template argument.

**Return** String representation of the type.

*RedirectStream* (page 512) **redirect** (std::ostream &out, std::ostream &dst)  
Redirect a stream to some other stream, by default a null stream.

**Return** Context for stream restoration (see *restore()* (page 507)).

#### Parameters

- out: Stream to redirect.
- dst: Destination stream.

*RedirectStream* (page 512) **redirect** (std::ostream &out)  
Redirect a stream to a null stream.

**Return** Context for stream restoration (see *restore()* (page 507)).

#### Parameters

- out: Stream to redirect.

*RedirectStream* (page 512) **redirect** (std::ostream &out, const std::string &file)

Redirect a stream to some file.

**Return** Context for stream restoration (see *restore()* (page 507)).

#### Parameters

- `out`: Stream to redirect.
- `file`: Name of file where stream should be redirected.

**void `restore`** (`std::ostream &out, RedirectStream` (page 512) `&redir`)

Restore a stream redirected with `redirect()` (page 506).

### Parameters

- `out`: Stream to be restored.
- `redir`: `RedirectStream` (page 512) returned from corresponding `redirect()` (page 506) call.

**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.

**Return** Whether value can be safely converted to template type.

### Parameters

- `in`: Value to range test.

**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.

**Return** Whether value can be safely converted to template type.

### Parameters

- `in`: Value to range test.

**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.

**Return** `true` if the conversion was successful, `false` if the datatypes/input value don't allow conversion.

### Parameters

- `in`: Value to convert.
- `out`: Converted value.

```
template <>
bool numericCast (double in, float &out)
    Convert a numeric value from double to float.

Specialization to handle NaN.
```

**Return** `true` if the conversion was successful, `false` if the datatypes/input value don't allow conversion.

### Parameters

- `in`: Value to convert.
- `out`: Converted value.

```
template <typename T>
std::string toString (const T &from)
    Convert a value to its string representation by writing to a stringstream.
```

**Return** String representation.

### Parameters

- `from`: Value to convert.

```
std::string toString (bool from)
    Convert a bool to a string.
```

```
std::string toString (double from, size_t precision = 10)
    Convert a double to string with a precision of 10 decimal places.
```

**Return** String representation of numeric value.

### Parameters

- `from`: Value to convert.

```
std::string toString (float from)
    Convert a float to string with a precision of 10 decimal places.
```

**Return** String representation of numeric value.

### Parameters

- `from`: Value to convert.

std::string **toString** (long long *from*)

Convert a long long int to string.

**Return** String representation of numeric value.

**Parameters**

- *from*: Value to convert.

std::string **toString** (unsigned long long *from*)

Convert an unsigned long long int to string.

**Return** String representation of numeric value.

**Parameters**

- *from*: Value to convert.

std::string **toString** (long *from*)

Convert a long int to string.

**Return** String representation of numeric value.

**Parameters**

- *from*: Value to convert.

std::string **toString** (unsigned int *from*)

Convert an unsigned int to string.

**Return** String representation of numeric value.

**Parameters**

- *from*: Value to convert.

std::string **toString** (int *from*)

Convert an int to string.

**Return** String representation of numeric value.

**Parameters**

- *from*: Value to convert.

std::string **toString** (unsigned short *from*)

Convert an unsigned short to string.

**Return** String representation of numeric value.

### Parameters

- `from`: Value to convert.

`std::string toString (short from)`

Convert a short int to string.

**Return** String representation of numeric value.

### Parameters

- `from`: Value to convert.

`std::string toString (char from)`

Convert a char (treated as numeric) to string.

**Return** String representation of numeric value.

### Parameters

- `from`: Value to convert.

`std::string toString (unsigned char from)`

Convert an unsigned char (treated as numeric) to string.

**Return** String representation of numeric value.

### Parameters

- `from`: Value to convert.

`std::string toString (signed char from)`

Convert a signed char (treated as numeric) to string.

**Return** String representation of numeric value.

### Parameters

- `from`: Value to convert.

`template <typename T>`

`bool fromString (const std::string &from, T *&to)`

`template <typename T>`

`bool fromString (const std::string &from, T &to)`

Convert a string to a value by reading from a string stream.

**Return** `true` if the conversion was successful, `false` otherwise.

### Parameters

- `from`: String to convert.
- `to`: Converted value.

```
template <>
bool fromString(const std::string &from, std::string &to)
template <>
template<>
bool fromString<char>(const std::string &s, char &to)
    Convert a numeric string to a char numeric value.
    s String to convert.
```

**Return** `true` if the conversion was successful, `false` otherwise.

#### Parameters

- `to`: Converted numeric value.

```
template <>
template<>
bool fromString<unsigned char>(const std::string &s, unsigned char &to)
    Convert a numeric string to an unsigned char numeric value.
    s String to convert.
```

**Return** `true` if the conversion was successful, `false` otherwise.

#### Parameters

- `to`: Converted numeric value.

```
template <>
template<>
bool fromString<signed char>(const std::string &s, signed char &to)
    Convert a numeric string to a signed char numeric value.
    s String to convert.
```

**Return** `true` if the conversion was successful, `false` otherwise.

#### Parameters

- `to`: Converted numeric value.

```
template <>
template<>
bool fromString<double>(const std::string &s, double &d)
    Specialization conversion from string to double to handle Nan.
```

**Return** `true` if the conversion was successful, `false` otherwise.

#### Parameters

- `s`: String to be converted.

- `d`: Converted value.

```
template <typename E>
std::underlying_type<E>::type toNative (E e)
    Return the argument cast to its underlying type.
```

Typically used on an enum.

**Return** Converted variable.

### Parameters

- `e`: Variable for which to find the underlying type.

## Variables

```
const std::string dynamicLibExtension = ".so"
const char dirSeparator = '/'
const char pathListSeparator = ':'

struct BacktraceEntry
    #include <BacktraceImpl.hpp>
```

## Public Functions

```
BacktraceEntry()
```

## Public Members

```
std::string libname
void *addr
std::string symname
int offset

struct RedirectStream
    #include <Utils.hpp>
```

## Public Functions

```
RedirectStream()
```

## Public Members

```
std::ofstream *m_out  
std::streambuf *m_buf  
std::unique_ptr<NullOStream> m_null
```

### **pdal::Writer**

#### **class pdal::Writer**

A *Writer* (page 513) 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.

Inherits from *pdal::Stage* (page 487)

Subclassed by pdal::DbWriter, pdal::EptAddonWriter, pdal::FbxWriter, pdal::FlexWriter, pdal::GeoWaveWriter, pdal::GreyhoundWriter, pdal::MatlabWriter, pdal::NullWriter, pdal::PcdWriter, pdal::PlyWriter, pdal::SbetWriter, pdal::TextWriter, pdal::TileDBWriter

## 12.3.2 libLAS C API to PDAL transition guide

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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:

```
#include <liblas/capi/liblas.h>
```

For PDAL, in addition to PDAL headers, we also include standard headers which will be useful later:

```
#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:

```
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:

```
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::PointViewSet 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:

```
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();

xmin = las_header minX();
xmax = las_header maxX();
ymin = las_header minY();
ymax = las_header maxY();
```

The point record count in libLAS:

```
unsigned int n_features = LASHeader_GetPointRecordsCount(LAS_header);
```

is just point count in PDAL:

```
unsigned int n_features = las_header.pointCount();
```

WKT of a spatial reference system is obtained from the header in libLAS:

```
LAS_srs = LASHeader_GetSRS(LAS_header);
char* projstr = LASSRS_GetWKT_CompoundOK(LAS_srs);
```

In PDAL, spatial reference is part of the PointTable:

```
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:

```
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:

```
have_time = las_header.hasTime();
have_color = las_header.hasColor();
```

The presence of color, time and other dimensions can be also determined with:

```
pdal::Dimension::IdList dims = point_view->dims();
```

## Iterating over points

libLAS:

```
while ((LAS_point = LASReader_GetNextPoint(LAS_reader)) != NULL) {
    // ...
}
```

PDAL:

```
for (pdal::PointId idx = 0; idx < point_view->size(); ++idx) {
    // ...
}
```

## Point validity

The correct usage of libLAS required to test point validity:

```
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:

```
x = LASPoint_GetX(LAS_point);  
y = LASPoint_GetY(LAS_point);  
z = LASPoint_GetZ(LAS_point);
```

In PDAL, point coordinates are one of the dimensions:

```
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:

```
int return_no = LASPoint_GetReturnNumber(LAS_point);  
int n_returns = LASPoint_GetNumberOfReturns(LAS_point);
```

PDAL:

```
int return_no = point_view->getFieldAs<int>(Id::ReturnNumber, idx);  
int n_returns = point_view->getFieldAs<int>(Id::NumberOfReturns, idx);
```

## Classes

libLAS:

```
int point_class = (int) LASPoint_GetClassification(LAS_point);
```

PDAL:

```
int point_class = point_view->getFieldAs<int>(Id::Classification, idx);
```

### Color

libLAS:

```
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:

```
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:

```
double time = LASPoint_GetTime(LAS_point);
```

PDAL:

```
double time = point_view->getFieldAs<double>(Id::GpsTime, idx);
```

### Other point attributes

libLAS:

```
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:

```
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:

```
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.

## 12.4 FAQ

- How do you pronounce PDAL?

The proper spelling of the project name is PDAL, in uppercase. It is pronounced to rhyme with “GDAL”.

- 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_PCL=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.

- 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 47), 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 108)) 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 47) to limit memory consumption when possible.

- 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 can also use PCL through the [filters.pclblock](#) (page 219) mechanism. PDAL also supports reading and writing PCL PCD files using [readers.pcd](#) (page 81) and [writers.pcd](#) (page 126).

### 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 25) 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 25) 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 25)).

- 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 69) is outputting 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
```

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## 12.6 References

### 12.6.1 Citation

To cite PDAL in publications use:

PDAL Contributors, 2018. PDAL Point Data Abstraction Library.  
doi:10.5281/zenodo.2556738

A BibTeX entry for LaTeX users is

```
@misc{pdal_contributors_2018_2556738, author = {PDAL Contributors}, title = {PDAL Point Data Abstraction Library}, month = nov, year = 2018, doi = {10.5281/zenodo.2556738}, url = {\url{https://doi.org/10.5281/zenodo.2556738}}
```

}

### 12.6.2 Reference

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CHAPTER  
**THIRTEEN**

---

**INDICES AND TABLES**

- genindex
- search



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# INDEX

## A

Apps, 11

## B

boundary, 313

## C

capstone, 372

Citation, 522

classification, 340, 356

classifications, 329

Clipping, 317

CloudCompare, 8

Colorization, 323

Command line, 11

Conda, 17, 235

coordinate system, 299

csd, 370

CSV, 298

## D

Denoising, 328

Density, 332

density, 337

DSM, 349

DTM, 349

## E

elevation model, 349

Embed, 233

Entwine, 8

Extension, 234

## F

filtering, 340

Fusion, 8

## G

GDAL, 323

georeferencing, 288, 370

GeoWave, 62, 111

GNSS/IMU, 288, 370

Greyhound, 8

greyhound, 310

ground, 340

## H

hexagon tessellation, 332

histogram, 370

## I

info command, 297

Install, 235

installation, 297

intensity, 356

## J

JSON, 298

## L

LAStools, 7

libLAS, 8

## M

matplotlib, 370

metadata, 299

## N

nearby, 302

nearest, 302

Numpy, 11, 233, 370

## O

OGR, 313, 317, 332  
 Optech, 370  
 OrfeoToolbox, 8  
 outliers, 328

## P

PCL, 7, 520  
 pdal::BOX2D (C++ class), 453  
 pdal::BOX2D::BOX2D (C++ function), 453  
 pdal::BOX2D::clear (C++ function), 454  
 pdal::BOX2D::clip (C++ function), 455  
 pdal::BOX2D::contains (C++ function), 454, 455  
 pdal::BOX2D::empty (C++ function), 453  
 pdal::BOX2D::equal (C++ function), 454  
 pdal::BOX2D::getDefaultSpatialExtent (C++ function), 457  
 pdal::BOX2D::grow (C++ function), 454, 455  
 pdal::BOX2D::maxx (C++ member), 456  
 pdal::BOX2D::maxy (C++ member), 456  
 pdal::BOX2D::minx (C++ member), 456  
 pdal::BOX2D::miny (C++ member), 456  
 pdal::BOX2D::operator = (C++ function), 455  
 pdal::BOX2D::operator== (C++ function), 455  
 pdal::BOX2D::overlaps (C++ function), 455  
 pdal::BOX2D::toBox (C++ function), 456  
 pdal::BOX2D::toGeoJSON (C++ function), 456  
 pdal::BOX2D::toWKT (C++ function), 456  
 pdal::BOX2D::valid (C++ function), 454  
 pdal::BOX3D (C++ class), 457  
 pdal::BOX3D::BOX3D (C++ function), 457  
 pdal::BOX3D::clear (C++ function), 458  
 pdal::BOX3D::clip (C++ function), 459  
 pdal::BOX3D::contains (C++ function), 458  
 pdal::BOX3D::empty (C++ function), 457  
 pdal::BOX3D::equal (C++ function), 458  
 pdal::BOX3D::getDefaultSpatialExtent (C++ function), 460  
 pdal::BOX3D::grow (C++ function), 458, 459  
 pdal::BOX3D::maxz (C++ member), 460  
 pdal::BOX3D::minz (C++ member), 460  
 pdal::BOX3D::operator= (C++ function), 459  
 pdal::BOX3D::operator== (C++ function), 459  
 pdal::BOX3D::overlaps (C++ function), 460  
 pdal::BOX3D::to2d (C++ function), 460  
 pdal::BOX3D::toBox (C++ function), 460  
 pdal::BOX3D::toWKT (C++ function), 460  
 pdal::BOX3D::valid (C++ function), 457  
 pdal::Charbuf (C++ class), 461  
 pdal::Charbuf::Charbuf (C++ function), 461  
 pdal::Charbuf::initialize (C++ function), 461  
 pdal::Dimension (C++ type), 461  
 pdal::Dimension::base (C++ function), 462  
 pdal::Dimension::BaseType (C++ type), 462  
 pdal::Dimension::COUNT (C++ member), 463  
 pdal::Dimension::DetailList (C++ type), 462  
 pdal::Dimension::Double (C++ enumerator), 462  
 pdal::Dimension::extractName (C++ function), 463  
 pdal::Dimension::Float (C++ enumerator), 462  
 pdal::Dimension::Floating (C++ enumerator), 462  
 pdal::Dimension::fromName (C++ function), 462  
 pdal::Dimension::interpretationName (C++ function), 462  
 pdal::Dimension::None (C++ enumerator), 462  
 pdal::Dimension::operator>> (C++ function), 463  
 pdal::Dimension::operator<< (C++ function), 463  
 pdal::Dimension::PROPRIETARY (C++ member), 463  
 pdal::Dimension::Signed (C++ enumerator), 462  
 pdal::Dimension::Signed16 (C++ enumerator), 462  
 pdal::Dimension::Signed32 (C++ enumerator), 462  
 pdal::Dimension::Signed64 (C++

enumerator), 462  
pdal::Dimension::Signed8 (C++ enumerator), 462  
pdal::Dimension::size (C++ function), 462  
pdal::Dimension::toName (C++ function), 462  
pdal::Dimension::type (C++ function), 463  
pdal::Dimension::Type (C++ type), 462  
pdal::Dimension::Unsigned (C++ enumerator), 462  
pdal::Dimension::Unsigned16 (C++ enumerator), 462  
pdal::Dimension::Unsigned32 (C++ enumerator), 462  
pdal::Dimension::Unsigned64 (C++ enumerator), 462  
pdal::Dimension::Unsigned8 (C++ enumerator), 462  
pdal::Extractor (C++ class), 463  
pdal::Extractor::Extractor (C++ function), 464  
pdal::Extractor::get (C++ function), 464, 465  
pdal::Extractor::good (C++ function), 464  
pdal::Extractor::operator bool (C++ function), 464  
pdal::Extractor::operator>> (C++ function), 465, 466  
pdal::Extractor::position (C++ function), 464  
pdal::Extractor::seek (C++ function), 464  
pdal::Extractor::skip (C++ function), 464  
pdal::FileUtils (C++ type), 466  
pdal::Filter (C++ class), 470  
pdal::Filter::Filter (C++ function), 471  
pdal::IStream (C++ class), 471  
pdal::IStream::~IStream (C++ function), 472  
pdal::IStream::IStream (C++ function), 471  
pdal::IStream::operator bool (C++ function), 472  
pdal::Log (C++ class), 474  
pdal::Log::~Log (C++ function), 474  
pdal::Log::clearFloat (C++ function), 475  
pdal::Log::floatPrecision (C++ function), 475  
pdal::Log::get (C++ function), 475  
pdal::Log::getLevel (C++ function), 474  
pdal::Log::getLevelString (C++ function), 475  
pdal::Log::getLogStream (C++ function), 475  
pdal::Log::leader (C++ function), 475  
pdal::Log::Log (C++ function), 476  
pdal::Log::popLeader (C++ function), 475  
pdal::Log::pushLeader (C++ function), 474  
pdal::Log::setLeader (C++ function), 474  
pdal::Log::setLevel (C++ function), 474  
pdal::Metadata (C++ class), 476  
pdal::Metadata::getNode (C++ function), 476  
pdal::Metadata::inferType (C++ function), 476  
pdal::Metadata::Metadata (C++ function), 476  
pdal::MetadataNode (C++ class), 476  
pdal::MetadataNode::add (C++ function), 477  
pdal::MetadataNode::addEncoded (C++ function), 477  
pdal::MetadataNode::addList (C++ function), 477  
pdal::MetadataNode::addListEncoded (C++ function), 477  
pdal::MetadataNode::addOrUpdate (C++ function), 477  
pdal::MetadataNode::addWithType (C++ function), 477  
pdal::MetadataNode::childNames (C++ function), 478  
pdal::MetadataNode::children (C++ function), 478  
pdal::MetadataNode::clone (C++ function), 477  
pdal::MetadataNode::description (C++ function), 478  
pdal::MetadataNode::empty (C++ function), 478  
pdal::MetadataNode::find (C++ function), 478  
pdal::MetadataNode::findChild (C++ function), 478  
pdal::MetadataNode::findChildren (C++ function), 478  
pdal::MetadataNode::hasChildren (C++ function), 478  
pdal::MetadataNode::jsonValue (C++ function), 478  
pdal::MetadataNode::kind (C++ function), 478  
pdal::MetadataNode::MetadataNode (C++

function), 477  
pdal::MetadataNode::name (C++ function), 478  
pdal::MetadataNode::operator (C++ function), 478  
pdal::MetadataNode::operator bool (C++ function), 478  
pdal::MetadataNode::type (C++ function), 477  
pdal::MetadataNode::valid (C++ function), 478  
pdal::MetadataNode::value (C++ function), 478  
pdal::Options (C++ class), 478  
pdal::Options::add (C++ function), 479  
pdal::Options::addConditional (C++ function), 479  
pdal::Options::fromFile (C++ function), 479  
pdal::Options::getKeys (C++ function), 479  
pdal::Options::getOptions (C++ function), 479  
pdal::Options::getValues (C++ function), 479  
pdal::Options::Options (C++ function), 478  
pdal::Options::remove (C++ function), 479  
pdal::Options::replace (C++ function), 479  
pdal::Options::toCommandLine (C++ function), 479  
pdal::Options::toMetadata (C++ function), 479  
pdal::PointTable (C++ class), 479  
pdal::PointTable::~PointTable (C++ function), 480  
pdal::PointTable::PointTable (C++ function), 480  
pdal::PointTable::supportsView (C++ function), 480  
pdal::PointView (C++ class), 480  
pdal::PointView::~PointView (C++ function), 480  
pdal::PointView::append (C++ function), 480  
pdal::PointView::appendPoint (C++ function), 480  
pdal::PointView::begin (C++ function), 480  
pdal::PointView::build2dIndex (C++ function), 483  
pdal::PointView::build3dIndex (C++ function), 483  
pdal::PointView::calculateBounds (C++ function), 481  
pdal::PointView::clearTemps (C++ function), 482  
pdal::PointView::compare (C++ function), 481  
pdal::PointView::createMesh (C++ function), 482  
pdal::PointView::dimName (C++ function), 481  
pdal::PointView::dims (C++ function), 481  
pdal::PointView::dimSize (C++ function), 481  
pdal::PointView::dimType (C++ function), 481  
pdal::PointView::dimTypes (C++ function), 481  
pdal::PointView::dump (C++ function), 481  
pdal::PointView::empty (C++ function), 480  
pdal::PointView::end (C++ function), 480  
pdal::PointView::getField (C++ function), 480  
pdal::PointView::getFieldAs (C++ function), 480  
pdal::PointView::getOrAddPoint (C++ function), 482  
pdal::PointView::getPackedPoint (C++ function), 481  
pdal::PointView::getPoint (C++ function), 482  
pdal::PointView::getRawField (C++ function), 481  
pdal::PointView::hasDim (C++ function), 481  
pdal::PointView::id (C++ function), 480  
pdal::PointView::invalidateProducts (C++ function), 482  
pdal::PointView::layout (C++ function), 481  
pdal::PointView::makeNew (C++ function), 480  
pdal::PointView::mesh (C++ function), 482  
pdal::PointView::operator= (C++ function), 480  
pdal::PointView::point (C++ function), 480  
pdal::PointView::pointSize (C++ function), 481  
pdal::PointView::PointView (C++ function),

480  
pdal::PointView::setField (C++ function), 481  
pdal::PointView::setPackedPoint (C++  
function), 482  
pdal::PointView::size (C++ function), 480  
pdal::PointView::spatialReference (C++  
function), 481  
pdal::PointView::table (C++ function), 481  
pdal::PointView::toMetadata (C++ function),  
    482  
pdal::ProgramArgs (C++ class), 483  
pdal::ProgramArgs::add (C++ function),  
    483–485  
pdal::ProgramArgs::addSynonym (C++  
function), 486  
pdal::ProgramArgs::commandLine (C++  
function), 486  
pdal::ProgramArgs::dump (C++ function),  
    486  
pdal::ProgramArgs::dump2 (C++ function),  
    486  
pdal::ProgramArgs::dump3 (C++ function),  
    487  
pdal::ProgramArgs::parse (C++ function), 485  
pdal::ProgramArgs::parseSimple (C++  
function), 485  
pdal::ProgramArgs::reset (C++ function), 486  
pdal::ProgramArgs::set (C++ function), 484  
pdal::Reader (C++ class), 487  
pdal::Stage (C++ class), 487  
pdal::Stage::~Stage (C++ function), 488  
pdal::Stage::addAllArgs (C++ function), 490  
pdal::Stage::addConditionalOptions (C++  
function), 489  
pdal::Stage::addOptions (C++ function), 490  
pdal::Stage::execute (C++ function), 488  
pdal::Stage::findNonstreamable (C++  
function), 489  
pdal::Stage::getInputs (C++ function), 491  
pdal::Stage::getMetadata (C++ function), 491  
pdal::Stage::getName (C++ function), 491  
pdal::Stage::getSpatialReference (C++  
function), 489  
pdal::Stage::isDebug (C++ function), 490  
pdal::Stage::log (C++ function), 490  
pdal::Stage::parseName (C++ function), 491  
pdal::Stage::parseTagName (C++ function),  
    492  
pdal::Stage::pipelineStreamable (C++  
function), 489  
pdal::Stage::prepare (C++ function), 488  
pdal::Stage::preview (C++ function), 488  
pdal::Stage::removeOptions (C++ function),  
    490  
pdal::Stage::serialize (C++ function), 491  
pdal::Stage::setInput (C++ function), 488  
pdal::Stage::setLog (C++ function), 490  
pdal::Stage::setOptions (C++ function), 489  
pdal::Stage::setProgressFd (C++ function),  
    488  
pdal::Stage::setSpatialReference (C++  
function), 489  
pdal::Stage::setTag (C++ function), 491  
pdal::Stage::Stage (C++ function), 488  
pdal::Stage::startLogging (C++ function), 490  
pdal::Stage::stopLogging (C++ function), 490  
pdal::Stage::tag (C++ function), 491  
pdal::StageFactory (C++ class), 492  
pdal::StageFactory::createStage (C++  
function), 492  
pdal::StageFactory::destroyStage (C++  
function), 493  
pdal::StageFactory::inferReaderDriver (C++  
function), 493  
pdal::StageFactory::inferWriterDriver (C++  
function), 493  
pdal::StageFactory::StageFactory (C++  
function), 492  
pdal::Utils (C++ type), 494  
pdal::Utils::BacktraceEntry (C++ class), 512  
pdal::Utils::BacktraceEntry::addr (C++  
member), 512  
pdal::Utils::BacktraceEntry::BacktraceEntry  
(C++ function), 512  
pdal::Utils::BacktraceEntry::libname (C++  
member), 512  
pdal::Utils::BacktraceEntry::offset (C++  
member), 512  
pdal::Utils::BacktraceEntry::symname (C++  
member), 512

pdal::Utils::backtraceImpl (C++ function), [512](#)  
 pdal::Utils::base64\_decode (C++ function), [501](#)  
 pdal::Utils::base64\_encode (C++ function), [500, 501](#)  
 pdal::Utils::checksum (C++ function), [499](#)  
 pdal::Utils::closeProgress (C++ function), [495](#)  
 pdal::Utils::contains (C++ function), [495, 496](#)  
 pdal::Utils::demangle (C++ function), [503](#)  
 pdal::Utils::dirSeparator (C++ member), [512](#)  
 pdal::Utils::dynamicLibExtension (C++ member), [512](#)  
 pdal::Utils::eatcharacter (C++ function), [500](#)  
 pdal::Utils::eatwhitespace (C++ function), [500](#)  
 pdal::Utils::endsWith (C++ function), [498](#)  
 pdal::Utils::escapeJSON (C++ function), [503](#)  
 pdal::Utils::escapeNonprinting (C++ function), [503](#)  
 pdal::Utils::extractDim (C++ function), [495](#)  
 pdal::Utils::fromString (C++ function), [510, 511](#)  
 pdal::Utils::fromString<char> (C++ function), [511](#)  
 pdal::Utils::fromString<double> (C++ function), [511](#)  
 pdal::Utils::fromString<Eigen::MatrixXd> (C++ function), [494](#)  
 pdal::Utils::fromString<signed char> (C++ function), [511](#)  
 pdal::Utils::fromString<unsigned char> (C++ function), [511](#)  
 pdal::Utils::getenv (C++ function), [499](#)  
 pdal::Utils::hexDump (C++ function), [504](#)  
 pdal::Utils::iequals (C++ function), [498](#)  
 pdal::Utils::inRange (C++ function), [507](#)  
 pdal::Utils::insertDim (C++ function), [495](#)  
 pdal::Utils::normal (C++ function), [497](#)  
 pdal::Utils::normalizeLongitude (C++ function), [504](#)  
 pdal::Utils::numericCast (C++ function), [507, 508](#)  
 pdal::Utils::openProgress (C++ function), [495](#)  
 pdal::Utils::pathListSeparator (C++ member),

pdal::Utils::portable\_pclose (C++ function), [501](#)  
 pdal::Utils::portable\_popen (C++ function), [501](#)  
 pdal::Utils::printError (C++ function), [495](#)  
 pdal::Utils::random (C++ function), [497](#)  
 pdal::Utils::random\_seed (C++ function), [497](#)  
 pdal::Utils::redirect (C++ function), [506](#)  
 pdal::Utils::RedirectStream (C++ class), [512](#)  
 pdal::Utils::RedirectStream::m\_buf (C++ member), [513](#)  
 pdal::Utils::RedirectStream::m\_null (C++ member), [513](#)  
 pdal::Utils::RedirectStream::m\_out (C++ member), [513](#)  
 pdal::Utils::RedirectStream::RedirectStream (C++ function), [512](#)  
 pdal::Utils::remove (C++ function), [496](#)  
 pdal::Utils::remove\_if (C++ function), [496](#)  
 pdal::Utils::replaceAll (C++ function), [502](#)  
 pdal::Utils::restore (C++ function), [507](#)  
 pdal::Utils::run\_shell\_command (C++ function), [501](#)  
 pdal::Utils::screenWidth (C++ function), [503](#)  
 pdal::Utils::setenv (C++ function), [499](#)  
 pdal::Utils::simpleWordexp (C++ function), [506](#)  
 pdal::Utils::sround (C++ function), [498](#)  
 pdal::Utils::startsWith (C++ function), [498](#)  
 pdal::Utils::toDouble (C++ function), [495](#)  
 pdal::Utils::tolower (C++ function), [498](#)  
 pdal::Utils::toMetadata (C++ function), [495](#)  
 pdal::Utils::toNative (C++ function), [512](#)  
 pdal::Utils::toString (C++ function), [508–510](#)  
 pdal::Utils::toupper (C++ function), [498](#)  
 pdal::Utils::trim (C++ function), [500](#)  
 pdal::Utils::trimLeading (C++ function), [500](#)  
 pdal::Utils::trimTrailing (C++ function), [500](#)  
 pdal::Utils::typeidName (C++ function), [506](#)  
 pdal::Utils::uniform (C++ function), [497](#)  
 pdal::Utils::unsetenv (C++ function), [499](#)  
 pdal::Utils::wordWrap (C++ function), [502](#)  
 pdal::Utils::wordWrap2 (C++ function), [502](#)  
 pdal::Utils::writeProgress (C++ function), [495](#)

pdal::Writer (C++ class), 513  
pip, 235  
poisson, 337  
Potree, 310  
project, 372  
pronounce, 519  
Python, 11, 233–235, 370

## Q

QGIS, 292, 313  
query, 302  
Quickstart, 17

## R

range filter, 329  
Raster, 323  
rasterization, 356  
References, 522  
Reprojection, 305  
RGB, 323  
RIEGL, 370

## S

sample, 337  
search, 302  
SOCS, 288  
Source, 235  
spatial reference system, 299  
Stage, 487  
Start Here, 297

## T

thinning, 337

## U

Utils, 494  
UTM, 305, 370

## V

Vector, 317  
voxel sampling, 337

## W

web services, 310  
WGS84, 305, 370