



PDAL: Point cloud Data Abstraction Library

Release 2.3.0

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PDAL is a C++ library for translating and manipulating [point cloud data](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 57) and *Writers* (page 115) to list data formats it supports, and see *Filters* (page 150) 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 297) 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>

**CHAPTER
ONE**

NEWS

1.1 06-28-2021

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

<https://mapscaping.com/blogs/the-mapscaping-podcast/pdal-point-data-abstraction-library>

1.2 05-19-2021

PDAL 2.2.1 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.

CHAPTER TWO

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). 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 150) on point clouds into *pipelines* (page 47) 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 73) stage, a *Reprojection* (page 222) stage, and a *PostgreSQL Writer* (page 138), 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. 1: A simple PDAL pipeline composed of a reader, filter, and writer stages.

A PDAL JSON *Pipeline* (page 47) 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 35), to allow you to execute them.

Note: Raster processing tools often compose operations with this approach. PDAL conceptually steals its pipeline modeling from **GDAL** (<http://gdal.org/>)'s **Virtual Raster Format**

(http://www.gdal.org/gdal_vrttut.html).

2.1.3 How is it different than other tools?

LAStools

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

1. All components of PDAL are released as open source software under an **OSI** (<https://opensource.org/licenses>)-approved license.
2. PDAL allows application developers to provide proprietary extensions that act as stages in processing pipelines. These might be things like custom format readers, specialized exploitation algorithms, or entire processing pipelines.
3. PDAL can operate on point cloud data of any format – not just **ASPRS LAS** (<http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html>). **LAStools** (<http://lastools.org>) can read and write formats other than LAS, but relates all data to its internal handling of LAS data, limiting it to *dimension* (page 289) types provided by the LAS format.
4. PDAL is coordinated by users with its declarative **JSON** (page 47) syntax. LAStools is coordinated by linking lots of small, specialized command line utilities together with intricate arguments.
5. PDAL is an open source project, with all of its development activities available online at <https://github.com/PDAL/PDAL>

PCL

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

Entwine

Potree

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

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

Others

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

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

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

2.1.4 Where did PDAL come from?

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

PDAL evolved out of the development of database storage and access capabilities for the U.S. Army Corps of Engineers [CRREL](#) (<http://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact>-

Sheet-Article-View/Article/476649/remote-sensinggeographic-information-systems-center/GRiD (<http://lidar.io/>) project. Functionality that was creeping into libLAS (<http://liblas.org/>) was pulled into a new library, and it was designed from the ground up to mimic successful extract, transform, and load libraries in the geospatial software domain. PDAL has steadily attracted more contributors as other software developers use it to provide point cloud data translation and processing capability to their software.

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

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

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

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

Note: Possible point cloud dimension types provided and supported by PDAL can be found at [Dimensions](#) (page 289).

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 150), [Readers](#) (page 57), and [Writers](#) (page 115). 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 45) 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 523) 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 513) and its [source code](#) (<https://github.com/PDAL/PDAL/tree/master/test/unit>).

See also:

PDAL [software](#) (page 307) [development](#) (page 471) [tutorials](#) (page 485) 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 31) about a data set
- Data [translation](#) (page 42) 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 30)
 - *Merge* (page 34) or *split* (page 37) data
 - *Catalog* (page 40) collections of data
-

Note: The command line utilities are often simply *pipeline* (page 35) and *Pipeline* (page 47) collected into a convenient application. In many cases you can replicate the functionality of an application entirely within a single pipeline.

Python API

PDAL supports both embedding [Python](http://python.org/) (<http://python.org/>) and extending with [Python](http://python.org/) (<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 297) document contains information on how to install and use the PDAL Python extension.

Julia Plugin

PDAL supports embedding [|Julia|](#) filters. These allow you to dynamically interact with point cloud data in a more comfortable and familiar language environment for geospatial practitioners, while still maintaining high performance.

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

See also:

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

Documentation for the stage [*filters.julia*](#) (page 284)

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

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 - *Current Release(s)* (page 13)
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 - * *RPMs* (page 15)
 - * *Debian* (page 15)
 - * *Alpine* (page 15)
 - * *Conda* (page 16)

3.1.1 Current Release(s)

- **2021-05-19 PDAL-2.3.0-src.tar.gz**
(<https://github.com/PDAL/PDAL/releases/download/2.3.0/PDAL-2.3.0-src.tar.gz>)
[Release Notes](https://github.com/PDAL/PDAL/releases/tag/2.3.0) (<https://github.com/PDAL/PDAL/releases/tag/2.3.0>) ([md5](#)
(<https://github.com/PDAL/PDAL/releases/download/2.3.0/PDAL-2.3.0-src.tar.gz.md5>))

3.1.2 Past Releases

- **2020-08-20** [PDAL-2.2.0-src.tar.gz](#)
(<https://github.com/PDAL/PDAL/releases/download/2.2.0/PDAL-2.2.0-src.tar.gz>)
- **2020-03-20** [PDAL-2.1.0-src.tar.gz](#)
(<https://github.com/PDAL/PDAL/releases/download/2.1.0/PDAL-2.1.0-src.tar.gz>)
- **2019-08-23** [PDAL-2.0.1-src.tar.gz](#)
(<https://github.com/PDAL/PDAL/releases/download/2.0.1/PDAL-2.0.1-src.tar.gz>)
- **2019-05-09** [PDAL-1.9.1-src.tar.gz](#)
(<https://github.com/PDAL/PDAL/releases/download/1.9.1/PDAL-1.9.1-src.tar.gz>)
- **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>)
- **2018-10-12** [PDAL-1.8.0-src.tar.gz](#)
(<http://download.osgeo.org/pdal/PDAL-1.8.0-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, MATLAB, MBIO, OpenSceneGraph, RDBLIB, and RiVLib. To enable any of these plugins, the reader will need to install any required dependencies and build PDAL from source.

Table 1: PDAL Distribution Feature Comparison

	Docker	RPMs	Debian	Alpine	<i>Conda</i> (page 16)
Platform(s)	linux	linux	linux	linux	win64, mac, linux
PDAL version	2.3			2.2	2.3
CPD				X	
E57	X				X
HDF	X				X
I3S					X
Icebridge	X			X	X
NITF	X				X (except Windows)
pgpointcloud	X			X	X
SLPK					X
TileDB	X				X (except Windows)

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=*&branch=edge.

Users have a choice of three separate packages.

1. `pdal` will install the PDAL binaries only, and is suitable for users who will be using the PDAL command line applications.
2. `pdal-dev` will install development files which are required for users building their own software that will link against PDAL.
3. `py-pdal` will install the PDAL Python extension.

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

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

```
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 it's dependencies) live in the [Conda Forge](#) (<https://anaconda.org/conda-forge/pdal>) channel, the command to install both the PDAL application and the Python extension is

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

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

CHAPTER
FOUR

QUICKSTART

4.1 Quickstart

4.1.1 Introduction

The quickest way to start using PDAL is to leverage builds that were constructed by the PDAL development team using [Conda](https://conda.io/docs/) (<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 73) file. It will utilize the PDAL [command line application](#) (page 25) to inspect the file.

Note: If you need to compile your own copy of PDAL, see [Compilation](#) (page 458) for more details.

4.1.2 Install Conda

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

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

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

Run Conda

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

Test Installation

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

Install the PDAL Package

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

Warning: It is a good idea to install PDAL in 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 can read more about it [here](#) (<https://conda.io/projects/conda/en/latest/user-guide/getting-started.html#managing-envs>).

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

```
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 ##
```

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```
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
setup-tools-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	conda-forge [vc14]
icu:	58.2-vc14_0	conda-forge [vc14]
intel-openmp:	2018.0.3-0	
jpeg:	9b-vc14_2	conda-forge [vc14]
kealib:	1.4.7-vc14_4	conda-forge [vc14]
krb5:	1.14.6-vc14_0	conda-forge [vc14]
laszip:	3.2.2-vc14_0	conda-forge [vc14]
laz-perf:	1.2.0-vc14_1	conda-forge [vc14]

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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
wincerestore:	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%	
setuptools-39.2.0	591 KB #####
↳ / 100%	
numpy-1.14.3	42 KB #####
↳ / 100%	

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```
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 31) 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 447) to learn how to embed and use PDAL in your own applications.
- [Readers](#) (page 57) lists the formats that PDAL can read, [Filters](#) (page 150) lists the kinds of operations you can do with PDAL, and [Writers](#) (page 115) lists the formats PDAL can write.
- [Tutorials](#) (page 307) contains a number of walk-through tutorials for achieving many tasks with PDAL.
- [The PDAL workshop](#) (page 351) 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 297) describes how PDAL embeds and extends Python and how you can leverage these capabilities in your own programs.

See also:

[Community](#) (page 45) 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 --drivers
$ pdal --options writers.las
```

All commands support the following options:

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

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

```
$ pdal translate \
  --writers.las.creation_doy="42" \
  input.las \
  output.las
```

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

5.1.1 chamfer

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

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

$$d_{CD}(X, Y) = \sum_{x \in X} \min_{y \in Y} \|x - y\|_2^2 + \sum_{y \in Y} \min_{x \in X} \|x - y\|_2^2$$

```
$ pdal chamfer <source> <candidate>
```

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

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

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

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

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

5.1.2 delta

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
```

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```
4,0.00,0.00,0.00  
5,0.00,0.00,0.00
```

5.1.3 density

The density command produces a tessellated hexagonal OGR layer (http://www.gdal.org/ogr_utilities.html) from the output of *filters.hexbin* (page 265).

```
$ 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
```

5.1.4 eval

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

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

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

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

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

```
$ pdal eval predicted.las truth.las --labels 2,4
{
  "confusion_matrix": "[[5240537,3860,24102],[268015,3179304,326677],
  [111453,115516,2950315]]",
  "f1_score": 0.944,
  "labels": [
    {
      "accuracy": 0.967,
      "f1_score": 0.973,
      "intersection_over_union": 0.947,
      "label": "1",
      "precision": 0.951,
      "sensitivity": 0.995,
      "specificity": 0.929,
      "support": 5268499
    },
    {
      "accuracy": 0.934,
      "f1_score": 0.914,
      "intersection_over_union": 0.842,
      "label": "2",
      "precision": 0.999,
      "sensitivity": 0.842,
      "specificity": 0.999,
      "support": 3773996
    }
  ],
  "mean_intersection_over_union": 0.894,
  "overall_accuracy": 0.931,
  "pdal_version": "2.2.0 (git-version: 6e80b9)",
  "predicted_file": "predicted.las",
  "truth_file": "truth.las"
}
```

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

5.1.5 ground

The `ground` command is used to segment the input point cloud into ground versus non-ground returns using [filters.smrf](#) (page 155) and [filters.outlier](#) (page 159).

```
$ 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
--extract	Extract ground returns?
--reset	Reset classifications prior to segmenting?
--denoise	Apply statistical outlier removal prior to ↴segmenting?
--returns	Include last returns?
--scalar	Elevation scalar?
--threshold	Elevation threshold?
--cut	Cut net size?
--ignore	A range query to ignore when processing

5.1.6 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	Source filename
--candidate arg	Candidate filename

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

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

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

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

5.1.7 info

Displays information about a point cloud file, such as:

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

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

-- input , -i	Input file name
--all	Dump statistics, schema and metadata
--point, -p	Point to dump --point="1-5,10,100-200" (0..)
~indexed)	
--query	Return points in order of distance from the specified location (2D or 3D) --query Xcoord,Ycoord[,Zcoord][/count]
--stats	Dump stats on all points (reads entire..)
~dataset)	
--boundary	Compute a hexagonal hull/boundary of dataset

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--dimensions	Dimensions on which to compute statistics
--enumerate	Dimensions whose values should be enumerated
--schema	Dump the schema
--pipeline-serialization	Output filename for pipeline serialization
--summary	Dump summary of the info
--metadata	Dump file metadata info
--stdin, -s	Read a pipeline file from standard input

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

Example 1:

```
$ pdal info test/data/las/1.2-with-color.las \
    --query="636601.87, 849018.59, 425.10"
{
    "0": {
        "Blue": 134,
        "Classification": 1,
        "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,
    }
}
```

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```

    "NumberOfReturns": 1,
    "PointSourceId": 7327,
    "Red": 143,
    "ReturnNumber": 1,
    "ScanAngleRank": -10,
    "ScanDirectionFlag": 1,
    "UserData": 126,
    "X": 636606.76000000001,
    "Y": 849053.94000000006,
    "Z": 425.8899999999999
},
...

```

Example 2:

```

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

```

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```
"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
},
...
...
```

5.1.8 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.

5.1.9 pipeline

The `pipeline` command is used to execute *Pipeline* (page 47) JSON. By default the pipeline is run in stream mode if possible, otherwise in standard mode. See *Reading with PDAL* (page 307) or *Pipeline* (page 47) for more information.

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

--input, -i	Input filename
--dims	Limit loaded dimensions to this <code>list</code> . Note ↴ that X, Y and Z are always loaded.
--pipeline-serialization	Output file for pipeline serialization
--validate	Validate but do not process the pipeline. Also reports whether a pipeline can be streamed.
--progress	Name of file or FIFO to which stages should ↴ <code>write</code>
↳ <code>create</code> the progress file.	progress information. The file/FIFO must exist. PDAL will not ↴ <code>create</code> the progress file.
--stdin, -s	Read pipeline from standard input
--metadata	Metadata filename
--stream	Run in stream mode. If not possible, exit.
--nostream	Run in standard mode.

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",
    {
```

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```
"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.

5.1.10 random

The `random` command is used to create a random point cloud. It uses [readers.faux](#) (page 64) 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)
--count	How many points should we write?
--bounds	Extent (in XYZ to clip output to)
--mean	A comma-separated or quoted, space-separated list of ↵
means	(normal mode): --mean 0.0,0.0,0.0 --mean "0.0 0.0 0.0"
--stdev	A comma-separated or quoted, space-separated list of standard deviations (normal mode): --stdev 0.0,0.0,0.0 --stdev "0.0 ↵
0.0 0.0"	
--distribution	Distribution (uniform / normal)

5.1.11 sort

The `sort` command uses [filters.mortonorder](#) (page 212) 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	

5.1.12 split

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

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

```
--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.

5.1.13 tile

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

This command is similar to the `split` (page 37) 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_\(programming\)](https://en.wikipedia.org/wiki/Glob_(programming))) to allow multiple files as input.

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

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

Example 1:

```
$ pdal tile infile.laz "outfile_#.bpf"
```

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

Example 2:

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

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

5.1.14 tindex

The `tindex` command is used to create a [GDAL](http://www.gdal.org) (<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: Output red
↳ 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 with no SRS to this value
--write_absolute_path	Write absolute rather than relative file paths
--stdin, -s	Read filespec pattern from standard input

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) (<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.

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

5.1.15 translate

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

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

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

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 voxel grid filter, followed by the SMRF filter and a range filter. We can even set stage-specific parameters as shown.

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

Example 3:

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

```
$ 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 45), [GitHub](#) (page 46), [Gitter](#) (<https://gitter.im/PDAL/PDAL>) and [IRC](#) (page 46). Please feel welcome to ask questions and participate in all of the venues. The [Mailing List](#) (page 45) communication channel is for general questions, development discussion, and feedback. The [GitHub](#) (page 46) communication channel is for development activities, bug reports, and testing. The [IRC](#) (page 46) 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_\(software\)](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 447) 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 46). Gitter uses your [GitHub](#) (page 46) 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 45) and [GitHub](#) (page 46) 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 42), 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 35) 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 51) representations.
- a JSON array, being the array described above without being encapsulated by a JSON object.

Simple Example

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

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



Fig. 1: A simple pipeline to convert *LAS* (page 73) to *BPF* (page 57) 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 121) writer:

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

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```

    "type": "filters.merge",
    "tag": "merged",
    "inputs": [
        "A2",
        "B"
    ],
},
{
    "type": "writers.gdal",
    "filename": "output.tif"
}
]

```



Fig. 2: A more complex pipeline that merges two inputs together but uses *filters.reprojection* (page 222) 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 258), 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:

```
[  
    "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 42) or [pdal pipeline](#) (page 35) PDAL uses stream mode if possible. If stream mode can't be used the applications fall back to standard mode processing. Streamable stages are tagged in the stage documentation with a blue bar. Users can explicitly choose to use standard mode by using the `--nostream` option. Users of the PDAL API can explicitly control the selection of the PDAL processing mode.

7.1.3 Pipelines

Pipeline Array

PDAL JSON pipelines are an array of stages.

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

Old format:

```
{  
    "pipeline" :  
    [  
        "inputfile",  
        "outputfile"
```

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```
    ]  
}
```

Equivalent new format:

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

- The pipeline array may have any number of string or *Stage Objects* (page 51) 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 57), *Writers* (page 115), and *Filters* (page 150).

- 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 placed in a separate file. See [Option Files](#) (page 52) for details.

Filename Globbing

- A filename may contain the wildcard character `*` to match any string of characters. This can be useful if working with multiple input files in a directory (e.g., merging all files).
Filename globbing ONLY works in pipeline file specifications. It doesn't work when a filename is provided as an option through a command-line application like `pdal pipeline` or `pdal translate`.

Option Files

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

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

```
{  
    "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 57) to *LAS* (page 126), inferring both the reader and writer type, and setting a number of options on the writer stage.

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

Python HAG

In our next example, the reader and writer types are once again inferred. After reading the input file, the ferry filter is used to copy the Z dimension into a new height above ground (HAG) dimension. Next, the *filters.python* (page 278) 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) (<https://raw.githubusercontent.com/PDAL/PDAL/master/test/data/autzen/hag.py.in>).

See also:

filters.hag_nn (page 171) describes using a specific filter to do this job in more detail.

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

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```
 },
"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 155), filters out all points but the ground returns (classification value of 2) using the [filters.range](#) (page 250), and then creates the DTM using the [writers.gdal](#) (page 121).

```
[
  "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.

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

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

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```
[  
  {  
    "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.

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

See also:

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

Note: Issuing the command `pdal info --options` will list all available stages and their options. See [info](#) (page 31) for more.

7.2 Stages

The stages of a PDAL [Pipeline](#) (page 47) are divided into [Readers](#) (page 57), [Filters](#) (page 150) and [Writers](#) (page 115). Stages may support [streaming mode](#) (page 49) or not, depending on their functionality or particular implementation. Many stages are built into the base PDAL library (the file `pdalcpp.so` on Unix, `pdalcpp.dylib` on OSX and `pdalcpp.dll` on Windows). PDAL can also load stages that have been built separately. These stages are called plugins.

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

PDAL will automatically load plugins when necessary. PDAL plugins have a specific naming pattern:

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

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

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

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

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

7.3 Readers

Readers provide *Dimensions* (page 289) to *Pipeline* (page 47). 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 107), a complex database like *readers.pgpointcloud* (page 90), or a network service like *readers.ept* (page 59).

7.3.1 readers.bpf

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

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

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

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example

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

Options

filename BPF file to read [Required]

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

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

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

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

7.3.2 readers.buffer

The *readers.buffer* (page 58) 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 471) 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 471) for an example usage scenario for `readers.buffer` (page 58).

Options

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

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

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

7.3.3 readers.ept

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

Sample EPT datasets of hundreds of billions of points in size may be viewed with [Potree](#) (<http://potree.entwine.io/data/nyc.html>) or '[Plasio](#)'.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example

This example downloads a small area around the 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>).

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

Additional attributes created by the [EPT addon writer](#) (page 117) 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 117).

Options

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

spatialreference Spatial reference to apply to the data. Overrides any SRS in the input itself.
Can be specified as a WKT, proj.4 or EPSG string. [Default: none]

bounds The extents of the resource to select in 2 or 3 dimensions, expressed as a string, e.g.:
`([xmin, xmax], [ymin, ymax], [zmin, zmax])`. If omitted, the entire dataset

will be selected.

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

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

addons A mapping of assignments of the form `DimensionName : AddonPath`, which assigns dimensions from the specified paths to the named dimensions. These addon dimensions are created by the *EPT addon writer* (page 117). If the dimension names already exist in the EPT Schema (<https://entwine.io/entwine-point-tile.html#schema>) for the given resource, then their values will be overwritten with those from the appropriate addon.

Addons may used to override well-known *dimension* (page 289). 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 determined from the file’s position in EPT metadata file `entwine-files.json`.

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

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.

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

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

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

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

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

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

7.3.4 readers.e57

The **E57 Reader** supports reading from E57 files.

The reader supports E57 files with Cartesian point clouds.

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

Only dimensions present in all of the point clouds will be read.

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

Note: The E57 `cartesianInvalidState` dimension is mapped to the Omit PDAL dimension. A

range filter can be used to filter out the invalid points.

Dynamic Plugin

This stage requires a dynamic plugin to operate

Streamable Stage

This stage supports streaming operations

Example 1

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

Example 2

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

Options

filename E57 file to read [Required]

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

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

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

7.3.5 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

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

Options

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

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

override_srs Spatial reference to apply to data. [Optional]

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

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

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

7.3.6 readers.gdal

The [GDAL](http://gdal.org) (<http://gdal.org>) reader reads [GDAL 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.

```
[  
  {  
    "type": "readers.gdal",  
    "filename": "./pdal/test/data/autzen/autzen.jpg"  
  },  
  {  
    "type": "writers.text",  
    "filename": "outputfile.txt"  
  }  
]
```

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) (<http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html>) file using *writers.las* (page 126).

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

Options

filename [GDALOpen](#)

(https://gdal.org/api/raster_c_api.html#gdal_8h_1aca05455472359964151f9c891d678d5e)
‘able raster file to read [Required]

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

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

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

header A comma-separated list of *dimension* (page 289) IDs to map bands to. The length of the list must match the number of bands in the raster.

7.3.7 readers.hdf

The **HDF reader** reads data from files in the **HDF5** format.

(<https://www.hdfgroup.org/solutions/hdf5/>) You must explicitly specify a mapping of HDF datasets to PDAL dimensions using the dimensions parameter. ALL dimensions must be scalars and be of the same length. Compound types are not supported at this time.

Dynamic Plugin

This stage requires a dynamic plugin to operate

Streamable Stage

This stage supports streaming operations

Example

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

```
[  
  {  
    "type": "readers.hdf",  
    "filename": "test/data/hdf/autzen.h5",  
    "dimensions":  
    {  
      "X" : "autzen/X",  
      "Y" : "autzen/Y",  
      "Z" : "autzen/Z",  
      "Red" : "autzen/Red",  
      "Blue" : "autzen/Blue",  
      "Green" : "autzen/Green",  
      "Classification" : "autzen/Classification",  
      "EdgeOfFlightLine" : "autzen/EdgeOfFlightLine",  
      "GpsTime" : "autzen/GpsTime",  
    }  
  }  
]
```

(continues on next page)

(continued from previous page)

```
        "Intensity" : "autzen/Intensity",
        "NumberOfReturns" : "autzen/NumberOfReturns",
        "PointSourceId" : "autzen/PointSourceId",
        "ReturnNumber" : "autzen/ReturnNumber",
        "ScanAngleRank" : "autzen/ScanAngleRank",
        "ScanDirectionFlag" : "autzen/ScanDirectionFlag",
        "UserData" : "autzen/UserData"
    }
},
{
    "type" : "writers.las",
    "filename": "output.las",
    "scale_x": 1.0e-5,
    "scale_y": 1.0e-5,
    "scale_z": 1.0e-5,
    "offset_x": "auto",
    "offset_y": "auto",
    "offset_z": "auto"
}
]
```

Note: All dimensions must be simple numeric HDF datasets with equal lengths. Compound types, enum types, string types, etc. are not supported.

Warning: The HDF reader does not set an SRS.

Common Use Cases

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

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

```
[
  {
    "type": "readers.hdf",
    "filename": "ATL03_20190906201911_10800413_002_01.h5",
    "dimensions":
    {
      "X" : "gt11/heights/lon_ph",
      "Y" : "gt11/heights/lat_ph",
      "Z" : "gt11/heights/h_ph"
    }
  },
  {
    "type" : "writers.las",
    "filename": "output.las"
  }
]
```

Options

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

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

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

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

7.3.8 readers.i3s

Indexed 3d Scene Layer (I3S) (<https://github.com/Esri/i3s-spec/blob/master/format/Index3d%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.

```
[  
  {  
    "type": "readers.i3s",  
    "filename": "https://tiles.arcgis.com/tiles/8cv2FuXuWSff0nbL/  
    ↪arcgis/rest/services/AUTZEN_LiDAR/SceneServer",  
    "obb": {  
      "center": [  
        636590,  
        849216,  
        460  
      ],  
      "halfSize": [  
        590,  
        281,  
        60  
      ],  
      "quaternion": [  
        [  
          0,  
          0,  
          0,  
          1  
        ]  
      ]  
    }  
  }  
]
```

```
pdal translate i3s://https://tiles.arcgis.com/tiles/8cv2FuXuWSff0nbL/  
    ↪arcgis/rest/services/AUTZEN_LiDAR/SceneServer \  
    autzen.las \  
    --readers.i3s.threads=64
```

Options

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

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

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

filename I3S file stored remotely. These must be prefaced with an "i3s://".

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

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

Example: --readers.i3s.threads=64

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

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

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`

7.3.9 readers.ilvis2

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

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. 3: Dimensions provided by the ILVIS2 reader

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example

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

Options

filename File to read from [Required]

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

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

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

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

metadata XML metadata file to coincidentally read [Optional]

7.3.10 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://laszip.org>) files. In order to use compressed LAS (LAZ), your version of PDAL must be built with one of the two supported decompressors, [LASzip](#) (<http://laszip.org>) or [LAZperf](#) (<https://github.com/verma/laz-perf>). See the *compression* (page 75) 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 126) to facilitate transfer of header information from source to destination LAS/LAZ files.

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

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

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example

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

Options

filename LAS file to read [Required]

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

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

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

extra_dims Extra dimensions to be read as part of each point beyond those specified by the LAS point format. The format of the option is <dimension_name>=<type>[, . . .]. Any valid PDAL *type* (page 295) can be specified.

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

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

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

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

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

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

7.3.11 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 *dimension* (page 289) 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

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

Options

filename Input file name. [Required]

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

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

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

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

7.3.12 readers.memoryview

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

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

7.3.13 Usage

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

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

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

void pushField(const Field&);
```

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

```
using PointIncrementer = std::function<char *(PointId)>;  
  
void setIncrementer(PointIncrementer inc);
```

Options

None.

7.3.14 readers.mbio

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

Dynamic Plugin

This stage requires a dynamic plugin to operate

Streamable Stage

This stage supports streaming operations

Example

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

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

Options

filename Filename to read from [Required]

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

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

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

format Name of number of format of file being read. See MB-System documentation for a list of all formats

(http://www3.mbari.org/products/mbsystem/html/mbsystem_formats.html). [Required]

datatype Type of data to read. Either 'multibeam' or 'sidescan'. [Default: 'multibeam']

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

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

7.3.15 readers.mrsid

Note: The MrSID reader is deprecated and will be removed in a future release.

Implements MrSID 4.0 LiDAR Compressor. It requires the [Lidar_DSDK](#) (<https://www.extensis.com/support/developers>) to be able to decompress and read data.

Dynamic Plugin

This stage requires a dynamic plugin to operate

Example

```
[  
  {  
    "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]

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

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

7.3.16 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) (<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 73) and [*writers.las*](#) (page 126) to actually read and write the data.

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

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example

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

Options

filename Filename to read from [Required]

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

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

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

extra_dims Extra dimensions to be read as part of each point beyond those specified by the LAS point format. The format of the option is <dimension_name>=<type>[, . . .]. Any PDAL *type* (page 295) can be specified.

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

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

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

7.3.17 readers.numpy

PDAL has support for processing data using [filters.python](#) (page 278), but it is also convenient to read data from [Numpy](#) (<http://www.numpy.org/>) for processing in PDAL.

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

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

Array Types

`readers.numpy` supports reading data in two forms:

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

Structured Arrays

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

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

The `numpy` reader supports reading these Numpy arrays and mapping field names to standard PDAL [dimension](#) (page 289) 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
        }
      ]
    }
  ]
}
```

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```
},
{
  "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

Loading Options

readers.numpy (page 83) supports two modes of operation - the first is to pass a reference to a .npy file to the `filename` argument. It will simply load it and read.

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

Loading from a Python script

A reference to a Python function that returns a Numpy array can also be used to tell *readers.numpy* (page 83) what to load. The following example itself loads a Numpy array from a Python script

Python Script

```
import numpy as np

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

Command Line Invocation

Using the above Python file with its `load` function, the following `pdal_info` invocation passes in the reference to the filename to load.

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

Pipeline

An example *Pipeline* (page 47) definition would follow:

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

Options

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

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

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

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

dimension *Dimension* (page 289) name to map raster values

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

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

function The function name in the module to call.

fargs The function args to pass to the function

Note: The functionality of the 'assign_z' option in previous versions is provided with *filters.assign* (page 205)

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

7.3.18 readers.optech

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

Default Embedded Stage

This stage is enabled by default

Example

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

Options

filename csd file to read [Required]

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

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

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

7.3.19 readers.pcd

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

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example

```
[  
  {  
    "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]

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

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

7.3.20 readers.pgPointCloud

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

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

Dynamic Plugin

This stage requires a dynamic plugin to operate

Example

```
[  
  {  
    "type": "readers.pgPointCloud",  
    "connection": "dbname='lidar' user='user'",  
    "table": "lidar",  
    "column": "pa",  
    "spatialreference": "EPSG:26910",  
    "where": "PC_Intersects(pa, ST_MakeEnvelope(560037.36, 5114846.  
→45, 562667.31, 5118943.24, 26910))"  
  },  
  {  
    "type": "writers.text",  
    "filename": "output.txt"  
  }  
]
```

Options

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

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

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

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

table Database table to read from. [Required]

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

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

7.3.21 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 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

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

Options

filename ply file to read [Required]

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

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

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

7.3.22 readers pts

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

Default Embedded Stage

This stage is enabled by default

Example Pipeline

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

Options

filename File to read. [Required]

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

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

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

7.3.23 readers.qfit

The **QFIT reader** read from files in the **QFIT** format

(<http://nsidc.org/data/docs/daac/icebridge/ilatm1b/docs/ReadMe.qfit.txt>) originated for the Airborne Topographic Mapper (ATM) project at NASA Goddard Space Flight Center.

Default Embedded Stage

This stage is enabled by default

Example

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

Options

filename File to read from [Required]

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

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

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

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

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

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

7.3.24 readers.rdb

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

Dynamic Plugin

This stage requires a dynamic plugin to operate

Streamable Stage

This stage supports streaming operations

Installation

To build PDAL with rdb support, set `rdb_DIR` to the path of your local `rdplib` installation. `rdplib` 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 `rdplib` 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 rdblib version required to build the driver and run the tests: 2.1.6
 - This driver was developed and tested on Ubuntu 17.10 using GCC 7.2.0.
-

Example

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

```

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

```

Options

filename Name of file to read [Required]

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

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

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

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

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

Dimensions

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

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 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 2: Example:

```

1  [{"  
2      "compression_options": "shuffle",  
3      "default_value": 0,  
4      "description": "Cartesian point coordinates wrt. application_  
5      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 }
```

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```

13   "title": "XYZ",
14   "unit_symbol": "m"
15 },
16 {
17   "compression_options": "shuffle",
18   "default_value": 0,
19   "description": "Target surface reflectance",
20   "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 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": {

```

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```

16 "crs": {
17     "epsg": 4956,
18     "wkt": "GEOCCS[\"NAD83(HARN) \\/ Geocentric\",DATUM[\"NAD83(HARN)\"
19 \",SPHEROID[\"GRS 1980\",6378137.000,298.257222101,AUTHORITY[\"EPSG\",\
20 \"7019\"]],AUTHORITY[\"EPSG\",\"6152\"]],PRIMEM[\"Greenwich\",0.
21 \r0000000000000000,AUTHORITY[\"EPSG\",\"8901\"]],UNIT[\"Meter\",1.
22 \r0000000000000000,AUTHORITY[\"EPSG\",\"9001\"]],AXIS[\"X\",OTHER],
23 \rAXIS[\"Y\",EAST],AXIS[\"Z\",NORTH],AUTHORITY[\"EPSG\",\"4956\"]]"
24     },
25     "pose": [
26         0.837957447, 0.379440385, -0.392240121, -2505819.156,
27         -0.545735575, 0.582617132, -0.602270669, -3847595.645,
28         0.000000000, 0.718736580, 0.695282481, 4412064.882,
29         0.000000000, 0.000000000, 0.000000000, 1.000
30     ]
31 }
32 }
```

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

Details about the metadata objects see RDB SDK documentation.

List “transactions”

List of transaction objects describing the history of the file.

Listing 4: Example:

```

1 [{  
2     "agent": "RDB Library 2.1.6-1677 (x86_64-windows, Apr 5 2018,  
3 \r10:58:39)",  
4     "comments": "",  
5     "id": 1,  
6     "fdb": "RDB Library 2.1.6-1677 (x86_64-windows, Apr 5 2018,  
7 \r10:58:39)",  
8     "settings": {  
9         "cache_size": 524288000,  
10        "chunk_size": 65536,  
11        "chunk_size_lod": 20,  
12    }  
13 }
```

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```
10  "compression_level": 10,
11  "primary_attribute": {
12      "compression_options": "shuffle",
13      "default_value": 0,
14      "description": "Cartesian point coordinates wrt. application ↴
15      coordinate system (0: X, 1: Y, 2: Z)",
16      "invalid_value": "",
17      "length": 3,
18      "maximum_value": 535000,
19      "minimum_value": -535000,
20      "name": "riegl.xyz",
21      "resolution": 0.00025,
22      "scale_factor": 1,
23      "storage_class": "variable",
24      "title": "XYZ",
25      "unit_symbol": "m"
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": "",
```

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```
49     "title": "Meta data saved"  
50 }]
```

Details about the transaction objects see RDB SDK documentation.

7.3.25 readers.rxp

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

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

Dynamic Plugin

This stage requires a dynamic plugin to operate

Streamable Stage

This stage supports streaming operations

Installation

To build PDAL with rxp support, set RiVLib_DIR to the path of your local RiVLib installation. RiVLib can be obtained from the [RIEGL download pages](http://www.riegl.com/members-area/software-downloads/libraries/) (<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.

Example

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

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

We set the `discard_high_return_numbers` option to true on the [writers.las](#) (page 126). 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 278) to filter those points earlier in the pipeline.

Options

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

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

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

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

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

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

reflectance_as_intensity If “true”, in addition to storing reflectance values directly, also stores the values as Intensity by mapping the reflectance values in the range from `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]

7.3.26 readers.sbet

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

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example

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

Options

filename File to read from [Required]

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

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

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

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

7.3.27 readers.sqlite

The **SQLite Reader** allows you to read data stored in a [SQLite database](https://sqlite.org/) (<https://sqlite.org/>) using a scheme that PDAL wrote using the [writers.sqlite](#) (page 144) writer. 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

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

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

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

7.3.28 readers.slpk

Scene Layer Packages (SLPK) (https://github.com/Esri/i3s-spec/blob/master/format/Indexed%203d%20Scene%20Layer%20Format%20Specification.md#_8_1) is a specification created by Esri as a format for their 3D Scene Layer and scene services. SLPK is a format that allows you to package all the necessary *13S* (page 69) 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.

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

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

Options

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

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

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

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

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

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

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

7.3.29 readers.terrassolid

The **Terrassolid Reader** loads points from Terrassolid (<https://www.terrassolid.com/home.php>) files (.bin). It supports both Terrassolid format 1 and format 2.

Example

```
[  
  {  
    "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]

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

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

7.3.30 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) properly for C++ language double-precision values.

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

Quoted dimension names

When the first character of the header is a double quote, each dimension name is assumed to be surrounded by double quotes. A single separator character is expected between the dimension names (spaces are stripped). If no separator character is found, a space is assumed. You can set the *separator* (page 110) character if it differs from that in the header. Note that PDAL requires dimension names that consist only of alphabetic characters and underscores. Edit the header line or use the *header* (page 110) option to set the dimension names to ones that PDAL understands.

Unquoted dimension names

The first non alpha-numeric character encountered is treated as a separator between dimension names. The separator in the header line can be overridden by the *separator* (page 110) option.

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

Blank lines are ignored after the header line is read.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example Input File

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

```
X,Y,Z  
289814.15,4320978.61,170.76  
289814.64,4320978.84,170.76  
289815.12,4320979.06,170.75  
289815.60,4320979.28,170.74  
289816.08,4320979.50,170.68  
289816.56,4320979.71,170.66  
289817.03,4320979.92,170.63
```

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```
289817.53,4320980.16,170.62
289818.01,4320980.38,170.61
289818.50,4320980.59,170.58
```

Example #1

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

Example #2

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

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

Options

filename text file to read [Required]

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

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

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

header String to use as the file header. All lines in the file are assumed to be records containing point data unless skipped with the *skip* (page 110) option. [Default: None]

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

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

7.3.31 readers.tiledb

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

Dynamic Plugin

This stage requires a dynamic plugin to operate

Streamable Stage

This stage supports streaming operations

Example

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

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```
    }  
]
```

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]

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

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

7.3.32 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 40) 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 tindex reader to automatically merge and query the
data described by the tiles.

Default Embedded Stage

This stage is enabled by default

Basic Example

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

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

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

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

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

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

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) to use to define the tile index layer.

bounds A 2D box to pre-filter the tile index. If it is set, it will override any [wkt](#) (page 113) option.

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

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

filter_srs Transforms any [wkt](#) (page 113) or [bounds](#) (page 113) 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) filter clause to use on the layer. It only works in combination with tile index layers that are defined with [lyr_name](#) (page 112)

dialect [OGR SQL](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** \(page 57\)](#) Read BPF files encoded as version 1, 2, or 3. BPF is an NGA specification for point cloud data.

[**readers.buffer** \(page 58\)](#) Special stage that allows you to read data from your own PointView rather than fetching data from a specific reader.

[**readers.ept** \(page 59\)](#) Used for reading [Entwine Point Tile](https://entwine.io) (<https://entwine.io>) format.

[**readers.e57** \(page 62\)](#) Read point clouds in the E57 format.

[**readers.faux** \(page 64\)](#) Used for testing pipelines. It does not read from a file or database, but generates synthetic data to feed into the pipeline.

[**readers.gdal** \(page 65\)](#) Read GDAL readable raster data sources as point clouds.

[**readers.hdf** \(page 67\)](#) Read data from files in the HDF5 format.

[**readers.i3s** \(page 69\)](#) Read data stored in the Esri I3S format. The data is read from an appropriate server.

[**readers.ilvis2** \(page 72\)](#) Read from files in the ILVIS2 format.

[**readers.las** \(page 73\)](#) 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** \(page 76\)](#) Read point cloud data from MATLAB .mat files where dimensions are stored as arrays in a MATLAB struct.

[**readers.mbio**](#) (page 78) Read sonar bathymetry data from formats supported by the MB-System library.

[**readers.memoryview**](#) (page 77) Read data from memory where dimension data is arranged in rows. For use only with the PDAL API.

[**readers.mrsid**](#) (page 80) Read data compressed by the MrSID 4.0 LiDAR Compressor. Requires the LizardTech Lidar_DSDK.

[**readers.nitf**](#) (page 81) Read point cloud data (LAS or LAZ) wrapped in NITF 2.1 files.

[**readers.numpy**](#) (page 83) Read point cloud data from Numpy .npy files.

[**readers.optech**](#) (page 88) Read Optech Corrected Sensor Data (.csd) files.

[**readers.pcd**](#) (page 89) Read files in the PCD format.

[**readers.pgpointcloud**](#) (page 90) Read point cloud data from a PostgreSQL database with the PostgreSQL Pointcloud extension enabled.

[**readers.ply**](#) (page 91) Read points and vertices from either ASCII or binary PLY files.

[**readers.pts**](#) (page 92) Read data from Leica Cyclone PTS files.

[**readers.qfit**](#) (page 93) Read data in the QFIT format originated for NASA's Airborne Topographic Mapper project.

[**readers.rxp**](#) (page 101) 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 94) 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 103) Read the SBET format.

[**readers.sqlite**](#) (page 104) Read data stored in a SQLite database.

[**readers.slpk**](#) (page 105) Read data stored in an Esri SLPK file.

[**readers.terrasolid**](#) (page 107) TerraSolid Reader

[**readers.text**](#) (page 107) Read point clouds from ASCII text files.

[**readers.tiledb**](#) (page 110) Read point cloud data from a TileDB instance.

[**readers.tindex**](#) (page 111) The tindex (tile index) reader allows you to automatically merge and query data described in tile index files that have been generated using the PDAL tindex command.

7.4 Writers

Writers consume data provided by *Readers* (page 57). 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 289)

7.4.1 writers.bpf

BPF is an [NGA specification](https://nsgreg.nga.mil/doc/view?i=4202) (<https://nsgreg.nga.mil/doc/view?i=4202>) for point cloud data. The PDAL **BPF Writer** only supports writing of version 3 BPF format files.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example

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

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 258), [filters.chipper](#) (page 254) or [filters.divider](#) (page 257). [Required]

compression This option can be set to true to cause the file to be written with Zlib compression as described in the BPF specification. [Default: false]

format Specifies the format for storing points in the file. [Default: dim]

- dim: Dimension-major (non-interleaved). All data for a single dimension are stored contiguously.
- point: Point-major (interleaved). All data for a single point are stored contiguously.
- byte: Byte-major (byte-segregated). All data for a single dimension are stored contiguously, but bytes are arranged such that the first bytes for all points are stored contiguously, followed by the second bytes of all points, etc. See the BPF specification for further information.

bundledfile Path of file to be written as a bundled file (see specification). The path part of the filespec is removed and the filename is stored as part of the data. This option can be specified as many times as desired.

header_data Base64-encoded data that will be decoded and written following the standard BPF header.

coord_id The coordinate ID (UTM zone) of the data. Southern zones take negative values. A value of 0 indicates cartesian instead of UTM coordinates. A value of ‘auto’ will attempt to set the UTM zone from a suitable spatial reference, or set to 0 if no such SRS is set. [Default: 0]

scale_x, scale_y, scale_z Scale to be divided from the X, Y and Z nominal values, respectively, after the offset has been applied. The special value “auto” can be specified, which causes the writer to select a scale to set the stored values of the dimensions to range from [0, 2147483647]. [Default: .01]

Note: written value = (nominal value - offset) / scale.

offset_x, offset_y, offset_z Offset to be subtracted from the X, Y and Z nominal values, respectively, before the value is scaled. The special value “auto” can be specified, which causes the writer to set the offset to the minimum value of the dimension. [Default: auto]

Note: written value = (nominal value - offset) / scale.

Note: Because BPF data is always stored in UTM, the XYZ offsets are set to “auto” by

default. This is to avoid truncation of the decimal digits (which may occur with offsets left at 0).

output_dims If specified, limits the dimensions written for each point. Dimensions are listed by name and separated by commas. X, Y and Z are required and must be explicitly listed.

where An expression that limits points passed to a writer. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a 'where' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: `auto`]

7.4.2 writers.ept_addon

The **EPT Addon Writer** supports writing additional dimensions to [Entwine Point Tile](https://entwine.io/entwine-point-tile.html) (<https://entwine.io/entwine-point-tile.html>) datasets. The EPT addon writer may only be used in a pipeline with an [EPT reader](#) (page 59), and it creates additional attributes for an existing dataset rather than creating a brand new one.

The addon dimensions created by this writer are stored independently from the corresponding EPT dataset, therefore write-access to the EPT resource itself is not required to create and use addon dimensions.

Default Embedded Stage

This stage is enabled by default

Example

This example downloads the Autzen dataset (10M points) and runs the [SMRF filter](#) (page 155), 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"  
  },
```

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```
[  
  {  
    "type": "filters.assign",  
    "assignment": "Classification[:] = 0"  
  },  
  {  
    "type": "filters.smrf"  
  },  
  {  
    "type": "writers.ept_addon",  
    "addons": { "~/entwine/addons/autzen/smrf": "Classification" }  
  }  
]
```

And here is a follow-up example of reading this dataset with the *EPT reader* (page 59) with the created addon overwriting the Classification value. The output is then written to a single file with the *LAS writer* (page 126).

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

This is an example of using multiple mappings in the addons option to apply a new color scheme with *filters.colorinterp* (page 175) 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": { "Classification": "Classification" }  
  }  
]
```

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```

"addons": {
    "~/.entwine/addons/autzen/interp/Red": "Red",
    "~/.entwine/addons/autzen/interp/Green": "Green",
    "~/.entwine/addons/autzen/interp/Blue": "Blue"
}
]

```

The following pipeline will 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.

where An expression that limits points passed to a writer. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: `auto`]

7.4.3 writers.e57

The **E57 Writer** supports writing to E57 files.

The writer supports E57 files with Cartesian point clouds.

Note: E57 files can contain multiple point clouds stored in a single file. The writer will only write a single cloud per file.

Note: Spherical format points are not supported.

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

Dynamic Plugin

This stage requires a dynamic plugin to operate

Streamable Stage

This stage supports streaming operations

Example

```
[  
 {  
   "type": "readers.las",  
   "filename": "inputfile.las"  
 },
```

(continues on next page)

(continued from previous page)

```
{
    "type": "writers.e57",
    "filename": "outputfile.e57",
    "doublePrecision": false
}
]
```

Options

filename E57 file to write [Required]

doublePrecision Use double precision for storage (false by default).

where An expression that limits points passed to a writer. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: **auto**]

7.4.4 writers.gdal

The **GDAL writer** creates a raster from a point cloud using an interpolation algorithm. Output is produced using **GDAL** (<http://gdal.org>) and can use any [driver that supports creation of rasters](#) (http://www.gdal.org/formats_list.html). A [data_type](#) (page 123) 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 123) 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 123) and the square root of two. If a circle with the provided radius doesn't encompass the entire cell, it is possible that some points will not be considered at all, including those that may be within the bounds of the raster cell.

The GDAL writer creates rasters using the data specified in the [dimension](#) (page 123) 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 123) 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 123) 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"
```

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```

    }
]
```

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 258), *filters.chipper* (page 254) or *filters.divider* (page 257). [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 123) * sqrt(2)]

power Exponent of the distance when computing IDW. Close points have higher significance than far points. [Default: 1.0]

gdaldriver GDAL code of the [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](#) (page 295) to use for the output raster. Many GDAL drivers only support a limited set of output data types. [Default: depends on the driver]

nodata The value to use for a raster cell if no data exists in the input data with which to compute an output cell value. [Default: depends on the [data_type](#) (page 123). -9999 for double, float, int and short, 9999 for unsigned int and unsigned short, 255 for unsigned char and -128 for char]

output_type A comma separated list of statistics for which to produce raster layers. The supported values are “min”, “max”, “mean”, “idw”, “count”, “stdev” and “all”. The option may be specified more than once. [Default: “all”]

window_size The maximum distance from a donor cell to a target cell when applying the fallback interpolation method. See the stage description for more information. [Default: 0]

dimension A dimension name to use for the interpolation. [Default: “Z”]

bounds The bounds of the data to be written. Points not in bounds are discarded. The format is ([minx, maxx],[miny,maxy]). [Optional]

origin_x X origin (lower left corner) of the grid. [Default: None]

origin_y Y origin (lower left corner) of the grid. [Default: None]

width Number of cells in the X direction. [Default: None]

height Number of cells in the Y direction. [Default: None]

override_srs Write the raster with the provided SRS. [Default: None]

default_srs Write the raster with the provided SRS if none exists. [Default: None]

where An expression that limits points passed to a writer. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: **auto**]

Note: You may use the 'bounds' option, or 'origin_x', 'origin_y', 'width' and 'height', but not both.

Note: Unless the raster being written is empty, the spatial reference will automatically come from the data and does not need to be set with 'override_srs' or 'default_srs'.

7.4.5 writers.gltf

GLTF is a file format [specification](https://www.khronos.org/gltf/) (<https://www.khronos.org/gltf/>) for 3D graphics data. If a mesh has been generated for a PDAL point view, the **GLTF Writer** will produce simple output in the GLTF format. PDAL does not currently support many of the attributes that can be found in a GLTF file. This writer creates a *binary* GLTF.

Default Embedded Stage

This stage is enabled by default

Example

```
[  
    "infile.las",  
    {  
        "type": "filters.poisson",  
        "depth": 12  
    },  
    {  
        "type": "writers.gltf",  
        "filename": "output.glb",  
        "red": 0.8,  
        "metallic": 0.5  
    }  
]
```

Options

filename Name of the GLTF (.glb) file to be written. [Required]

metallic The metallic factor of the faces. [Default: 0]

roughness The roughness factor of the faces. [Default: 0]

red The red component of the color applied to the faces. [Default: 0]

green The green component of the color applied to the faces. [Default: 0]

blue The blue component of the color applied to the faces. [Default: 0]

alpha The alpha component to be applied to the faces. [Default: 1.0]

double_sided Whether the faces are colored on both sides, or just the side visible from the initial observation point (positive normal vector). [Default: false]

where An expression that limits points passed to a writer. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: **auto**]

7.4.6 writers.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 127) 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* (or *filename*) 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",  
    }]
```

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```

        "filename": "path-to-my-file.input"
    }],
    "filename": "outputfile.las"
}
]

```

Note: *data* or *filename* must be specified. Data must always be provided as base64 encoded strings, but content of *filename* is expected to be raw data.

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 258), [filters.chipper](#) (page 254) or [filters.divider](#) (page 257). [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`, `libblas`, `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 0 and 65535 - 0 implies “unassigned”) [Default: 0]

discard_high_return_numbers If true, discard all points with a return number greater than the maximum supported by the point format (5 for formats 0-5, 15 for formats 6-10). [Default: false]

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> [, . . .]. Any valid PDAL *type* (page 295) can be specified.

The special value all can be used in place of a dimension/type list to request that all dimensions that can’t be stored in the predefined LAS point record get added as extra data at the end of each point record.

PDAL writes an extra bytes VLR (User ID: LASF_Spec, Record ID: 4) when extra dims are written. The VLR describes the extra dimensions specified by this option. Note that reading of this VLR is only specified for LAS version 1.4, though some systems will honor it for earlier file formats. The *LAS reader* (page 73) requires the option use_eb_vlr in order to read the extra bytes VLR for files written with 1.1 - 1.3 LAS format.

Setting –verbose=Info will provide output on the names, types and order of dimensions being written as part of the LAS extra bytes.

pdal_metadata Write two VLRs containing **JSON** (<http://www.json.org/>) output with both the *Metadata* (page 469) and *Pipeline* (page 47) serialization. [Default: false]

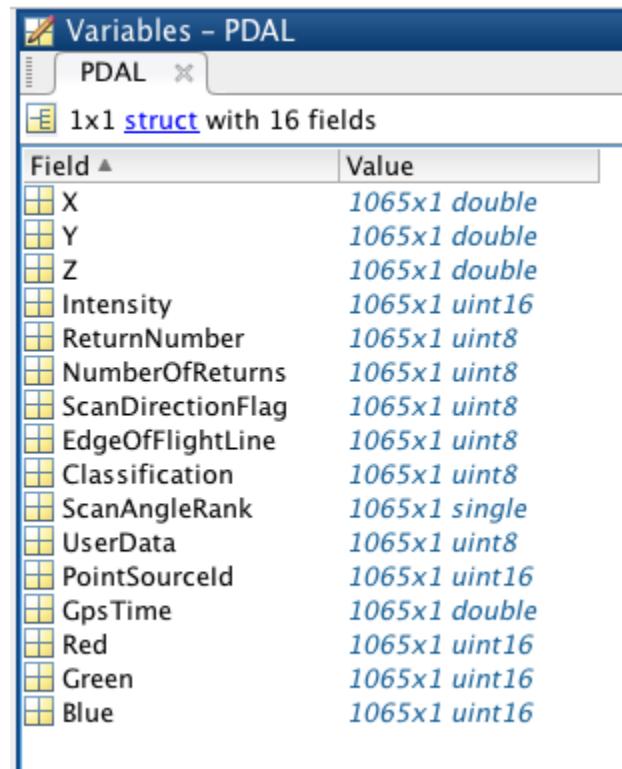
where An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: `auto`]

7.4.7 writers.matlab

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

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



The screenshot shows the MATLAB Variables browser window titled "Variables - PDAL". It displays a table of 16 fields under the heading "1x1 struct with 16 fields". The table has two columns: "Field" and "Value".

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”]

where An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: **auto**]

7.4.8 writers.nitf

The [NITF](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

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

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```

    "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 258), *filters.chipper* (page 254) or *filters.divider* (page 257).

clevel 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: AIMDB.ACQUISITION_DATE if set or <spaces>]

iid2 Image identifier 2 (80 characters) [Default: <spaces>]

fscltx File classification text (43 characters) [Default: <spaces>]

aimidb Comma separated list of name/value pairs to complete the AIMIDB (Additional Image ID) TRE record (format name:value). Required: ACQUISITION_DATE, will default to IDATIM value. [Default: NITF defaults]

acftb Comma separated list of name/value pairs to complete the ACFTB (Aircraft Information) TRE record (format name:value). Required: SENSOR_ID, SENSOR_ID_TYPE [Default: NITF defaults]

where An expression that limits points passed to a writer. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: `auto`]

7.4.9 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.

7.4.10 writers.ogr

The **OGR Writer** will create files of various [vector formats](#) (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 258), [filters.chipper](#) (page 254) or [filters.divider](#) (page 257).

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 135).

where An expression that limits points passed to a writer. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: `auto`]

7.4.11 writers.pcd

The **PCD Writer** supports writing to Point Cloud Data (PCD) (https://pcl-tutorials.readthedocs.io/en/latest/pcd_file_format.html) formatted files, which are used by the **Point Cloud Library (PCL)** (<http://pointclouds.org>).

By default, compression is not enabled, and the PCD writer will output ASCII formatted data.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Note: X, Y, and Z dimensions will be written as single-precision floats by default to be compatible with most of the existing PCL point types. These dimensions can be forced to

double-precision using the *order* option, but the PCL code reading this data must be capable of reading double-precision fields (i.e., it is not the responsibility of PDAL to ensure this compatibility).

Note: When working with large coordinate values it is recommended that users first translate the coordinate values using [filters.transformation](#) (page 225) to avoid loss of precision when writing single-precision XYZ data.

Example

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

Options

filename PCD file to write [Required]

compression Level of PCD compression to use (ascii, binary, compressed) [Default: “ascii”]

precision Decimal Precision for output of values. This can be overridden for individual dimensions using the *order* option. [Default: 2]

order Comma-separated list of dimension names in the desired output order. For example “X,Y,Z,Red,Green,Blue”. Dimension names can optionally be followed by a PDAL type (e.g., Unsigned32) and dimension-specific precision (used only with “ascii” compression). Ex: “X=Float:2, Y=Float:2, Z=Float:3, Intensity=Unsigned32” If no precision is specified the value provided with the [precision](#) (page 137) option is used. The default dimension type is double precision float. [Default: none]

keep_unspecified If true, writes all dimensions. Dimensions specified with the *order* (page 137) option precede those not specified. [Default: **true**]

where An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: `auto`]

7.4.12 writers.pgpointcloud

The **PostgreSQL Pointcloud Writer** allows you to write to PostgreSQL database that have the [PostgreSQL Pointcloud](#) (<http://github.com/pramsey/pointcloud>) extension enabled. The Pointcloud extension stores point cloud data in tables that contain rows of patches. Each patch in turn contains a large number of spatially nearby points.

While you can theoretically store the contents of a whole file of points in a single patch, it is more practical to store a table full of smaller patches, where the patches are under the PostgreSQL page size (8kb). For most LIDAR data, this practically means a patch size of between 400 and 600 points.

In order to create patches of the right size, the Pointcloud writer should be preceded in the pipeline file by [*filters.chipper*](#) (page 254).

The pgpointcloud format does not support WKT spatial reference specifications. A subset of spatial references can be stored by using the ‘`srid`’ option, which allows storage of an [EPSG code](#) (<http://www.epsg.org>) that covers many common spatial references. PDAL makes no attempt to reproject data to your specified srid. Use [*filters.reprojection*](#) (page 222) 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",  
    "size": 1000,  
    "overlap": 500  
  },  
  {  
    "type": "writers.pgpointcloud",  
    "connection": "dbname=pgPointCloud user=postgres",  
    "patch_size": 1000,  
    "overlap": 500  
  }]
```

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```

    "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,z> options are given the value of 1.0 and unspecified offset_<x,y,z> are given the value of 0.0.

output_dims If specified, limits the dimensions written for each point. Dimensions are listed by name and separated by commas.

where An expression that limits points passed to a writer. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: **auto**]

7.4.13 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 272) and *filters.poisson* (page 273) 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"  
}
```

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```
    }  
]
```

Options

filename ply file to write [Required]

storage_mode Type of ply file to write. Valid values are ‘ascii’, ‘little endian’, ‘big endian’. [Default: “ascii”]

dims List of dimensions (and [Types](#) (page 295)) in the format <dimension_name>[=<type>] [, . . .] to write as output. (e.g., “Y=int32_t, X, Red=char”) [Default: All dimensions with stored types]

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

sized_types PLY has variously been written with explicitly sized type strings (‘int8’, ‘float32’, ‘uint32’, etc.) and implied sized type strings (‘char’, ‘float’, ‘int’, etc.). If true, explicitly sized type strings are used. If false, implicitly sized type strings are used. [Default: true]

precision If specified, the number of digits to the right of the decimal place using f-style formatting. Only permitted when ‘storage_mode’ is ‘ascii’. See the [printf](#) (<https://en.cppreference.com/w/cpp/io/c/fprintf>) reference for more information. [Default: g-style formatting (variable precision)]

where An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: **auto**]

7.4.14 writers.raster

The **Raster Writer** writes an existing raster to a file. Output is produced using [GDAL](#) (<http://gdal.org>) and can use any [driver that supports creation of rasters](#) (http://www.gdal.org/formats_list.html). A [data_type](#) (page 143) can be specified for the raster (double, float, int32, etc.). If no data type is specified, the data type with the largest range supported by the driver is used.

Cells that have no value are given a value specified by the [nodata](#) (page 143) option.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Basic Example

This pipeline reads the file autzen_trim.las, triangulates the data, creates a raster based on the Z dimension as determined by interpolation of the location and values of ‘Z’ of the vertices of a containing triangle, if any exists. The resulting raster is written to “outputfile.tif”.

```
[  
    "pdal/test/data/las/autzen_trim.las",  
    {  
        "type": "filters.delaunay"  
    }  
    {  
        "type": "filters.faceraster",  
        "resolution": 1  
    }  
    {  
        "type": "writers.raster"  
        "filename": "outputfile.tif"  
    }  
]
```

Options

filename Name of output file. [Required]

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.

rasters A comma-separated list of raster names to be written as bands of the raster. All rasters must have the same limits (origin/width/height). Rasters following the first that don't have the same limits will be dropped. If no raster names are provided, only the first raster found will be placed into a single band for output.

data_type The [data type](#) (page 295) to use for the output raster. Many GDAL drivers only support a limited set of output data types. [Default: depends on the driver]

nodata The value to use for a raster cell if the raster contains no data in a cell. Note that the nodata written to the output may be different from that of the raster being written. [Default: depends on the [data type](#) (page 143). -9999 for double, float, int and short, 9999 for unsigned int and unsigned short, 255 for unsigned char and -128 for char]

where An expression that limits points passed to a writer. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: `auto`]

7.4.15 writers.sbet

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

Default Embedded Stage

This stage is enabled by default

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]

where An expression that limits points passed to a writer. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: **auto**]

7.4.16 writers.sqlite

The [SQLite](http://sqlite.org) (<http://sqlite.org>) driver outputs point cloud data into a PDAL-specific scheme that matches the approach of *readers.pgpointcloud* (page 90) and *readers.oci*.

Dynamic Plugin

This stage requires a dynamic plugin to operate

Example

```
[  
    {  
        "type": "readers.las",  
        "filename": "inputfile.las"  
    },  
    {
```

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```
"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.

where An expression that limits points passed to a writer. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: `auto`]

7.4.17 writers.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) 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 147) option is used. [Default: none]

keep_unspecified If true, writes all dimensions. Dimensions specified with the `order` (page 147) option precede those not specified. [Default: `true`]

jcallback When producing GeoJSON, the callback allows you to wrap the data in a function, so the output can be evaluated in a `<script>` tag.

quote_header When producing CSV, should the column header named by quoted? [Default: `true`]

write_header Whether a header should be written. [Default: `true`]

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: “,”]

where An expression that limits points passed to a writer. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘`where`’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: `auto`]

7.4.18 writers.tiledb

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

Dynamic Plugin

This stage requires a dynamic plugin to operate

Streamable Stage

This stage supports streaming operations

Example

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

chunk_size Point cache size for chunked writes [Optional]

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

compression_level TileDB compression level for chosen compression [Optional]

append Append to an existing TileDB array with the same schema [Optional]

stats Dump query stats to stdout [Optional]

filters JSON array or object of compression filters for either *coords* or *attributes* of the form
`{coords/attributename : {"compression": name, compression_options: value, ...}}`
[Optional]

where An expression that limits points passed to a writer. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the writer was run. [Default: `auto`]

By default TileDB will use the following set of compression filters for coordinates and attributes;

```
{
  "coords": [
    {"compression": "bit-shuffle"},  

    {"compression": "gzip", "compression_level": 9}
  ],  

  "Intensity": {"compression": "bzip2", "compression_level": 5},  

  "ReturnNumber": {"compression": "zstd", "compression_level": 75},  

  "NumberOfReturns": {"compression": "zstd", "compression_level": 75},  

  "ScanDirectionFlag": {"compression": "bzip2", "compression_level": 5},  

  "EdgeOfFlightLine": {"compression": "bzip2", "compression_level": 5},  

  "Classification": {"compression": "gzip", "compression_level": 9},  

  "ScanAngleRank": {"compression": "bzip2", "compression_level": 5},  

  "UserData": {"compression": "gzip", "compression_level": 9},  

  "PointSourceId": {"compression": "bzip2"},  

  "Red": {"compression": "rle"},  

  "Green": {"compression": "rle"},  

  "Blue": {"compression": "rle"},  

  "GpsTime": [
    {"compression": "bit-shuffle"},  

    {"compression": "zstd", "compression_level": 75}
  ]
}
```

writers.bpf (page 115) Write BPF version 3 files. BPF is an NGA specification for point cloud data.

writers.ept_addon (page 117) Append additional dimensions to Entwine resources.

writers.e57 (page 120) Write data in the E57 format.

writers.gdal (page 121) Create a raster from a point cloud using an interpolation algorithm.

writers.gltf (page 124) Write mesh data in GLTF format. Point clouds without meshes cannot be written.

writers.las (page 126) Write ASPRS LAS versions 1.0 - 1.4 formatted data. LAZ support is

also available if enabled at compile-time.

[**writers.matlab**](#) (page 130) Write MATLAB .mat files. The output has a single array struct.

[**writers.nitf**](#) (page 131) Write LAS and LAZ point cloud data, wrapped in a NITF 2.1 file.

[**writers.null**](#) (page 134) Provides a sink for points in a pipeline. It's the same as sending pipeline output to /dev/null.

[**writers.ogr**](#) (page 135) Write a point cloud as a set of OGR points/multipoints

[**writers.pcd**](#) (page 136) Write PCD-formatted files in the ASCII, binary, or compressed format.

[**writers.pgpointcloud**](#) (page 138) Write to a PostgreSQL database that has the PostgreSQL Pointcloud extension enabled.

[**writers.ply**](#) (page 140) Write points as PLY vertices. Can also emit a mesh as a set of faces.

[**writers.raster**](#) (page 141) Writes rasters using GDAL. Rasters must be created using a PDAL filter.

[**writers.sbet**](#) (page 143) Write data in the SBET format.

[**writers.sqlite**](#) (page 144) Write point cloud data in a scheme that matches the approach used in the PostgreSQL Pointcloud and OCI readers.

[**writers.text**](#) (page 146) Write points in a text file. GeoJSON and CSV formats are supported.

[**writers.tiledb**](#) (page 147) Write points into a TileDB database.

7.5 Filters

Filters operate on data as inline operations. They can remove, modify, reorganize, and add points to the data stream as it goes by. Some filters can only operate on dimensions they understand (consider [*filters.reprojection*](#) (page 222) doing geographic reprojection on XYZ coordinates), while others do not interrogate the point data at all and simply reorganize or split data.

7.5.1 Create

PDAL filters commonly create new dimensions (e.g., HeightAboveGround) or alter existing ones (e.g., Classification). These filters will not invalidate an existing KD-tree.

Note: We treat those filters that alter XYZ coordinates separately.

Note: When creating new dimensions, be mindful of the writer you are using and whether or not the custom dimension can be written to disk if that is the desired behavior.

Classification

Ground/Unclassified

filters.csf

The **Cloth Simulation Filter (CSF)** classifies ground points based on the approach outlined in [Zhang2016].

Default Embedded Stage

This stage is enabled by default

Example

The sample pipeline below uses CSF to segment ground and non-ground returns, using default options, and writing only the ground returns to the output file.

```
[  
    "input.las",  
    {  
        "type": "filters.csf"  
    },  
    {  
        "type": "filters.range",  
        "limits": "Classification[2:2]"  
    },  
    "output.laz"  
]
```

Options

resolution Cloth resolution. [Default: **1.0**]

ignore A *range* (page 252) of values of a dimension to ignore.

returns Return types to include in output. Valid values are “first”, “last”, “intermediate” and “only”. [Default: “**last, only**”]

threshold Classification threshold. [Default: **0.5**]

smooth Perform slope post-processing? [Default: **true**]

step Time step. [Default: **0.65**]

rigidness Rigidness. [Default: **3**]

iterations Maximum number of iterations. [Default: **500**]

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.pmf

The **Progressive Morphological Filter (PMF)** is a method of segmenting ground and non-ground returns. This filter is an implementation of the method described in [[Zhang2003](#)].

Default Embedded Stage

This stage is enabled by default

Example

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

(continues on next page)

(continued from previous page)

```
"output.las"
]
```

Notes

- *slope* (page 154) controls the height threshold at each iteration. A slope of 1.0 represents a 1:1 or 45°.
- *initial_distance* (page 154) 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 154) 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 154) by the difference in window size between the current and last iteration, plus the *initial_distance* (page 154). This height threshold is constant across all cells and is maxed out at the *max_distance* (page 154) 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 154) values will result in a lot of potentially extra iteration. This parameter can have a strongly negative impact on computation performance.
- *exponential* (page 154) is used to control the rate of growth of morphological window sizes toward *max_window_size* (page 154). 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 250) to the pipeline.

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

Note: [Zhang2003] describes the consequences and relationships of the parameters in more detail and is the canonical resource on the topic.

Options

cell_size Cell Size. [Default: 1]

exponential Use exponential growth for window sizes? [Default: true]

ignore Range of values to ignore. [Optional]

initial_distance Initial distance. [Default: 0.15]

returns Comma-separated list of return types into which data should be segmented. Valid groups are “last”, “first”, “intermediate” and “only”. [Default: “last, only”]

max_distance Maximum distance. [Default: 2.5]

max_window_size Maximum window size. [Default: 33]

slope Slope. [Default: 1.0]

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.skewnessbalancing

Skewness Balancing classifies ground points based on the approach outlined in [[Bartels2010](#)].

Default Embedded Stage

This stage is enabled by default

Note: For Skewness Balancing to work well, the scene being processed needs to be quite flat, otherwise many above ground features will begin to be included in the ground surface.

Example

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

```
[  
    "input.las",  
    {  
        "type": "filters.skewnessbalancing"  
    },  
    {  
        "type": "filters.range",  
        "limits": "Classification[2:2]"  
    },  
    "output.laz"  
]
```

Options

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

Note: The Skewness Balancing method is touted as being threshold-free. We may still in the future add convenience parameters that are common to other ground segmentation filters, such as `returns` or `ignore` to limit the points under consideration for filtering.

filters.smrf

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

Default Embedded Stage

This stage is enabled by default

Example #1

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

```
[  
    "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].

```
[  
    "input.las",  
    {  
        "type": "filters.smrf",  
        "scalar": 1.2,  
        "slope": 0.2,  
        "threshold": 0.45,  
        "window": 16.0  
    },  
    {  
        "type": "filters.range",  
        "limits": "Classification[2:2]"  
    },  
    "output.laz"  
]
```

Options

cell Cell size. [Default: 1.0]

classbits Selectively ignore points marked as “synthetic”, “keypoint”, or “withheld”. [Default: empty string, use all points]

cut Cut net size (`cut=0` skips the net cutting step). [Default: 0.0]

dir Optional output directory for debugging intermediate rasters.

ignore A *range* (page 252) of values of a dimension to ignore.

returns Return types to include in output. Valid values are “first”, “last”, “intermediate” and “only”. [Default: “last, only”]

scalar Elevation scalar. [Default: 1.25]

slope Slope (rise over run). [Default: 0.15]

threshold Elevation threshold. [Default: 0.5]

window Max window size. [Default: 18.0]

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

***filters.csf* (page 151)** Label ground/non-ground returns using [Zhang2016].

***filters.pmf* (page 152)** Label ground/non-ground returns using [Zhang2003].

***filters.skewnessbalancing* (page 154)** Label ground/non-ground returns using [Bartels2010].

***filters.smrf* (page 155)** Label ground/non-ground returns using [Pingel2013].

Noise

filters.elm

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

ELM begins by rasterizing the input point cloud data at the given `cell` (page 159) 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 159) size of 20 and applying the *classification* (page 159) 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 159) 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
```

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```
        },
        {
            "type": "filters.range",
            "limits": "Classification![7:7]"
        },
        "output.las"
    ]
```

Options

cell Cell size. [Default: 10.0]

class Classification value to apply to noise points. [Default: 7]

threshold Threshold value to identify low noise points. [Default: 1.0]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.outlier

The **outlier filter** provides two outlier filtering methods: radius and statistical. These two approaches are discussed in further detail below.

It is worth noting that both filtering methods simply apply a classification value of 7 to the noise points (per the [LAS specification](#) (http://www.asprs.org/a/society/committees/standards/LAS_1_4_r13.pdf)). To remove the noise points altogether, users can add a *range filter* (page 250) 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 μ_i to each of the k nearest neighbors (where k is configurable and specified by [mean_k](#) (page 163)). 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 σ . From this, the threshold is computed as

$$t = \mu + m\sigma$$

where m is a user-defined multiplier specified by [multiplier](#) (page 163).

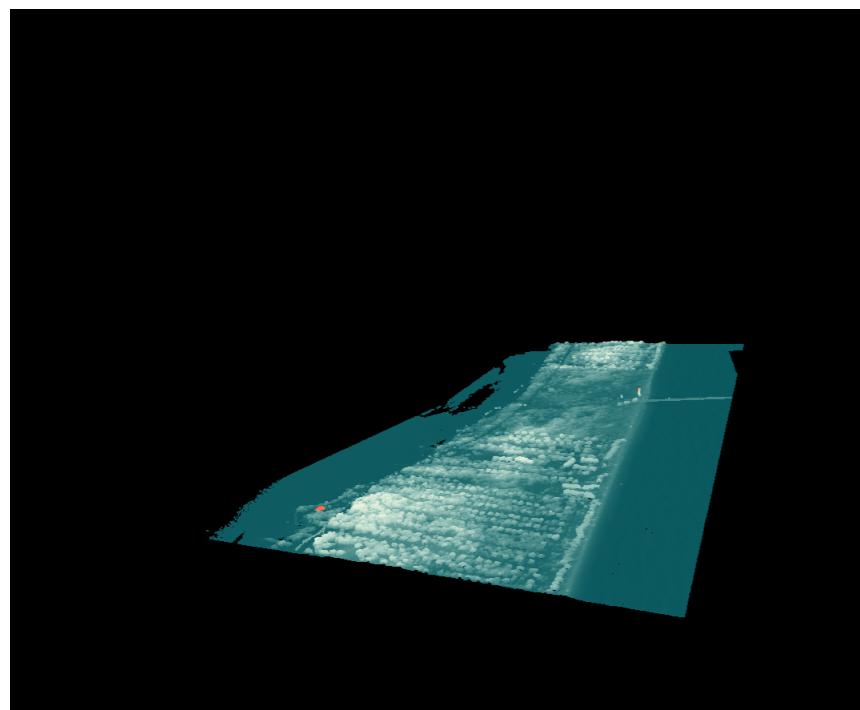
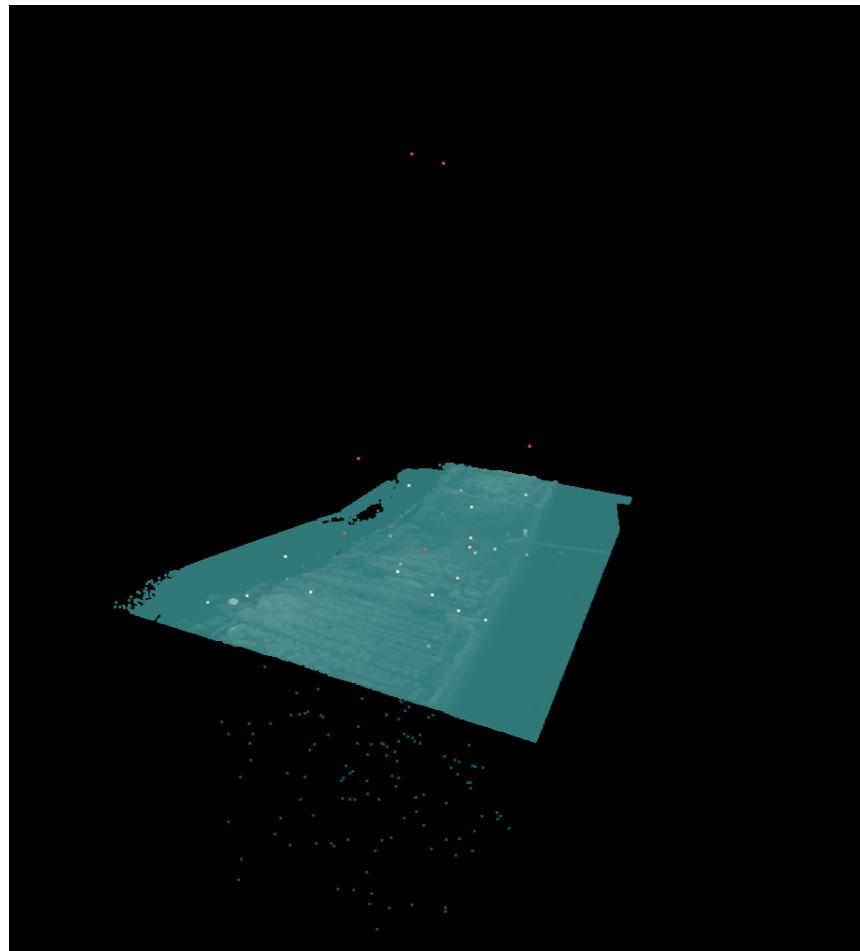
We now iterate over the pre-computed mean distances μ_i and compare to computed threshold value. If μ_i is greater than the threshold, it is marked as an outlier.

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

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

After outlier removal, the noise points are removed.

See [[Rusu2008](#)] 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 163)). If $k_i < k_{min}$, where k_{min} is the minimum number of neighbors specified by `min_k` (page 163), it is marked as an outlier.

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

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"  
]
```

Options

class The classification value to apply to outliers. [Default: 7]

method The outlier removal method (either “statistical” or “radius”). [Default: “statistical”]

min_k Minimum number of neighbors in radius (radius method only). [Default: 2]

radius Radius (radius method only). [Default: 1.0]

mean_k Mean number of neighbors (statistical method only). [Default: 8]

multiplier Standard deviation threshold (statistical method only). [Default: 2.0]

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

[filters.elm \(page 157\)](#) Marks low points as noise.

[filters.outlier \(page 159\)](#) Label noise points using either a statistical or radius outlier detection.

Consensus

[filters.neighborclassifier](#)

The **neighborclassifier filter** allows you update the value of the classification for specific points to a value determined by a K-nearest neighbors vote. For each point, the [k](#) (page 164) 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.

Similiarly, 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 252) which selects points to be processed by the filter. Can be specified multiple times. Points satisfying any range will be processed

k An integer which specifies the number of neighbors which vote on each selected point.

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

***filters.neighborclassifier* (page 163)** Update pointwise classification using k-nearest neighbor consensus voting.

Height Above Ground

filters.hag_delaunay

The **Height Above Ground Delaunay filter** takes as input a point cloud with Classification set to 2 for ground points. It creates a new dimension, HeightAboveGround, that contains the normalized height values.

Note: We expect ground returns to have the classification value of 2 in keeping with the [ASPRS Standard LIDAR Point Classes](#)

(http://www.asprs.org/a/society/committees/standards/LAS_1_4_r13.pdf).

Ground points may be generated by *filters.pmf* (page 152) or *filters.smrf* (page 155), but you can use any method you choose, as long as the ground returns are marked.

Normalized heights are a commonly used attribute of point cloud data. This can also be referred to as *height above ground* (HAG) or *above ground level* (AGL) heights. In the end, it is simply a measure of a point’s relative height as opposed to its raw elevation value.

The filter creates a delaunay triangulation of the *count* (page 167) ground points closest to the non-ground point in question. If the non-ground point is within the triangulated area, the assigned HeightAboveGround is the difference between its Z value and a ground height interpolated from the three vertices of the containing triangle. If the non-ground point is outside of the triangulated area, its HeightAboveGround is calculated as the difference between its Z value and the Z value of the nearest ground point.

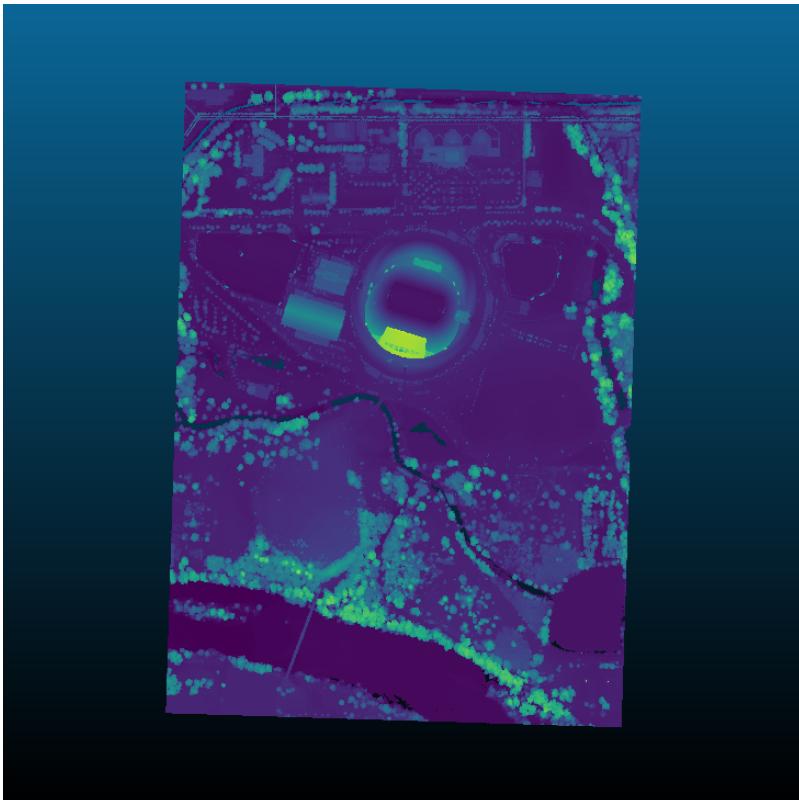
Choosing a value for *count* (page 167) is difficult, as placing the non-ground point in the triangulated area depends on the layout of the nearby points. If, for example, all the ground points near a non-ground point lay on one side of that non-ground point, finding a containing triangle will fail.

Default Embedded Stage

This stage is enabled by default

Example #1

Using the autzen dataset (here shown colored by elevation), which already has points classified as ground



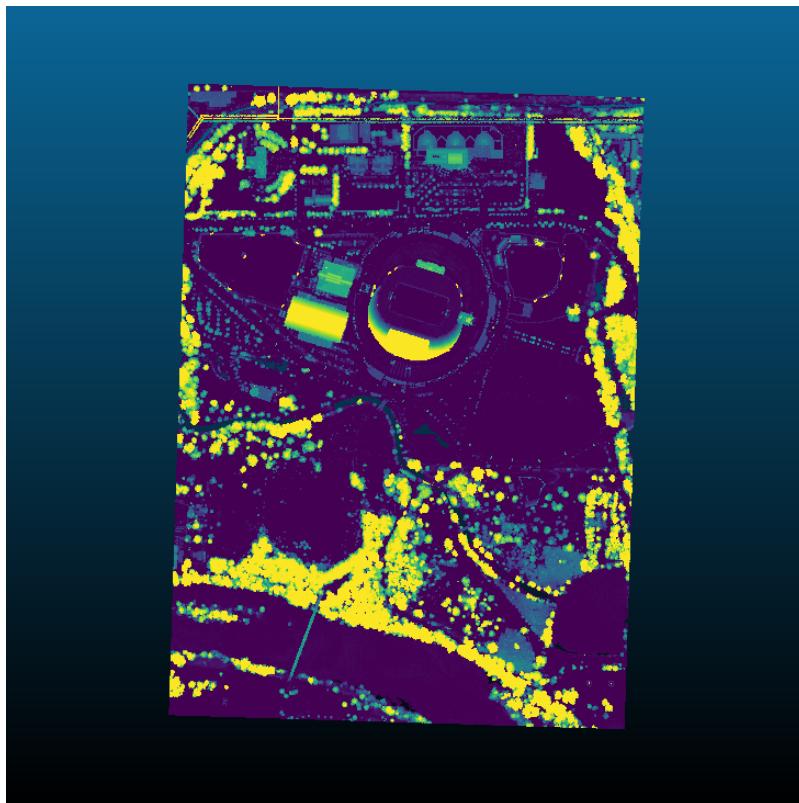
we execute the following pipeline

```
[  
  "autzen.laz",  
  {  
    "type": "filters.hag_delaunay"  
  },  
  {  
    "type": "writers.laz",  
    "filename": "autzen_hag_delaunay.laz",  
    "extra_dims": "HeightAboveGround=float32"  
  }  
]
```

which is equivalent to the pdal translate command

```
$ pdal translate autzen.laz autzen_hag_delaunay.laz hag_delaunay \  
  --writers.las.extra_dims="HeightAboveGround=float32"
```

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



Options

count The number of ground neighbors to consider when determining the height above ground for a non-ground point. [Default: 10]

allow_extrapolation If false and a non-ground point lies outside of the bounding box of all ground points, its HeightAboveGround is set to 0. If true and delaunay is set, the HeightAboveGround is set to the difference between the heights of the non-ground point and nearest ground point. [Default: false]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

[filters.hag_dem](#)

The **Height Above Ground (HAG) Digital Elevation Model (DEM) filter** loads a GDAL-readable raster image specifying the DEM. The Z value of each point in the input is compared against the value at the corresponding X,Y location in the DEM raster. It creates a new dimension, `HeightAboveGround`, that contains the normalized height values.

Normalized heights are a commonly used attribute of point cloud data. This can also be referred to as *height above ground* (HAG) or *above ground level* (AGL) heights. In the end, it is simply a measure of a point's relative height as opposed to its raw elevation value.

Default Embedded Stage

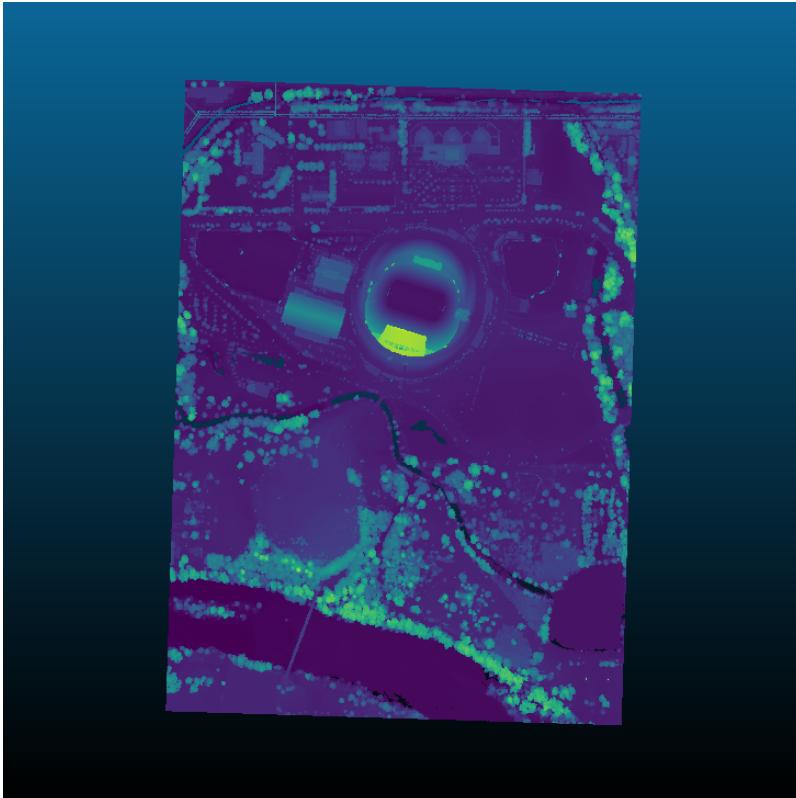
This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example #1

Using the autzen dataset (here shown colored by elevation)



we generate a DEM based on the points already classified as ground

```
$ pdal translate autzen.laz autzen_dem.tif range \
--filters.range.limits="Classification[2:2]" \
--writers.gdal.output_type="idw" \
--writers.gdal.resolution=6 \
--writers.gdal.window_size=24
```

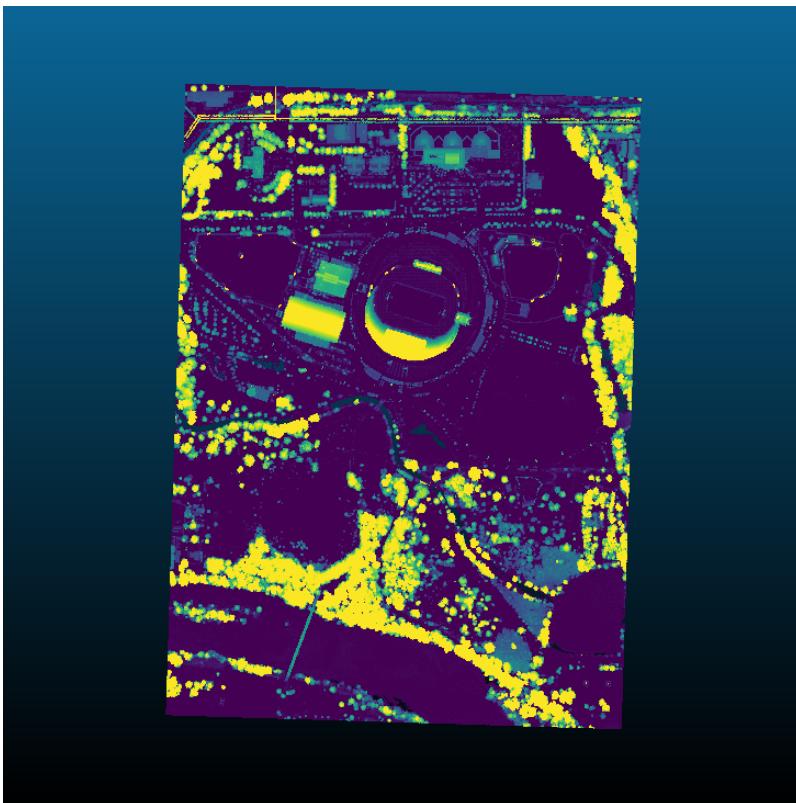
and execute the following pipeline

```
[
  "autzen.laz",
  {
    "type": "filters.hag_dem",
    "raster": "autzen_dem.tif"
  },
  {
    "type": "writers.las",
    "filename": "autzen_hag_dem.laz",
    "extra_dims": "HeightAboveGround=float32"
  }
]
```

which is equivalent to the `pdal translate` command

```
$ pdal translate autzen.laz autzen_hag_dem.laz hag_dem \
--filters.hag_dem.raster=autzen_dem.tif \
--writers.las.extra_dims="HeightAboveGround=float32"
```

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



Options

raster GDAL-readable raster to use for DEM.

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

zero_ground If true, set HAG of ground-classified points to 0 rather than comparing Z value to raster DEM. [Default: true]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.hag_nn

The **Height Above Ground Nearest Neighbor** filter takes as input a point cloud with Classification set to 2 for ground points. It creates a new dimension, HeightAboveGround, that contains the normalized height values.

Note: We expect ground returns to have the classification value of 2 in keeping with the [ASPRS Standard LIDAR Point Classes](#) (http://www.asprs.org/a/society/committees/standards/LAS_1_4_r13.pdf).

Ground points may be generated by [filters.pmf](#) (page 152) or [filters.smrf](#) (page 155), but you can use any method you choose, as long as the ground returns are marked.

Normalized heights are a commonly used attribute of point cloud data. This can also be referred to as *height above ground* (HAG) or *above ground level* (AGL) heights. In the end, it is simply a measure of a point's relative height as opposed to its raw elevation value.

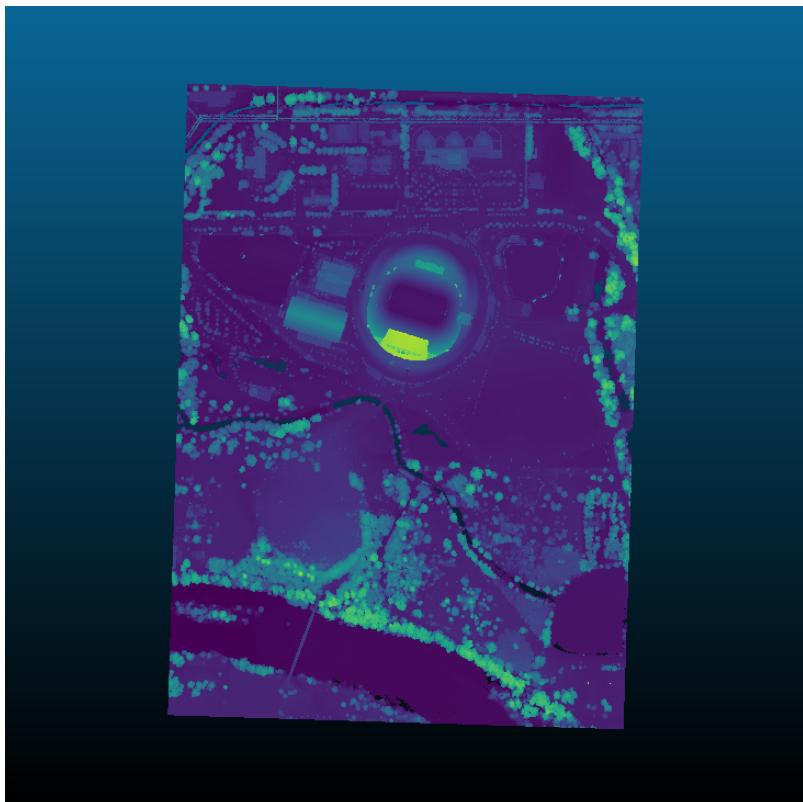
The filter finds the [count](#) (page 174) ground points nearest the non-ground point under consideration. It calculates an average ground height weighted by the distance of each ground point from the non-ground point. The HeightAboveGround is the difference between the Z value of the non-ground point and the interpolated ground height.

Default Embedded Stage

This stage is enabled by default

Example #1

Using the autzen dataset (here shown colored by elevation), which already has points classified as ground



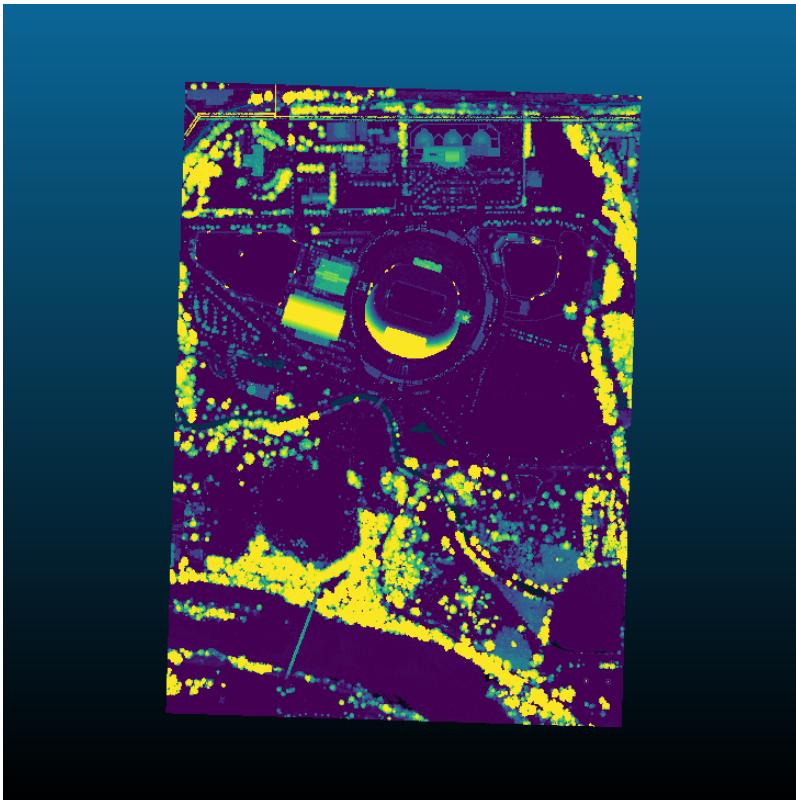
we execute the following pipeline

```
[  
    "autzen.laz",  
    {  
        "type": "filters.hag_nn"  
    },  
    {  
        "type": "writers.laz",  
        "filename": "autzen_hag_nn.laz",  
        "extra_dims": "HeightAboveGround=float32"  
    }  
]
```

which is equivalent to the `pdal translate` command

```
$ pdal translate autzen.laz autzen_hag_nn.laz hag_nn \  
    --writers.las.extra_dims="HeightAboveGround=float32"
```

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



Example #2

In the previous example, we chose to write `HeightAboveGround` using the `extra_dims` option of [`writers.las`](#) (page 126). If you'd instead like to overwrite your Z values, then follow the height filter with [`filters.ferry`](#) (page 209) as shown

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

Example #3

If you don't yet have points classified as ground, start with [filters.pmf](#) (page 152) or [filters.smrf](#) (page 155) to label ground returns, as shown

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

Options

count The number of ground neighbors to consider when determining the height above ground for a non-ground point. [Default: 1]

max_distance Use only ground points within *max_distance* of non-ground point when performing neighbor interpolation. [Default: None]

allow_extrapolation If false and a non-ground point lies outside of the bounding box of all ground points, its HeightAboveGround is set to 0. If true, extrapolation is used to assign the HeightAboveGround value. [Default: false]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

[filters.hag_delaunay](#) (page 165) Compute pointwise height above ground using triangulation. Requires points to be classified as ground/non-ground prior to estimating.

[filters.hag_dem](#) (page 168) Compute pointwise height above GDAL-readable DEM raster.

`filters.hag_nn` (page 171) Compute pointwise height above ground estimate. Requires points to be classified as ground/non-ground prior to estimating.

Colorization

`filters.colorinterp`

The color interpolation filter assigns scaled RGB values from an image based on a given dimension. It provides three possible approaches:

1. You provide a *minimum* (page 177) and *maximum* (page 177), and the data are scaled for the given *dimension* (page 177) accordingly.
2. You provide a *k* (page 178) and a *mad* (page 178) setting, and the scaling is set based on Median Absolute Deviation.
3. You provide a *k* (page 178) setting and the scaling is set based on the *k* (page 178)-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 176) for more information.

Note: *`filters.colorinterp`* (page 175) 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"  
    },
```

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```
"colorized.las"
```

```
]
```

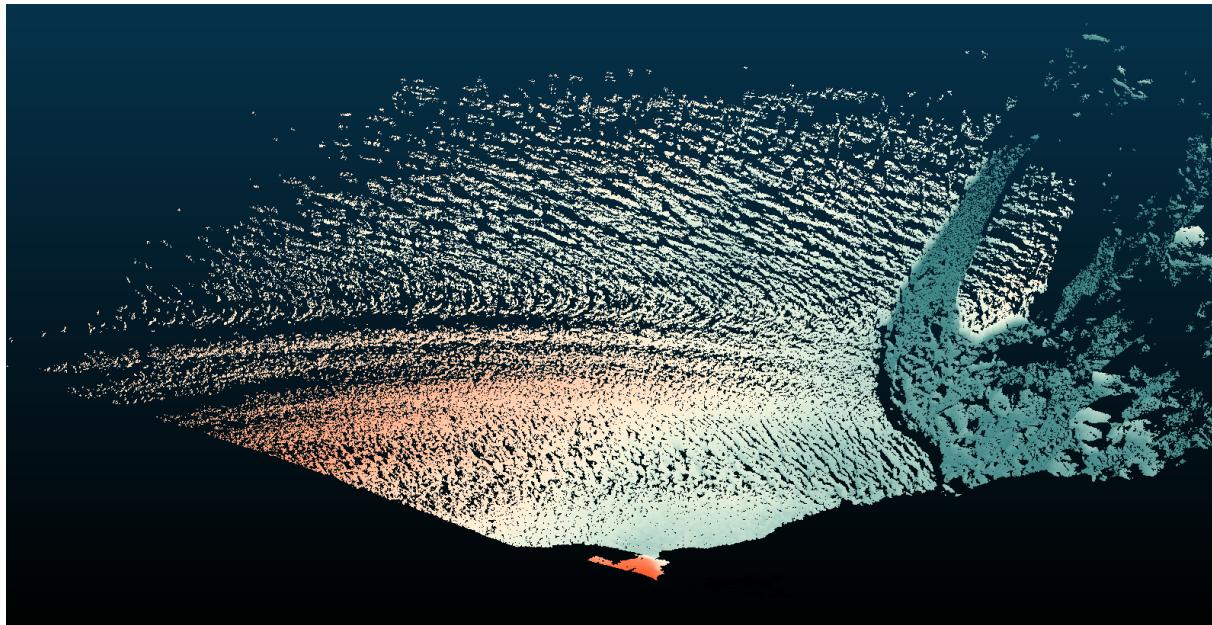


Fig. 4: Image data with interpolated colors based on Z dimension and `pestel_shades` ramp.

Default Ramps

PDAL provides a number of default color ramps you can use in addition to providing your own. Give the ramp name as the `ramp` (page 177) option to the filter and it will be used. Otherwise, provide a [GDAL](http://www.gdal.org) (<http://www.gdal.org>)-readable raster filename.

`awesome_green`

`black_orange`

`blue_orange`

A horizontal color bar transitioning from dark purple on the left to orange on the right.

`blue_hue`

A horizontal color bar transitioning from dark blue on the left to light blue on the right.

`blue_orange`

A horizontal color bar transitioning from dark purple on the left to orange on the right.

`blue_red`

A horizontal color bar transitioning from dark blue on the left to red on the right.

`heat_map`

A horizontal color bar transitioning from dark blue on the left to yellow on the right.

`pestel_shades`

A horizontal color bar transitioning from dark teal on the left to orange-red on the right.

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 178) value is also provided, the [k](#) (page 178) 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 178) value is also provided, the [k](#) (page 178) 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 177) and *maximum* (page 177) will be computed from the median and setting them will have no effect.
- mad** If true, *minimum* (page 177) and *maximum* (page 177) will be computed by the median absolute deviation. See *filters.mad* (page 239) for discussion. [Default: false]
- mad_multiplier** MAD threshold multiplier. Used in conjunction with *k* (page 178) to threshold the differencing. [Default: 1.4862]
- where** An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]
- where_merge** A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

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.

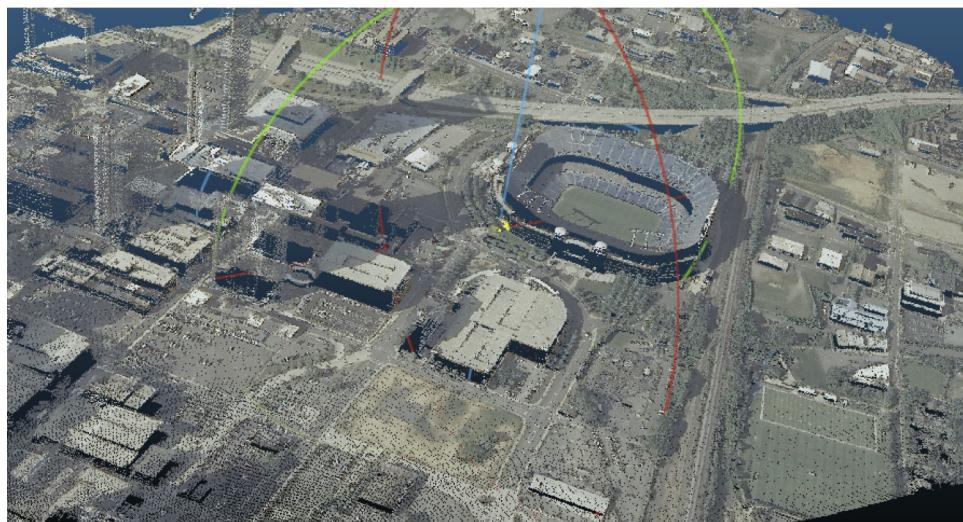


Fig. 5: After colorization, points take on the colors provided by the input image

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) can be read.

The bands of the raster to apply to each are selected using the “band” option, and the values of the band may be scaled before being written to the dimension. If the band range is 0-1, for example, it might make sense to scale by 256 to fit into a traditional 1-byte color value range.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example

```
[  
    "uncolored.las",  
    {  
        "type": "filters.colorization",  
        "dimensions": "Red:1:1.0, Blue, Green::256.0",  
        "raster": "aerial.tif"  
    },  
    "colorized.las"  
]
```

Considerations

Certain data configurations can cause degenerate filter behavior. One significant knob to adjust is the GDAL_CACHEMAX environment variable. One driver which can have issues is when a **TIFF** (http://www.gdal.org/frmt_gtiff.html) file is striped vs. tiled. GDAL’s data access in that situation is likely to cause lots of re-reading if the cache isn’t large enough.

Consider a striped TIFF file of 286mb:

```
-rw-r-----@ 1 hobu staff 286M Oct 29 16:58 orth-striped.tif
```

```
[  
    "colourless.laz",
```

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```
{  
    "type": "filters.colorization",  
    "raster": "orth-striped.tif"  
},  
"coloured-striped.las"  
]
```

Simple application of the [filters.colorization](#) (page 178) using the striped TIFF (http://www.gdal.org/frmt_gtiff.html) with a 268mb [readers.las](#) (page 73) 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_CACEMAX variable to a size larger than the TIFF file dramatically speeds up the color fetching:

```
[hobu@pyro knudsen (master)]$ export GDAL_CACEMAX=500  
[hobu@pyro knudsen (master)]$ time ~/dev/git/pdal/bin/pdal pipeline ↴  
striped.json  
  
real    0m19.034s  
user    0m15.557s  
sys    0m1.102s
```

Options

raster The raster file to read the band from. Any [format](#) (https://www.gdal.org/formats_list.html) supported by [GDAL](#) (<http://www.gdal.org>) may be read.

dimensions A comma separated list of dimensions to populate with values from the raster file. Dimensions will be created if they don't already exist. The format of each dimension is <name>:<band_number>:<scale_factor>. Either or both of band number and scale factor may be omitted as may ':' separators if the data is not ambiguous. If not supplied, band numbers begin at 1 and increment from the band number of the previous dimension. If not supplied, the scaling factor is 1.0. [Default: “Red:1:1.0, Green:2:1.0, Blue:3:1.0”]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

[filters.colorinterp \(page 175\)](#) Assign RGB colors based on a dimension and a ramp

[filters.colorization \(page 178\)](#) Fetch and assign RGB color information from a GDAL-readable datasource.

Clustering

filters.cluster

The Cluster filter first performs Euclidean Cluster Extraction on the input PointView and then labels each point with its associated cluster ID. It creates a new dimension `ClusterID` that contains the cluster ID value. Cluster IDs start with the value 1. Points that don’t belong to any cluster will 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]

is3d By default, clusters are formed by considering neighbors in a 3D sphere, but if **is3d** is set to false, it will instead consider neighbors in a 2D cylinder (XY plane only). [Default: true]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.dbSCAN

The DBSCAN filter performs Density-Based Spatial Clustering of Applications with Noise (DBSCAN) [Ester1996] and labels each point with its associated cluster ID. Points that do not belong to a cluster are given a Cluster ID of -1. The remaining clusters are labeled as integers starting from 0.

Default Embedded Stage

This stage is enabled by default

New in version 2.1.

Example

```
[  
  "input.las",  
  {  
    "type": "filters.dbSCAN",  
    "min_points": 10,
```

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```

    "eps":2.0,
    "dimensions":"X,Y,Z"
},
{
    "type":"writers.bpf",
    "filename":"output.bpf",
    "output_dims":"X,Y,Z,ClusterID"
}
]

```

Options

min_points The minimum cluster size `min_points` should be greater than or equal to the number of dimensions (e.g., X, Y, and Z) plus one. As a rule of thumb, two times the number of dimensions is often used. [Default: 6]

eps The epsilon parameter can be estimated from a k-distance graph (for $k = \text{min_points}$ minus one). `eps` defines the Euclidean distance that will be used when searching for neighbors. [Default: 1.0]

dimensions Comma-separated string indicating dimensions to use for clustering. [Default: X,Y,Z]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '`where`' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.litree

The purpose of the Li tree filter is to segment individual trees from an input `PointView`. In the output `PointView` points that are deemed to be part of a tree are labeled with a `ClusterID`. Tree IDs start at 1, with non-tree points given a `ClusterID` of 0.

Note: The filter differs only slightly from the paper in the addition of a few conditions on size of tree, minimum height above ground for tree seeding, and flexible radius for non-tree seed

insertion.

Note: In earlier PDAL releases (up to v2.2.0), ClusterID was stored in the TreeID Dimension.

Default Embedded Stage

This stage is enabled by default

Example

```
[  
    "input.las",  
    {  
        "type": "filters.litree",  
        "min_points": 50,  
        "min_height": 10.0,  
        "radius": 200.0  
    },  
    {  
        "type": "writers.las",  
        "filename": "output.laz",  
        "minor_version": 1.4,  
        "extra_dims": "all"  
    }  
]
```

Options

min_points Minimum number of points in a tree cluster. [Default: 10]

min_height Minimum height above ground to start a tree cluster. [Default: 3.0]

radius The seed point for the non-tree cluster is the farthest point in a 2D Euclidean sense from the seed point for the current tree. [Default: 100.0]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by

the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.lloydmeans

K-means clustering using Lloyd's algorithm labels each point with its associated cluster ID (starting at 0).

Default Embedded Stage

This stage is enabled by default

New in version 2.1.

Example

```
[  
    "input.las",  
    {  
        "type": "filters.lloydmeans",  
        "k": 10,  
        "maxiters": 20,  
        "dimensions": "X,Y,Z"  
    },  
    {  
        "type": "writers.las",  
        "filename": "output.laz",  
        "minor_version": 4,  
        "extra_dims": "all"  
    }  
]
```

Options

k The desired number of clusters. [Default: 10]

maxiters The maximum number of iterations. [Default: 10]

dimensions Comma-separated string indicating dimensions to use for clustering. [Default: X,Y,Z]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.cluster (page 181) 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.dbSCAN (page 182) Perform Density-Based Spatial Clustering of Applications with Noise (DBSCAN) [Ester1996].

filters.litree (page 183) Segment and label individual trees. Returns a new dimension `TreeID` that indicates the tree that a point belongs to. `TreeID` starts at 1, with non-tree points given a `TreeID` of 0. [Li2012].

filters.lloydKmeans (page 185) Perform K-means clustering using Lloyd's algorithm. Returns a new dimension `ClusterID` with each point being assigned to a cluster. `ClusterID` starts at 0. [Lloyd1982].

Pointwise Features

filters.approximatecoplanar

The **approximate coplanar filter** implements a portion of the algorithm presented in [Limberger2015]. Prior to clustering points, the authors first apply an approximate coplanarity test, where points that meet the following criteria are labeled as approximately coplanar.

$$\lambda_2 > (s_\alpha \lambda_1) \& \& (s_\beta \lambda_2) > \lambda_3$$

$\lambda_1, \lambda_2, \lambda_3$ are the eigenvalues of a neighborhood of points (defined by `knn` nearest neighbors) in ascending order. The threshold values s_α and s_β 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 250) 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]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '`where`' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view

is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.covariancefeatures

This filter implements various local feature descriptors that are based on the covariance matrix of a point’s neighborhood.

The user can pick a set of feature descriptors by setting the `feature_set` option. The *dimensionality* (page 190) set of feature descriptors introduced below is the default. The user can also provide a comma-separated list of features to explicitly itemize those covariance features they wish to be computed. This can be combined with any supported presets like “Dimensionality”. Specifying “all” will compute all available features.

Supported features include:

- Anisotropy
- DemantkeVerticality
- Density
- Eigenentropy
- Linearity
- Omnivariance
- Planarity
- Scattering
- EigenvalueSum
- SurfaceVariation
- Verticality

Note: Density requires both `OptimalKNN` and `OptimalRadius` which can be computed by running *filters.optimalneighborhood* (page 199) prior to `filters.covariancefeatures`.

Example #1

```
[  
    "input.las",  
    {  
        "type": "filters.covariancefeatures",  
        "knn": 8,  
        "threads": 2,  
        "feature_set": "Dimensionality"  
    },  
    {  
        "type": "writers.bpf",  
        "filename": "output.bpf",  
        "output_dims": "X,Y,Z,Linearity,Planarity,Scattering,Verticality"  
    }  
]
```

Example #2

```
[  
    "input.las",  
    {  
        "type": "filters.optimalneighborhood"  
    },  
    {  
        "type": "filters.covariancefeatures",  
        "knn": 8,  
        "threads": 2,  
        "optimized": true,  
        "feature_set": "Linearity,Omnivariance,Density"  
    },  
    {  
        "type": "writers.las",  
        "minor_version": 4,  
        "extra_dims": "all",  
        "forward": "all",  
        "filename": "output.las"  
    }  
]
```

Options

knn The number of k nearest neighbors used for calculating the covariance matrix. [Default: 10]

threads The number of threads used for computing the feature descriptors. [Default: 1]

feature_set A comma-separated list of individual features or feature presets (e.g., “Dimensionality”) to be computed. To compute all available features, specify “all”. [Default: “Dimensionality”]

stride When finding k nearest neighbors, stride determines the sampling rate. A stride of 1 retains each neighbor in order. A stride of two selects every other neighbor and so on. [Default: 1]

min_k Minimum number of neighbors in radius (radius search only). [Default: 3]

radius If radius is specified, neighbors will be obtained by radius search rather than k nearest neighbors, subject to meeting the minimum number of neighbors (**min_k**).

mode By default, features are computed using the standard deviation along each eigenvector, i.e., using the square root of the computed eigenvalues (`mode="SQRT"`). `mode` also accepts “Normalized” which normalizes eigenvalue such that they sum to one, or “Raw” such that the eigenvalues are used directly. [Default: “SQRT”]

optimized `optimized` can be set to `true` to enable computation of features using precomputed optimal neighborhoods (found in the `OptimalKNN` dimension). Requires [`filters.optimalneighborhood`](#) (page 199) be run prior to this stage. [Default: false]

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘`where`’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

Dimensionality feature set

The features introduced in [\[Demantke2011\]](#) describe the shape of the neighborhood, indicating whether the local geometry is more linear (1D), planar (2D) or volumetric (3D) while the one introduced in [\[Guinard2017\]](#) adds the idea of a structure being vertical.

The dimensionality filter introduces the following four descriptors that are computed from the covariance matrix of a point’s neighbors (as defined by `knn` or `radius`):

- linearity - higher for long thin strips

- planarity - higher for planar surfaces
- scattering - higher for complex 3d neighbourhoods
- verticality - higher for vertical structures, highest for thin vertical strips

It introduces four new dimensions that hold each one of these values: **Linearity**, **Planarity**, **Scattering** and **Verticality**.

filters.eigenvalues

The **eigenvalue filter** returns the eigenvalues for a given point, based on its k-nearest neighbors.

The filter produces three new dimensions (`Eigenvalue0`, `Eigenvalue1`, and `Eigenvalue2`), which can be analyzed directly, or consumed by downstream stages for more advanced filtering. The eigenvalues are sorted in ascending order.

The eigenvalue decomposition is performed using Eigen's `SelfAdjointEigenSolver` (https://eigen.tuxfamily.org/dox/classEigen_1_1SelfAdjointEigenSolver.html).

Default Embedded Stage

This stage is enabled by default

Example

This pipeline demonstrates the calculation of the eigenvalues. The newly created dimensions are written out to BPF for further inspection.

```
[  
    "input.las",  
    {  
        "type": "filters.eigenvalues",  
        "knn": 8  
    },  
    {  
        "type": "writers.bpf",  
        "filename": "output.bpf",  
        "output_dims": "X,Y,Z,Eigenvalue0,Eigenvalue1,Eigenvalue2"  
    }  
]
```

Options

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

normalize Normalize eigenvalues such that the sum is 1. [Default: false]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.estimaterank

The **rank estimation filter** uses singular value decomposition (SVD) to estimate the rank of a set of points. Point sets with rank 1 correspond to linear features, while sets with rank 2 correspond to planar features. Rank 3 corresponds to a full 3D feature. In practice this can be used alone, or possibly in conjunction with other filters to extract features (e.g., buildings, vegetation).

Two parameters are required to estimate rank (though the default values will be suitable in many cases). First, the `knn` (page 193) parameter defines the number of points to consider when computing the SVD and estimated rank. Second, the `thresh` (page 193) 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 193) 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 250).

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

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.lof

The **Local Outlier Factor (LOF) filter** was introduced as a method of determining the degree to which an object is an outlier. This filter is an implementation of the method described in [\[Breunig2000\]](#).

The filter creates three new dimensions, **NNDistance**, **LocalReachabilityDistance** and **LocalOutlierFactor**, all of which are double-precision floating values. The **NNDistance** dimension records the Euclidean distance between a point and its k-th nearest neighbor (the

number of k neighbors is set with the [minpts](#) (page 195) option. The LocalReachabilityDistance is the inverse of the mean of all reachability distances for a neighborhood of points. This reachability distance is defined as the max of the Euclidean distance to a neighboring point and that neighbor's own previously computed NNDistance. 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 195) 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 195) 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.

Note: In earlier PDAL releases (up to v2.2.0), NNDistance was stored in the KDistance Dimemsion.

Default Embedded Stage

This stage is enabled by default

Example

The sample pipeline below computes the LOF with a neighborhood of 20 neighbors, followed by a range filter to crop out points whose LocalOutlierFactor exceeds 1.2 before writing the output.

```
[  
    "input.las",  
    {  
        "type": "filters.lof",  
        "minpts": 20  
    },  
    {  
        "type": "filters.range",  
        "limits": "LocalOutlierFactor[:1.2]"  
    },
```

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```
"output.laz"  
]
```

Options

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

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.miniball

The **Miniball Criterion** was introduced in [Weyrich2004] and is based on the assumption that points that are distant to the cluster built by their k-neighborhood are likely to be outliers. First, the smallest enclosing ball is computed for the k-neighborhood, giving a center point and radius [Fischer2010]. The miniball criterion is then computed by comparing the distance (from the current point to the miniball center) to the radius of the miniball.

The author suggests that the Miniball Criterion is more robust than the *Plane Fit Criterion* (page 200) around high-frequency details, but demonstrates poor outlier detection for points close to a smooth surface.

The filter creates a single new dimension, **Miniball**, that records the Miniball criterion for the current point.

Note: To inspect the newly created, non-standard dimensions, be sure to write to an output format that can support arbitrary dimensions, such as BPF.

Default Embedded Stage

This stage is enabled by default

Example

The sample pipeline below computes the Miniball criterion with a neighborhood of 8 neighbors. We do not apply a fixed threshold to single out outliers based on the Miniball criterion as the range of values can vary from one dataset to another. In general, higher values indicate the likelihood of a point being an outlier.

```
[  
    "input.las",  
    {  
        "type": "filters.miniball",  
        "knn": 8  
    },  
    "output.laz"  
]
```

Options

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

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.nndistance

The NNDistance filter runs a 3-D nearest neighbor algorithm on the input cloud and creates a new dimension, **NNDistance**, that contains a distance metric described by the *mode* (page 197) 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 197) nearest points. [Default: ‘kth’]

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

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘‘where’’ option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.normal

The **normal filter** returns the estimated normal and curvature for a collection of points. The algorithm first computes the eigenvalues and eigenvectors of the collection of points, which is comprised of the k-nearest neighbors. The normal is taken as the eigenvector corresponding to the smallest eigenvalue. The curvature is computed as

$$\text{curvature} = \frac{\lambda_0}{\lambda_0 + \lambda_1 + \lambda_2}$$

where λ_i are the eigenvalues sorted in ascending order.

The filter produces four new dimensions (NormalX, NormalY, NormalZ, and Curvature), which can be analyzed directly, or consumed by downstream stages for more advanced filtering.

The eigenvalue decomposition is performed using Eigen's [SelfAdjointEigenSolver](#) (https://eigen.tuxfamily.org/dox/classEigen_1_1SelfAdjointEigenSolver.html).

Normals will be automatically flipped towards positive Z, unless the [always_up](#) (page 199) flag is set to *false*. Users can optionally set any of the XYZ coordinates to specify a custom [viewpoint](#) (page 199) 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 199), normals will instead be inverted such that they are oriented towards the viewpoint, regardless of the [always_up](#) (page 199) flag. To disable all normal flipping, do not provide a [viewpoint](#) (page 199) and set [always_up](#) (page 199) to *false*.

In addition to [always_up](#) (page 199) and [viewpoint](#) (page 199), users can run a refinement step (off by default) that propagates normals using a minimum spanning tree. The propagated normals can lead to much more consistent results across the dataset.

Note: To enable normal propagation, users can set [refine](#) (page 199) to *true*.

Default Embedded Stage

This stage is enabled by default

Example

This pipeline demonstrates the calculation of the normal values (along with curvature). The newly created dimensions are written out to BPF for further inspection.

```
[  
    "input.las",  
    {  
        "type": "filters.normal",  
        "knn": 8  
    },  
    {  
        "type": "writers.bpf",  
        "filename": "output.bpf",  
        "output_dims": "X,Y,Z,NormalX,NormalY,NormalZ,Curvature"  
    }]
```

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```
    }  
]
```

Options

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

viewpoint A single WKT or GeoJSON 3D point. Normals will be inverted such that they are all oriented towards the viewpoint.

always_up A flag indicating whether or not normals should be inverted only when the Z component is negative. [Default: true]

refine A flag indicating whether or not to reorient normals using minimum spanning tree propagation. [Default: false]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.optimalneighborhood

The **Optimal Neighborhood** filter computes the eigenentropy (defined as the Shannon entropy of the normalized eigenvalues) for a neighborhood of points in the range **min_k** to **max_k**. The neighborhood size that minimizes the eigenentropy is saved to a new dimension **OptimalKNN**. The corresponding radius of the neighborhood is saved to **OptimalRadius**. These dimensions can be written to an output file or utilized directly by *filters.covariancefeatures* (page 188).

Default Embedded Stage

This stage is enabled by default

Example

```
[  
    "input.las",  
    {  
        "type": "filters.optimalneighborhood",  
        "min_k": 8,  
        "max_k": 50  
    },  
    {  
        "type": "writers.las",  
        "minor_version": 4,  
        "extra_dims": "all",  
        "forward": "all",  
        "filename": "output.las"  
    }  
]
```

Options

min_k The minimum number of k nearest neighbors to consider for optimal neighborhood selection. [Default: 10]

max_k The maximum number of k nearest neighbors to consider for optimal neighborhood selection. [Default: 100]

filters.planefit

The **Plane Fit Criterion** was introduced in [Weyrich2004] and computes the deviation of a point from a manifold approximating its neighbors. First, a plane is fit to each point's k-neighborhood by performing an eigenvalue decomposition. Next, the mean point to plane distance is computed by considering all points within the neighborhood. This is compared to the point to plane distance of the current point giving rise to the k-neighborhood. As the mean distance of the k-neighborhood approaches 0, the Plane Fit criterion will tend toward 1. As point to plane distance of the current point approaches 0, the Plane Fit criterion will tend toward 0.

The author suggests that the Plane Fit Criterion is well suited to outlier detection when considering noisy reconstructions of smooth surfaces, but produces poor results around small features and creases.

The filter creates a single new dimension, `PlaneFit`, that records the Plane Fit criterion for the current point.

Note: To inspect the newly created, non-standard dimensions, be sure to write to an output format that can support arbitrary dimensions, such as BPF.

Default Embedded Stage

This stage is enabled by default

Example

The sample pipeline below computes the Plane Fit criterion with a neighborhood of 8 neighbors. We do not apply a fixed threshold to single out outliers based on the Plane Fit criterion as the range of values can vary from one dataset to another. In general, higher values indicate the likelihood of a point being an outlier.

```
[  
    "input.las",  
    {  
        "type": "filters.planefit",  
        "knn": 8  
    },  
    "output.laz"  
]
```

Options

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

threads The number of threads used for computing the plane fit criterion. [Default: 1]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.radialdensity

The **Radial Density filter** creates a new attribute `RadialDensity` that contains the density of points in a sphere of given radius.

The density at each point is computed by counting the number of points falling within a sphere of given [radius](#) (page 202) (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 202) option.

Default Embedded Stage

This stage is enabled by default

Example

```
[  
    "input.las",  
    {  
        "type": "filters.radialdensity",  
        "radius": 2.0  
    },  
    {  
        "type": "writers.bpf",  
        "filename": "output.bpf",  
        "output_dims": "X,Y,Z,RadialDensity"  
    }  
]
```

Options

radius Radius. [Default: 1.0]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '`where`' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`,

skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.reciprocity

The **Nearest-Neighbor Reciprocity Criterion** was introduced in [Weyrich2004] and is based on a simple assumption, that valid points may be in the k-neighborhood of an outlier, but the outlier will most likely not be part of the valid point's k-neighborhood.

The author suggests that the Nearest-Neighbor Reciprocity Criterion is more robust than both the *Plane Fit* (page 200) and *Miniball* (page 195) Criterion, being equally sensitive around smooth and detailed regions. The criterion does however produce invalid results near manifold borders.

The filter creates a single new dimension, **Reciprocity**, that records the percentage of points(in the range 0 to 100) that are considered uni-directional neighbors of the current point.

Note: To inspect the newly created, non-standard dimensions, be sure to write to an output format that can support arbitrary dimensions, such as BPF.

Default Embedded Stage

This stage is enabled by default

Example

The sample pipeline below computes reciprocity with a neighborhood of 8 neighbors, followed by a range filter to crop out points whose **Reciprocity** percentage is less than 98% before writing the output.

```
[  
    "input.las",  
    {  
        "type": "filters.reciprocity",  
        "knn": 8  
    },  
    {  
        "type": "filters.range",  
        "limits": "Reciprocity[:98.0]"  
    },  
]
```

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```
"output.laz"  
]
```

Options

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

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

[***filters.approximatecoplanar* \(page 186\)**](#) Estimate pointwise planarity, based on k-nearest neighbors. Returns a new dimension `Coplanar` where a value of 1 indicates that a point is part of a coplanar neighborhood (0 otherwise).

[***filters.covariancefeatures* \(page 188\)**](#) Filter that calculates local features based on the covariance matrix of a point's neighborhood.

[***filters.eigenvalues* \(page 191\)**](#) Compute pointwise eigenvalues, based on k-nearest neighbors.

[***filters.estimaterank* \(page 192\)**](#) Compute pointwise rank, based on k-nearest neighbors.

[***filters.lof* \(page 193\)**](#) Compute pointwise Local Outlier Factor (along with K-Distance and Local Reachability Distance).

[***filters.miniball* \(page 195\)**](#) Compute a criterion for point neighbors based on the miniball algorithm.

[***filters.nndistance* \(page 196\)**](#) Compute a distance metric based on nearest neighbors.

[***filters.normal* \(page 197\)**](#) Compute pointwise normal and curvature, based on k-nearest neighbors.

[***filters.optimalneighborhood* \(page 199\)**](#) Compute optimal k nearest neighbors and corresponding radius by minimizing pointwise eigenentropy. Creates two new dimensions `OptimalKNN` and `OptimalRadius`.

[***filters.planefit* \(page 200\)**](#) Compute a deviation of a point from a manifold approximating its neighbors.

[***filters.radialdensity* \(page 202\)**](#) Compute pointwise density of points within a given radius.

`filters.reciprocity` (page 203) Compute the percentage of points that are considered uni-directional neighbors of a point.

Assignment

`filters.assign`

The assign filter allows you set the value of a dimension for all points to a provided value that pass a range filter.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Note: The `assignment` and `condition` options are deprecated and may be removed in a future release.

Options

assignment A `range` (page 252) followed by an assignment of a value (see example). Can be specified multiple times. The assignments are applied sequentially to the dimension value as set when the filter began processing. [Required]

condition A single `ranges` (page 252) that a point's values must pass in order for the assignment to be performed. [Default: none] [Deprecated - use 'value']

value A list of `assignment expressions` (page 206) to be applied to points. The list of values is evaluated in order. [Default: none]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a 'where' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view

is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

Assignment Expressions

The assignment expression syntax is an expansion on the PDAL expression syntax that provides for assignment of values to points. The generic expression is:

```
"value" : "Dimension = ValueExpression [WHERE ConditionalExpression]"
```

`Dimension` is the name of a PDAL dimension.

A `ValueExpression` consists of constants, dimension names and mathematical operators that evaluates to a numeric value. The supported mathematical operations are addition(+), subtraction(-), multiplication(*) and division(\).

A `ConditionalExpression` is an optional boolean value that must evaluate to *true* for the `ValueExpression` to be applied.

Example 1

```
"value" : "Red = Red / 256"
```

This scales the Red value by 1/256. If the input values are in the range 0 - 65535, the output value will be in the range 0 - 255.

Example 2

```
"value" :  
[  
    "Classification = 2 WHERE HeightAboveGround < 5",  
    "Classification = 1 WHERE HeightAboveGround >= 5"  
]
```

This sets the classification of points to either `Ground` or `Unassigned` depending on the value of the `HeightAboveGround` dimension.

Example 3

```
"value" :  
[  
    "X = 1",  
    "X = 2 WHERE X > 10"  
]
```

This sets the value of X for all points to 1. The second statement is essentially ignored since the first statement sets the X value of all points to 1 and therefore no points the ConditionalExpression of the second statement.

filters.overlay

The **overlay filter** allows you to set the values of a selected dimension based on an OGR-readable polygon or multi-polygon.

Default Embedded Stage

This stage is enabled by default

OGR SQL support

You can limit your queries based on OGR's SQL support. If the filter has both a *datasource* (page 209) and a *query* (page 209) 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#a9892ecb0bf61add295bd9decd13797a) 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) 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. [Default: first layer]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

***filters.assign* (page 205)** Assign values for a dimension range to a specified value.

***filters.overlay* (page 207)** Assign values to a dimension based on the extent of an OGR-readable data source or an OGR SQL query.

Dimension Create/Copy

filters.ferry

The ferry filter copies data from one dimension to another, creates new dimensions or both.

The filter is guided by a list of 'from' and 'to' dimensions in the format `<from>=><to>`. Data from the 'from' dimension is copied to the 'to' dimension. The 'from' dimension must exist. The 'to' dimension can be pre-existing or will be created by the ferry filter.

Alternatively, the format `=><to>` can be used to create a new dimension without copying data from any source. The values of the 'to' dimension are default initialized (set to 0).

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example 1

In this scenario, we are making copies of the X and Y dimensions into the dimensions StatePlaneX and StatePlaneY. Since the reprojection filter will modify the dimensions X and Y, this allows us to maintain both the pre-reprojection values and the post-reprojection values.

```
[  
    "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"
```

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```
        },
        {
            "type": "filters.ferry",
            "dimensions": ">=>Classification"
        },
        {
            "type": "filters.assign",
            "assignment": "Classification[::]=2"
        },
        "out.las"
    ]
```

Options

dimensions A list of dimensions whose values should be copied. The format of the option is `<from>=><to>, <from>=><to>, ...` Spaces are ignored. ‘from’ can be left empty, in which case the ‘to’ dimension is created and default-initialized. ‘to’ dimensions will be created if necessary.

Note: the old syntax that used ‘=’ instead of ‘=>’ between dimension names is still supported.

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

[*filters.ferry* \(page 209\)](#) Copy data from one dimension to another.

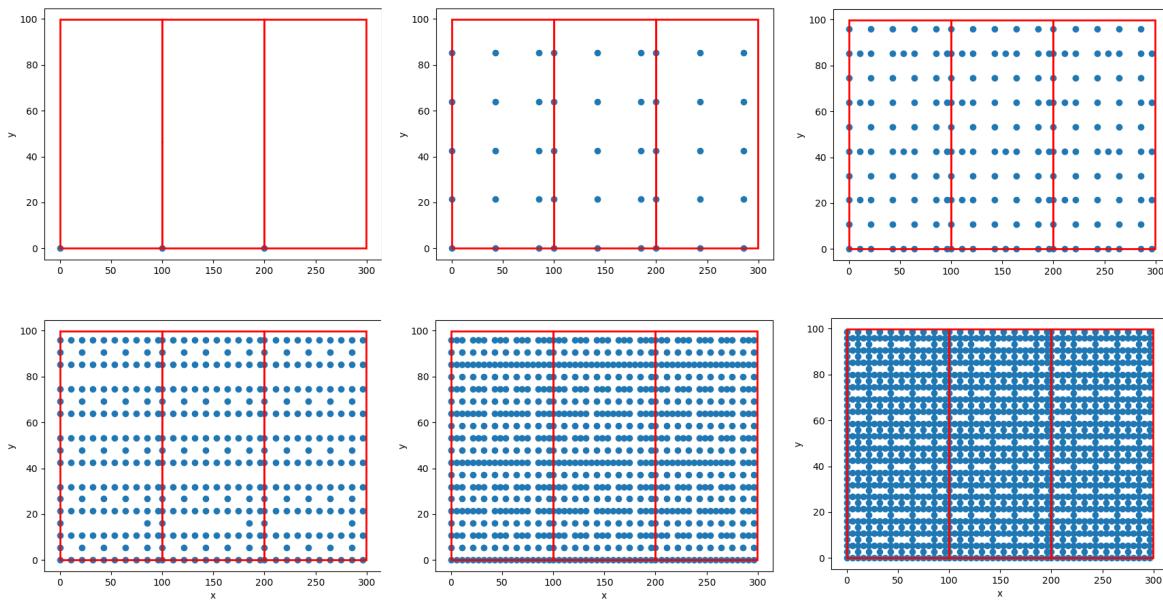
7.5.2 Order

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

filters.mortonorder

Sorts the XY data using [Morton ordering](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"  
    }
```

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```

},
{
    "type": "writers.las",
    "filename": "compressed.laz",
    "compression": "true"
}
]
```

Options

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.randomize

The randomize filter reorders the points in a point view randomly.

Default Embedded Stage

This stage is enabled by default

Example

```

[
    "input.las",
    {
        "type": "filters.randomize"
    },
    {
        "type": "writers.las",
        "filename": "output.las"
    }
]
```

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```
    }  
]
```

Options

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

`filters.sort`

The sort filter orders a point view based on the values of a *dimension* (page 215). The sorting can be done in increasing (ascending) or decreasing (descending) *order* (page 215).

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”]

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

[filters.mortonorder \(page 212\)](#) Sort XY data using Morton ordering (aka Z-order/Z-curve).

[filters.randomize \(page 213\)](#) Randomize points in a view.

[filters.sort \(page 214\)](#) Sort data based on a given dimension.

7.5.3 Move

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

Registration

[filters.cpd](#)

The **Coherent Point Drift (CPD) filter** uses the algorithm of [MS10] algorithm to compute a rigid, nonrigid, or affine transformation between datasets. The rigid and affine are what you’d expect; the nonrigid transformation uses Motion Coherence Theory [YG88] to “bend” the points to find a best alignment.

Note: CPD is computationally intensive and can be slow when working with many points (i.e. > 10,000). Nonrigid is significantly slower than rigid and affine.

The first input to the change filter are considered the “fixed” points, and all subsequent inputs are “moving” points. The output from the change filter are the “moving” points after the calculated transformation has been applied, one point view per input. Any additional information about the cpd registration, e.g. the rigid transformation matrix, will be placed in the stage’s metadata.

When to use CPD vs ICP

Summarized from the Non-rigid point set registration: Coherent Point Drift (http://graphics.stanford.edu/courses/cs468-07-winter/Papers/nips2006_0613.pdf) paper.

- CPD outperforms the ICP in the presence of noise and outliers by the use of a probabilistic assignment of correspondences between pointsets, which is innately more robust than the binary assignment used in ICP.
- CPD does not work well for large in-plane rotation, such transformation can be first compensated by other well known global registration techniques before CPD algorithm is carried out
- CPD is most effective when estimating smooth non-rigid transformations.

Dynamic Plugin

This stage requires a dynamic plugin to operate

Examples

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

If *method* (page 217) 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":  
    }
```

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```
{
    "iterations": 10,
    "method": "rigid",
    "runtime": 0.003839,
    "sigma2": 5.684342128e-16,
    "transform": "
        1 -6.21722e-17 1.30104e-18 5.
        29303e-11-8.99346e-17 1 2.60209e-18 -3.49247e-10 -2.1684e-
        19 1.73472e-18 1 -1.53477e-12 0 0
        0 1"
},
}
```

See also:

[filters.transformation](#) (page 225) to apply a transform to other points. [filters.icp](#) (page 217) for deterministic binary point pair assignments.

Options

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

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.icp

The **ICP filter** uses the Iterative Closest Point (ICP) algorithm to calculate a **rigid** (rotation and translation) transformation that best aligns two datasets. The first input to the ICP filter is considered the “fixed” points, and all subsequent points are “moving” points. The output from the filter are the “moving” points after the calculated transformation has been applied, one point view per input. The transformation matrix is inserted into the stage’s metadata.

Note: ICP requires the initial pose of the two point sets to be adequately close, which is not

always possible, especially when the transformation is non-rigid. ICP can handle limited non-rigid transformations but be aware ICP may be unable to escape a local minimum. Consider using CPD instead.

From [LLW+19]:

ICP starts with an initial guess of the transformation between the two point sets and then iterates between finding the correspondence under the current transformation and updating the transformation with the newly found correspondence. ICP is widely used because it is rather straightforward and easy to implement in practice; however, its biggest problem is that it does not guarantee finding the globally optimal transformation. In fact, ICP converges within a very small basin in the parameter space, and it easily becomes trapped in local minima. Therefore, the results of ICP are very sensitive to the initialization, especially when high levels of noise and large proportions of outliers exist.

Examples

```
[  
    "fixed.las",  
    "moving.las",  
    {  
        "type": "filters.icp"  
    },  
    "output.las"  
]
```

To get the `transform` matrix, you'll need to use the `--metadata` option from the pipeline command:

```
$ pdal pipeline icp-pipeline.json --metadata icp-metadata.json
```

The metadata output might start something like:

```
{  
    "stages":  
    {  
        "filters.icp":  
        {  
            "centroid": "      583394  5.2831e+06  498.152",  
            "composed": "          1  2.60209e-18 -1.97906e-09      -  
→ 0.374999  8.9407e-08          1  5.58794e-09      -0.614662  6.  
→ 98492e-10 -5.58794e-09          1  0.033234          0      -  
→ 0          0          1",  
    }  
}
```

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```

    "converged": true,
    "fitness": 0.01953125097,
    "transform": "
- 0.375 8.9407e-08      1 2.60209e-18 -1.97906e-09      -
- 5.58794e-09      1 5.58794e-09      -0.5625 6.98492e-10 -
- 0           0.00411987      0           0           0
- 0           1"
}

```

To apply this transformation to other points, the `centroid` and `transform` metadata items can be used with `filters.transformation` in another pipeline. First, move the centroid of the points to (0,0,0), then apply the transform, then move the points back to the original location. For the above metadata, the pipeline would be similar to:

```

[
{
  "type": "readers.las",
  "filename": "in.las"
},
{
  "type": "filters.transformation",
  "matrix": "1 0 0 -583394 0 1 0 -5.2831e+06 0 0 1 -498.152
- 0 0 0 1"
},
{
  "type": "filters.transformation",
  "matrix": "1 2.60209e-18 -1.97906e-09      -0.375 8.9407e-08
- 1 5.58794e-09      -0.5625 6.98492e-10 -5.58794e-09
- 1 0.00411987      0           0           0           1
"
},
{
  "type": "filters.transformation",
  "matrix": "1 0 0 583394 0 1 0 5.2831e+06 0 0 1 498.152 0 0
- 0 1"
},
{
  "type": "writers.las",
  "filename": "out.las"
}
]

```

Note: The composed metadata matrix is a composition of the three transformation steps outlined above, and can be used in a single call to `filters.transformation` as opposed to

the three separate calls.

See also:

[filters.transformation](#) (page 225) to apply a transform to other points. [filters.cpd](#) (page 215) for the use of a probabilistic assignment of correspondences between pointsets.

Options

max_iter Maximum number of iterations. [Default: **100**]

max_similar Max number of similar transforms to consider converged. [Default: **0**]

mse_abs Absolute threshold for MSE. [Default: **1e-12**]

rt Rotation threshold. [Default: **0.99999**]

tt Translation threshold. [Default: **9e-8**]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

[filters.cpd](#) (page 215) Compute and apply transformation between two point clouds using the Coherent Point Drift algorithm.

[filters.icp](#) (page 217) Compute and apply transformation between two point clouds using the Iterative Closest Point algorithm.

Predefined

filters.projpipeline

The projpipeline filter applies a coordinates transformation pipeline. The pipeline could be specified as PROJ string (single step operation or multiple step string starting with +proj=pipeline), a WKT2 string describing a CoordinateOperation, or a “urn:ogc:def:coordinateOperation:EPSG::XXXX” URN.

Note: The projpipeline filter does not consider any spatial reference information. However user could specify an output srs, but no check is done to ensure the compliance with the

provided transformation pipeline.

Note: The projpipeline filter is enabled if the version of GDAL is superior or equal to 3.0

Streamable Stage

This stage supports streaming operations

Example

This example shift point on the z-axis.

```
[  
    "untransformed.las",  
    {  
        "type": "filters.projpipeline",  
        "coord_op": "+proj=affine +zoff=100"  
    },  
    {  
        "type": "writers.las",  
        "filename": "transformed.las"  
    }  
]
```

This example apply a shift on the z-axis then reproject from utm 10 to WGS84, using the reverse_transfo flag. It also set the output srs

```
[  
    "utm10.las",  
    {  
        "type": "filters.projpipeline",  
        "coord_op": "+proj=pipeline +step +proj=unitconvert +xy_in=deg_<br/>+xy_out=rad +step +proj=utm +zone=10 +step +proj=affine +zoff=100",  
        "reverse_transfo": "true",  
        "out_srs": "EPSG:4326"  
    },  
    {  
        "type": "writers.las",  
        "filename": "wgs84.las"  
    }  
]
```

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```
}
```

```
]
```

Note: PDAL uses the GDAL *OGRCoordinateTransformation* class to transform coordinates. By default output angular units are in radians. To change to degrees we need to apply a unit conversion step.

Options

coord_op The coordinate operation string. Could be specified as PROJ string (single step operation or multiple step string starting with +proj=pipeline), a WKT2 string describing a CoordinateOperation, or a “urn:ogc:def:coordinateOperation:EPSG::XXXX” URN.

reverse_transfo Boolean, Whether the coordinate operation should be evaluated in the reverse path [Default: false]

out_srs The spatial reference system of the file to be written. Can be an EPSG string (e.g. “EPSG:26910”) or a WKT string. No check is done to ensure the compliance with the specified coordinate operation [Default: Not set]

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If *true*, the skipped points are added to the first point view returned by the skipped filter. If *false*, skipped points are placed in their own point view. If *auto*, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: *auto*]

filters.reprojection

The **reprojection filter** converts the X, Y and/or Z dimensions to a new spatial reference system. The old coordinates are replaced by the new ones. If you want to preserve the old coordinates for future processing, use a *filters.ferry* (page 209) 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]

in_axis_ordering An array of numbers that override the axis order for the in_srs (or if not specified, the inferred SRS from the previous Stage). “2, 1” for example would swap X and Y, which may be commonly needed for something like “EPSG:4326”.

out_axis_ordering An array of numbers that override the axis order for the out_srs. “2, 1” for example would swap X and Y, which may be commonly needed for something like “EPSG:4326”.

error_on_failure If true and reprojection of any point fails, throw an exception that terminates

PDAL . [Default: false]

filters.transformation

The transformation filter applies an arbitrary rotation+translation transformation, represented as a 4x4 *matrix* (page 226), 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

invert If set to true, applies the inverse of the provided transformation matrix. [Default: false]

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

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

Further details

A full tutorial about transformation matrices is beyond the scope of this documentation. Instead, we will provide a few pointers to introduce core concepts, especially as pertains to PDAL's handling of the `matrix` argument.

Transformations in a 3-dimensional coordinate system can be represented as an affine transformation using homogeneous coordinates. This 4x4 matrix can represent transformations describing operations like translation, rotation, and scaling of coordinates.

The transformation filter's `matrix` argument is a space delimited, 16 element string. This string is simply a row-major representation of the 4x4 matrix (i.e., first four elements correspond to the top row of the transformation matrix and so on).

In the event that readers are accustomed to an alternate representation of the transformation matrix, we provide some simple examples in the form of pure translations, rotations, and scaling, and show the corresponding `matrix` string.

Translation

A pure translation by t_x , t_y , and t_z in the X, Y, and Z dimensions is represented by the following matrix.

$$\begin{array}{cccc} 1 & 0 & 0 & t_x \\ 0 & 1 & 0 & t_y \\ 0 & 0 & 1 & t_z \\ 0 & 0 & 0 & 1 \end{array}$$

The JSON syntax required for such a translation is written as follows for $t_x = 7$, $t_y = 8$, and $t_z = 9$.

```
[  
  {  
    "type": "filters.transformation",  
    "matrix": "1  0  0  7  0  1  0  8  0  0  1  9  0  0  0  1"  
  }  
]
```

Scaling

Scaling of coordinates is also possible using a transformation matrix. The matrix shown below will scale the X coordinates by s_x , the Y coordinates by s_y , and Z by s_z .

$$\begin{matrix} s_x & 0 & 0 & 0 \\ 0 & s_y & 0 & 0 \\ 0 & 0 & s_z & 0 \\ 0 & 0 & 0 & 1 \end{matrix}$$

We again provide an example JSON snippet to demonstrate the scaling transformation. In the example, X and Y are not scaled at all (i.e., $s_x = s_y = 1$) and Z is magnified by a factor of 2 ($s_z = 2$).

```
[  
  {  
    "type": "filters.transformation",  
    "matrix": "1  0  0  0  0  1  0  0  0  0  0  2  0  0  0  0  1"  
  }  
]
```

Rotation

A rotation of coordinates by θ radians counter-clockwise about the z-axis is accomplished with the following matrix.

$$\begin{matrix} \cos \theta & -\sin \theta & 0 & 0 \\ \sin \theta & \cos \theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{matrix}$$

In JSON, a rotation of 90 degrees ($\theta = 1.57$ radians) takes the form shown below.

```
[
```

```
{
```

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```

    "type": "filters.transformation",
    "matrix": "0  0  -1  0  1  0  0  0  0  0  0  0  1  0  0  0  0  0  1"
}
]
```

Similarly, a rotation about the x-axis by θ radians is represented as

$$\begin{matrix} 1 & 0 & 0 & 0 \\ 0 & \cos \theta & -\sin \theta & 0 \\ 0 & \sin \theta & \cos \theta & 0 \\ 0 & 0 & 0 & 1 \end{matrix}$$

which takes the following form in JSON for a rotation of 45 degrees ($\theta = 0.785$ radians)

```

[
{
    "type": "filters.transformation",
    "matrix": "1  0  0  0  0  0.707  -0.707  0  0  0.707  0.707  0  0
              0  0  0  1"
}
]
```

Finally, a rotation by θ radians about the y-axis is accomplished with the matrix

$$\begin{matrix} \cos \theta & 0 & \sin \theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin \theta & 0 & \cos \theta & 0 \\ 0 & 0 & 0 & 1 \end{matrix}$$

and the JSON string for a rotation of 10 degrees ($\theta = 0.175$ radians) becomes

```

[
{
    "type": "filters.transformation",
    "matrix": "0.985  0  0.174  0  0  1  0  0  -0.174  0  0.985  0
              0  0  0  1"
}
]
```

filters.projpipeline (page 220) Apply coordinates operation on point triplets, based on PROJ pipeline string, WKT2 coordinates operations or URN definitions.

filters.reprojection (page 222) Reproject data using GDAL from one coordinate system to another.

filters.transformation (page 225) Transform each point using a 4x4 transformation matrix.

7.5.4 Cull

Some PDAL filters will cull points, returning a point cloud that is smaller than the input. These filters will invalidate an existing KD-tree.

Spatial

`filters.crop`

The **crop filter** removes points that fall outside or inside a cropping bounding box (2D or 3D), polygon, or point+distance. If more than one bounding region is specified, the filter will pass all input points through each bounding region, creating an output point set for each input crop region.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

The provided bounding regions are assumed to have the same spatial reference as the points unless the option `a_srs` (page 231) provides an explicit spatial reference for bounding regions. If the point input consists of multiple point views with differing spatial references, one is chosen at random and assumed to be the spatial reference of the input bounding region. In this case a warning will be logged.

Example 1

This example crops an input point cloud using a square polygon.

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

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(continued from previous page)

```
"filename": "file-cropped.las"  
}  
]
```

Example 2

This example crops all points more than 500 units in any direction from a point.

```
[  
    "file-input.las",  
    {  
        "type": "filters.crop",  
        "point": "POINT(0 0 0)",  
        "distance": 500  
    },  
    {  
        "type": "writers.las",  
        "filename": "file-cropped.las"  
    }  
]
```

Options

bounds The extent of the clipping rectangle in the format "[[xmin, xmax], [ymin, ymax]]". This option can be specified more than once by placing values in an array.

Note: 3D bounds can be given in the form ([xmin, xmax], [ymin, ymax], [zmin, zmax]).

Warning: If a 3D bounds is given to the filter, a 3D crop will be attempted, even if the Z values are invalid or inconsistent with the data.

polygon The clipping polygon, expressed in a well-known text string, eg: "POLYGON((0 0, 5000 10000, 10000 0, 0 0))". This option can be specified more than once by placing values in an array.

outside Invert the cropping logic and only take points outside the cropping bounds or polygon.
[Default: false]

point An array of WKT or GeoJSON 2D or 3D points (eg: "POINT(0 0 0)"). Requires *distance* (page 231).

distance Distance (radius) in units of common X, Y, and Z *Dimensions* (page 289) in combination with *point* (page 231). Passing a 2D point will crop using a circle. Passing a 3D point will crop using a sphere.

a_srs Indicates the spatial reference of the bounding regions. If not provided, it is assumed that the spatial reference of the bounding region matches that of the points.

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

Notes

1. See *Clipping data with polygons* (page 376); and *Clipping with Geometries* (page 330) for example usage scenarios for *filters.crop* (page 229).

filters.crop (page 229) Filter points inside or outside a bounding box or a polygon

Resampling

filters.decimation

The **decimation filter** retains every Nth point from an input point view.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example

```
[  
  {  
    "type": "readers.las",  
    "filename": "larger.las"  
  },  
  {  
    "type": "filters.decimation",  
    "step": 10  
  },  
  {  
    "type": "writers.las",  
    "filename": "smaller.las"  
  }  
]
```

See also:

`filters.voxelgrid` 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]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.fps

The **Farthest Point Sampling Filter** adds points from the input to the output PointView one at a time by selecting the point from the input cloud that is farthest from any point currently in the output.

See also:

[filters.sample](#) (page 234) produces a similar result, but while `filters.sample` allows us to target a desired separation of points via the `radius` parameter at the expense of knowing the number of points in the output, `filters.fps` allows us to specify exactly the number of output points at the expense of knowing beforehand the spacing between points.

Default Embedded Stage

This stage is enabled by default

Options

count Desired number of output samples. [Default: 1000]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.relaxationdartthrowing

The **Relaxation Dart Throwing Filter** is a variation on Poisson sampling. The approach was first introduced by [\[McCool1992\]](#). The filter operates nearly identically to [filters.sample](#) (page 234), except it will continue to shrink the radius with each pass through the point cloud until the desired number of output points is reached.

See also:

[filters.decimation](#) (page 231), [filters.fps](#) (page 233) and [filters.sample](#) (page 234) all perform some form of thinning or resampling.

Note: The `shuffle` option does not reorder points in the `PointView`, but shuffles the order in which the points are visited while processing, which can improve the quality of the result.

Default Embedded Stage

This stage is enabled by default

Options

decay Decay rate for the radius shrinkage. [Default: 0.9]

radius Starting minimum distance between samples. [Default: 1.0]

count Desired number of points in the output. [Default: 1000]

shuffle Choose whether or not to shuffle order in which points are visited. [Default: true]

seed Seed for random number generator, used only with `shuffle`.

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '`where`' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

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] and [Dippe1985], and has been applied to point clouds in other software [Mesh2009].

Our implementation of Poisson sampling is made streamable by voxelizing the space and only adding points to the output `PointView` if they do not violate the minimum distance criterion (as specified by `radius`). The voxelization allows several optimizations, first by checking for existing points within the same voxel as the point under consideration, which are mostly likely to violate the minimum distance criterion. Furthermore, we can easily visit neighboring voxels (limiting the search to those that are populated) without the need to create a KD-tree from the entire input `PointView` first and performing costly spatial searches.

See also:

[*filters.decimation*](#) (page 231), [*filters.fps*](#) (page 233), [*filters.relaxationdardthrowing*](#) (page 233), [*filters.voxelcenternearestneighbor*](#) (page 240), [*filters.voxelcentroidnearestneighbor*](#) (page 241), and [*voxeldownsize*](#) also perform decimation.

Note: Starting with PDAL v2.3, the `filters.sample` now supports streaming mode. As a result, there is no longer an option to `shuffle` points (or to provide a `seed` for the shuffle).

Note: Starting with PDAL v2.3, a `cell` option has been added that works with the existing `radius`. The user must provide one or the other, but not both. The provided option will be used to automatically compute the other. The relationship between `cell` and `radius` is such that the `radius` defines the radius of a sphere that circumscribes a voxel with edge length defined by `cell`.

Note: Care must be taken with selection of the `cell/radius` option. Although the filter can now operate in streaming mode, if the extents of the point cloud are large (or conversely, if the cell size is small) the voxel occupancy map which grows as a function of these variables can still require a large memory footprint.

Note: To operate in streaming mode, the filter will typically retain the first point to occupy a voxel (subject to the minimum distance criterion set forth earlier). This means that point ordering matters, and in fact, it is quite possible that points in the incoming stream can be ordered in such a way as to introduce undesirable artifacts (e.g., related to previous tiling of the data). In our experience, processing data that is still in scan order (ordered by `GpsTime`, if available) does produce reliable results, although to require this sort either internally or by inserting [*filters.sort*](#) (page 214) prior to sampling would break our ability to stream the data.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Options

cell Voxel cell size. If `radius` is set, `cell` is automatically computed such that the cell is circumscribed by the sphere defined by `radius`.

radius Minimum distance between samples. If `cell` is set, `radius` is automatically computed to define a sphere that circumscribes the voxel cell. Whether specified or derived, `radius` defines the minimum allowable distance between points.

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '`where`' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.decimation (page 231) Keep every Nth point.

filters.fps (page 233) The Farthest Point Sampling Filter adds points from the input to the output PointView one at a time by selecting the point from the input cloud that is farthest from any point currently in the output.

filters.relaxationdartthrowing (page 233) Relaxation dart throwing is a hierarchical variant of Poisson disk sampling, shrinking the minimum radius between iterations until the target number of output points is achieved.

filters.sample (page 234) Perform Poisson sampling and return only a subset of the input points.

Conditional

filters.dem

The **DEM filter** uses a source raster to keep point cloud data within a each cell within a computed range. For example, atmospheric or MTA noise in a scene can be quickly removed by keeping all data within 100m above and 20m below a preexisting elevation model.

Default Embedded Stage

This stage is enabled by default

Example

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

Options

limits A *range* (page 252) that defines the dimension and the magnitude above and below the value of the given dimension to filter.

For example “Z[20:100]” would keep all Z point cloud values that are within 100 units above and 20 units below the elevation model value at the given X and Y value.

raster GDAL readable raster (http://www.gdal.org/formats_list.html) data to use for filtering.

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

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.iqr

The **Interquartile Range Filter** automatically crops the input point cloud based on the distribution of points in the specified dimension. The Interquartile Range (IQR) is defined as the range between the first and third quartile (25th and 75th percentile). Upper and lower bounds are determined by adding 1.5 times the IQR to the third quartile or subtracting 1.5 times the IQR from the first quartile. The multiplier, which defaults to 1.5, can be adjusted by the user.

Note: This method can remove real data, especially ridges and valleys in rugged terrain, or tall features such as towers and rooftops in flat terrain. While the number of deviations can be

adjusted to account for such content-specific considerations, it must be used with care.

Default Embedded Stage

This stage is enabled by default

Example

The sample pipeline below uses the filter to automatically crop the Z dimension and remove possible outliers. The multiplier to determine high/low thresholds has been adjusted to be less aggressive and to only crop those outliers that are greater than the third quartile plus 3 times the IQR or are less than the first quartile minus 3 times the IQR.

```
[  
    "input.las",  
    {  
        "type": "filters.iqr",  
        "dimension": "Z",  
        "k": 3.0  
    },  
    "output.laz"  
]
```

Options

k The IQR multiplier used to determine upper/lower bounds. [Default: 1.5]

dimension The name of the dimension to filter.

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.mad

The **MAD filter** filter crops the input point cloud based on the distribution of points in the specified [dimension](#) (page 239). Specifically, we choose the method of median absolute deviation from the median (commonly referred to as MAD), which is robust to outliers (as opposed to mean and standard deviation).

Note: This method can remove real data, especially ridges and valleys in rugged terrain, or tall features such as towers and rooftops in flat terrain. While the number of deviations can be adjusted to account for such content-specific considerations, it must be used with care.

Default Embedded Stage

This stage is enabled by default

Example

The sample pipeline below uses filters.mad to automatically crop the Z dimension and remove possible outliers. The number of deviations from the median has been adjusted to be less aggressive and to only crop those outliers that are greater than four deviations from the median.

```
[  
    "input.las",  
    {  
        "type": "filters.mad",  
        "dimension": "Z",  
        "k": 4.0  
    },  
    "output.laz"  
]
```

Options

k The number of deviations from the median. [Default: 2.0]

dimension The name of the dimension to filter.

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

***filters.dem* (page 236)** Remove points that are in a raster cell but have a value far from the value of the raster.

***filters.iqr* (page 237)** Cull points falling outside the computed Interquartile Range for a given dimension.

***filters.mad* (page 239)** Cull points falling outside the computed Median Absolute Deviation for a given dimension.

Voxel

filters.voxelcenternearestneighbor

The **VoxelCenterNearestNeighbor filter** is a voxel-based sampling filter. The input point cloud is divided into 3D voxels at the given cell size. For each populated voxel, the coordinates of the voxel center are used as the query point in a 3D nearest neighbor search. The nearest neighbor is then added to the output point cloud, along with any existing dimensions.

Note: This is similar to the existing `filters.voxelgrid`. 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
```

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```
    },
    "output.las"
]
```

See also:

[filters.voxelcentroidnearestneighbor](#) (page 241) 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]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

[filters.voxelcentroidnearestneighbor](#)

The **VoxelCentroidNearestNeighbor Filter** is a voxel-based sampling filter. The input point cloud is divided into 3D voxels at the given cell size. For each populated voxel, we apply the following ruleset. For voxels with only one point, the point is passed through to the output. For voxels with exactly two points, the point closest the voxel center is returned. Finally, for voxels with more than two points, the centroid of the points within that voxel is computed. This centroid is used as the query point in a 3D nearest neighbor search (considering only those points lying within the voxel). The nearest neighbor is then added to the output point cloud, along with any existing dimensions.

Default Embedded Stage

This stage is enabled by default

Example

```
[  
    "input.las",  
    {  
        "type": "filters.voxelcentroidnearestneighbor",  
        "cell": 10.0  
    },  
    "output.las"  
]
```

See also:

[filters.voxelcenternearestneighbor](#) (page 240) offers a similar solution, using the voxel center as opposed to the voxel centroid for the query point.

Options

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

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.voxeldownsize

The **voxeldownsize filter** is a voxel-based sampling filter. The input point cloud is divided into 3D voxels at the given cell size. For each populated voxel, either first point entering in the voxel or center of a voxel (depending on mode argument) is accepted and voxel is marked as populated. All other points entering in the same voxel are filtered out.

Example

```
[  
    "input.las",  
    {  
        "type": "filters.voxeldownsize",  
        "cell": 1.0,  
        "mode": "center"  
    },  
    "output.las"  
]
```

See also:

[filters.voxelcenternearestneighbor](#) (page 240) offers a similar solution, using the coordinates of the voxel center as the query point in a 3D nearest neighbor search. The nearest neighbor is then added to the output point cloud, along with any existing dimensions.

Options

cell Cell size in the X, Y, and Z dimension. [Default: 0.001]

mode Mode for voxel based filtering. [Default: center] **center**: Coordinates of the first point found in each voxel will be modified to be the center of the voxel. **first**: Only the first point found in each voxel is retained.

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

Warning: If you choose **center** mode, you are overwriting the X, Y and Z values of retained points. This may invalidate other dimensions of the point if they depend on this location or the location of other points in the input.

[filters.voxelcenternearestneighbor](#) (page 240) Return the point within each voxel that is nearest the voxel center.

[filters.voxelcentroidnearestneighbor](#) (page 241) Return the point within each voxel that is nearest the voxel centroid.

[*filters.voxeldownsize* \(page 242\)](#) Retain either first point detected in each voxel or center of a populated voxel, depending on mode argument.

Position

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* \(page 213\)](#) 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"  
  }
```

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

See also:

[filters.tail](#) (page 253) is the dual to [filters.head](#) (page 244).

Options

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

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a 'where' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.locate

The Locate filter searches the specified [dimension](#) (page 246) for the minimum or maximum value and returns a single point at this location. If multiple points share the min/max value, the first will be returned. All dimensions of the input PointView will be output, subject to any overriding writer options.

Default Embedded Stage

This stage is enabled by default

Example

This example returns the point at the highest elevation.

```
[  
    "input.las",  
    {  
        "type": "filters.locate",  
        "dimension": "Z",  
        "minmax": "max"  
    },  
    "output.las"  
]
```

Options

dimension Name of the dimension in which to search for min/max value.

minmax Whether to return the minimum or maximum value in the dimension.

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.mongo

The **Mongo Filter** applies query logic to the input point cloud based on a MongoDB-style query expression using the point cloud attributes.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Example

This example passes through only the points whose Classification is non-zero.

```
[  
    "input.las",  
    {  
        "type": "filters.mongo",  
        "expression": {  
            "Classification": { "$ne": 0 }  
        }  
    },  
    "filtered.las"  
]
```

This example passes through only the points whose ReturnNumber is equal to the NumberOfReturns and the NumberOfReturns is greater than 1.

```
[  
    "input.las",  
    {  
        "type": "filters.mongo",  
        "expression": { "$and": [  
            { "ReturnNumber": "NumberOfReturns" },  
            { "NumberOfReturns": { "$gt": 1 } }  
        ] }  
    },  
    "filtered.las"  
]
```

Options

expression A JSON query *expression* (page 248) containing a combination of query comparisons and logical operators.

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

Expression

A query expression is a combination of comparison and logical operators that define a query which can be used to select matching points by their attribute values.

Comparison operators

There are 8 valid query comparison operators:

- `$eq`: Matches values equal to a specified value.
- `$gt`: Matches values greater than a specified value.
- `$gte`: Matches values greater than or equal to a specified value.
- `$lt`: Matches values less than a specified value.
- `$lte`: Matches values less than or equal to a specified value.
- `$ne`: Matches values not equal to a specified value.
- `$in`: Matches any of the values specified in the array.
- `$nin`: Matches none of the values specified in the array.

Comparison operators compare a point cloud attribute with an operand or an array of operands. An *operand* is either a numeric constant or a string representing a dimension name. For all comparison operators except for `$in` and `$nin`, the comparison value must be a single operand. For `$in` and `$nin`, the value must be an array of operands.

Comparison operator specifications must be contained within an object whose key is the dimension name to be compared.

```
{ "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]"  
    },
```

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(continued from previous page)

```
{
    "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 252). If more than one range is specified for a dimension, the criteria are treated as being logically ORed together. Ranges for different dimensions are treated as being logically ANDed.

Example:

```
Classification[1:2], Red[1:50], Blue[25:75], Red[75:255], ↪
  ↪Classification[6:7]
```

This specification will select points that have the classification of 1, 2, 6 or 7 and have a blue value or 25-75 and have a red value of 1-50 or 75-255. In this case, all values are inclusive.

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

Ranges

A range specification is a dimension name, followed by an optional negation character ('!'), and a starting and ending value separated by a colon, surrounded by parentheses or square brackets. Either the starting or ending values can be omitted. Parentheses indicate an open endpoint that doesn't include the adjacent value. Square brackets indicate a closed endpoint that includes the adjacent value.

Example 1:

```
Z[10:]
```

Selects all points with a Z value greater than or equal to 10.

Example 2:

```
Classification[2:2]
```

Selects all points with a classification of 2.

Example 3:

```
Red!(20:40]
```

Selects all points with red values less than or equal to 20 and those with values greater than 40

Example 4:

```
Blue[:255)
```

Selects all points with a blue value less than 255.

Example 5:

```
Intensity! [25:25]
```

Selects all points with an intensity not equal to 25.

filters.tail

The **Tail Filter** returns a specified number of points from the end of the **PointView**.

Note: If the requested number of points exceeds the size of the point cloud, all points are passed with a warning.

Default Embedded Stage

This stage is enabled by default

Example

Sort and extract the 100 lowest intensity points.

```
[  
  {  
    "type": "filters.sort",  
    "dimension": "Intensity",  
    "order": "DESC"  
  },  
  {  
    "type": "filters.tail",  
    "count": 100  
  }  
]
```

See also:

[filters.head](#) (page 244) is the dual to [filters.tail](#) (page 253).

Options

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

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.head (page 244) Return N points from beginning of the point cloud.

filters.locate (page 245) Return a single point with min/max value in the named dimension.

filters.mongo (page 246) Cull points using MongoDB-style expression syntax.

filters.range (page 250) Pass only points given a dimension/range.

filters.tail (page 253) Return N points from end of the point cloud.

7.5.5 New

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

Spatial

filters.chipper

The **Chipper Filter** takes a single large point cloud and converts it into a set of smaller clouds, or chips. The chips are all spatially contiguous and non-overlapping, so the result is a an irregular tiling of the input data.

Note: Each chip will have approximately, but not exactly, the *capacity* (page 256) point count specified.

See also:

The *PDAL split command* (page 37) utilizes the *filters.chipper* (page 254) to split data by capacity.

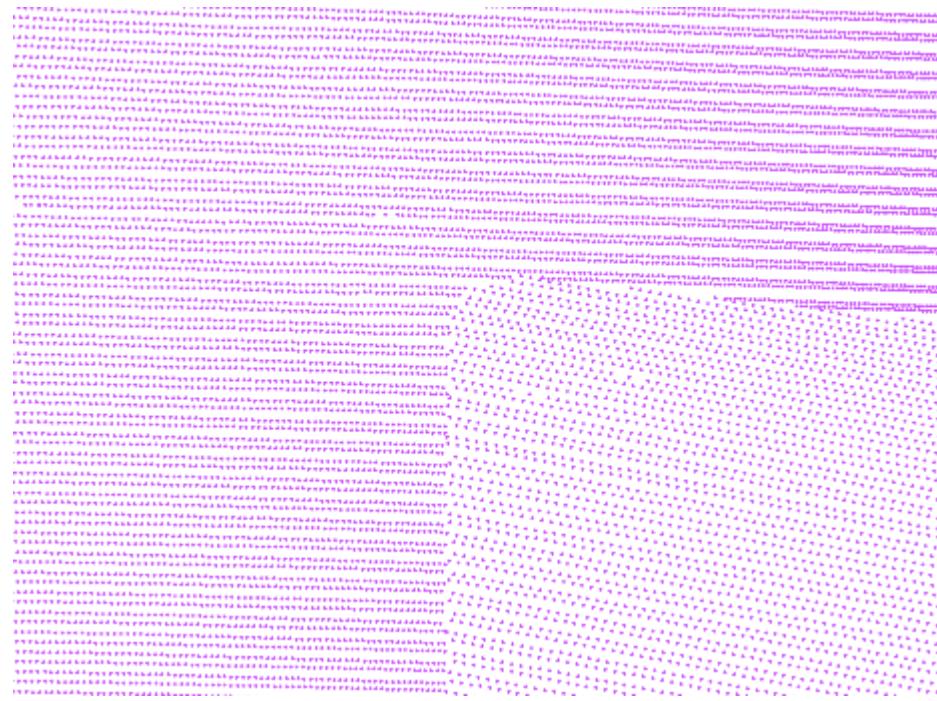


Fig. 6: Before chipping, the points are all in one collection.

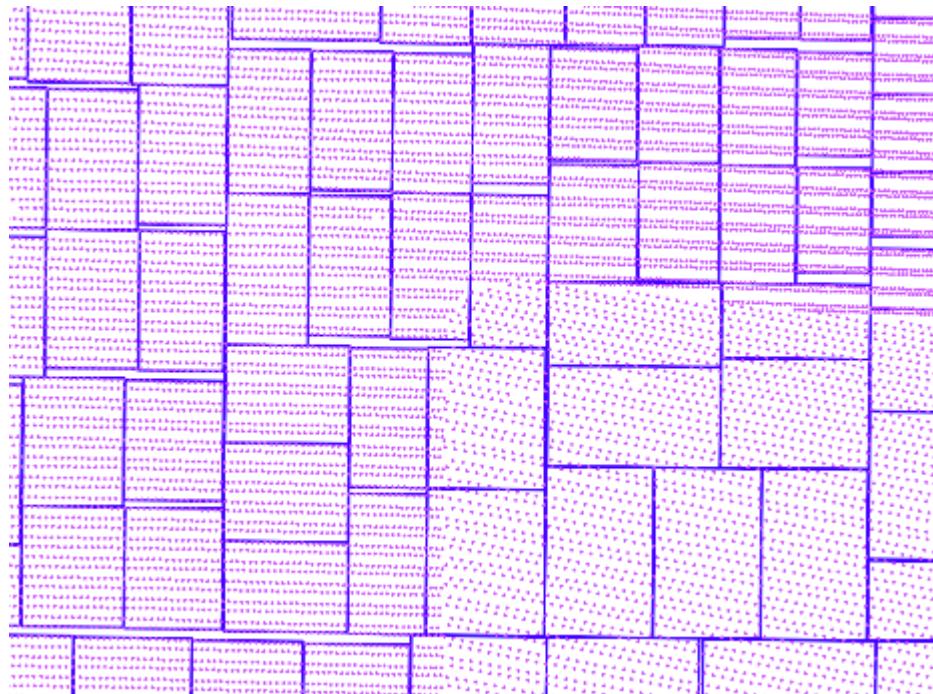


Fig. 7: After chipping, the points are tiled into smaller contiguous chips.

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'"  
    }  
]
```

Options

capacity How many points to fit into each chip. The number of points in each chip will not exceed this value, and will sometimes be less than it. [Default: 5000]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.divider

The **Divider Filter** breaks a point view into a set of smaller point views based on simple criteria. The number of subsets can be specified explicitly, or one can specify a maximum point count for each subset. Additionally, points can be placed into each subset sequentially (as they appear in the input) or in round-robin fashion.

Normally points are divided into subsets to facilitate output by writers that support creating multiple output files with a template (LAS and BPF are notable examples).

Default Embedded Stage

This stage is enabled by default

Example

This pipeline will create 10 output files from the input file readers.las.

```
[  
    "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]

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

Warning: You must specify exactly one of either `count` (page 257) or `capacity` (page 257).

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 259) and `origin_y` (page 259) 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]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.chipper (page 254) Organize points into spatially contiguous, squarish, and non-overlapping chips.

filters.divider (page 257) Divide points into approximately equal sized groups based on a simple scheme.

filters.splitter (page 258) Split data based on a X/Y box length.

Dimension

filters.groupby

The **Groupby Filter** takes a single **PointView** as its input and creates a **PointView** for each category in the named *dimension* (page 260) 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.

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.returns

The **Returns Filter** takes a single PointView as its input and creates a PointView for each of the user-specified *groups* (page 261) defined below.

“first” is defined as those points whose `ReturnNumber` is 1 when the `NumberOfReturns` is greater than 1.

“intermediate” is defined as those points whose `ReturnNumber` is greater than 1 and less than `NumberOfReturns` when `NumberOfReturns` is greater than 2.

“last” is defined as those points whose `ReturnNumber` is equal to `NumberOfReturns` when `NumberOfReturns` is greater than 1.

“only” is defined as those points whose `NumberOfReturns` is 1.

Default Embedded Stage

This stage is enabled by default

Example

This example creates two separate output files for the “last” and “only” returns.

```
[  
    "input.las",  
    {  
        "type": "filters_returns",  
        "groups": "last,only"  
    },  
    "output_#.las"  
]
```

Options

groups Comma-separated list of return number groupings. Valid options are “first”, “last”, “intermediate” or “only”. [Default: “last”]

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘where’ option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.separatescanline

The **Separate scan line Filter** takes a single **PointView** as its input and creates a **PointView** for each scan line as its output. **PointView** must contain the **EdgeOfFlightLine** dimension.

Default Embedded Stage

This stage is enabled by default

Example

The following pipeline will create a set of text files, where each file contains only 10 scan lines.

```
[  
    "input.text",  
    {  
        "type": "filters.separatescanline",  
        "groupby": 10  
    },  
    "output_#.text"  
]
```

Options

groupby The number of lines to be grouped by. [Default : 1]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.groupby (page 259) Split data categorically by dimension.

filters.returns (page 260) Split data by return order (e.g., ‘first’, ‘last’, ‘intermediate’, ‘only’).

filters.separatescanline (page 261) Split data based on scan lines.

7.5.6 Join

Multiple point clouds can be joined to form a single point cloud. These filters will invalidate an existing KD-tree.

filters.merge

The **Merge Filter** combines input from multiple sources into a single output. In most cases, this happens automatically on output and use of the merge filter is unnecessary. However, there may be special cases where merging points prior to a particular filter or writer is necessary or desirable.

The merge filter will log a warning if its input point sets are based on different spatial references. No checks are made to ensure that points from various sources being merged have similar dimensions or are generally compatible.

Default Embedded Stage

This stage is enabled by default

Example 1

This pipeline will create an output file “output.las” that concatenates the points from “file1”, “file2” and “file3”. Note that the explicit use of the merge filter is unnecessary in this case (removing the merge filter will yield the same result).

```
[  
    "file1",  
    "file2",  
    "file3",  
    {  
        "type": "filters.merge"  
    },  
    "output.las"  
]
```

Example 2

Here are a pair of unlikely pipelines that show one way in which a merge filter might be used. The first pipeline simply reads the input files “utm1.las”, “utm2.las” and “utm3.las”. Since the points from each input set are carried separately through the pipeline, three files are created as output, “out1.las”, “out2.las” and “out3.las”. “out1.las” contains the points in “utm1.las”. “out2.las” contains the points in “utm2.las” and “out3.las” contains the points in “utm3.las”.

```
[  
    "utm1.las",
```

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```
"utm2.las",
"utm3.las",
"out#.las"
]
```

Here is the same pipeline with a merge filter added. The merge filter will combine the points in its input: “utm1.las” and “utm2.las”. Then the result of the merge filter is passed to the writer along with “utm3.las”. This results in two output files: “out1.las” contains the points from “utm1.las” and “utm2.las”, while “out2.las” contains the points from “utm3.las”.

```
[
  "utm1.las",
  "utm2.las",
  {
    "type" : "filters.merge"
  },
  "utm3.las",
  "out#.las"
]
```

Options

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.merge (page 263) Merge data from two different readers into a single stream.

7.5.7 Metadata

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

Note: *filters.cpd* (page 215) and *filters.icp* (page 217) 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.

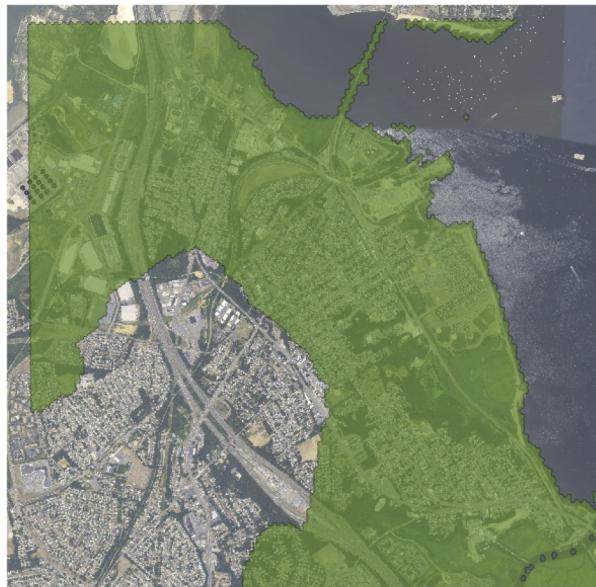


Fig. 8: Hexbin output shows boundary of actual points in point buffer, not just rectangular extents.

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

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",  
  {
```

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(continued from previous page)

```
        "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,
          "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  
    },  
    "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 268) is not explicitly set. [Default: 5000]

threshold Number of points that have to fall within a hexagon boundary before it is considered “in” the data set. [Default: 15]

precision Minimum number of significant digits to use in writing out the well-known text of the boundary polygon. [Default: 8]

preserve_topology Use GEOS SimplifyPreserveTopology instead of Simplify for polygon simplification with *smooth* option. [Default: true]

smooth Use GEOS simplify operations to smooth boundary to a tolerance [Default: true]

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

[filters.info](#)

The **Info filter** provides simple information on a point set as metadata. It is usually invoked by the info command, rather than by user code. The data provided includes bounds, a count of points, dimension names, spatial reference, and points meeting a query criteria.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

```
[  
    "input.las",  
    {  
        "type": "filters.info",  
        "point": "1-5"  
    }  
]
```

Options

point A comma-separated list of single point IDs or ranges of points. For example “2-6, 10, 25” selects eight points from the input set. The first point has an ID of 0. The *point* (page 269) option can’t be used with the *query* (page 269) 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 269) option can’t be used with the *point* (page 269) option. [Default: no points are selected.]

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.stats

The **Stats Filter** calculates the minimum, maximum and average (mean) values of dimensions. On request it will also provide an enumeration of values of a dimension and skewness and kurtosis.

The output of the stats filter is metadata that can be stored by writers or used through the PDAL API. Output from the stats filter can also be quickly obtained in JSON format by using the command “pdal info –stats”.

Note: The filter can compute both sample and population statistics. For kurtosis, the filter can also compute standard and excess kurtosis. However, only a single value is reported for each

statistic type in metadata, and that is the sample statistic, rather than the population statistic. For kurtosis the sample excess kurtosis is reported. This seems to match the behavior of many other software packages.

Example

```
[  
    "input.las",  
    {  
        "type": "filters.stats",  
        "dimensions": "X,Y,Z,Classification",  
        "enumerate": "Classification"  
    },  
    {  
        "type": "writers.las",  
        "filename": "output.las"  
    }  
]
```

Options

dimensions A comma-separated list of dimensions whose statistics should be processed. If not provided, statistics for all dimensions are calculated.

enumerate A comma-separated list of dimensions whose values should be enumerated. Note that this list does not add to the list of dimensions that may be provided in the *dimensions* (page 270) option.

count Identical to the *enumerate* (page 270) option, but provides a count of the number of points in each enumerated category.

global A comma-separated list of dimensions for which global statistics (median, mad, mode) should be calculated.

advanced Calculate advanced statistics (skewness, kurtosis). [Default: false]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view

is returned and it has the same point count as it did when the filter was run. [Default: auto]

filters.hexbin (page 265) Tessellate XY domain and determine point density and/or point boundary.

filters.info (page 268) Generate metadata about the point set, including a point count and spatial reference information.

filters.stats (page 269) Compute statistics about each dimension (mean, min, max, etc.).

7.5.8 Mesh

Meshes can be computed from point clouds. These filters will invalidate an existing KD-tree.

filters.delaunay

The **Delaunay Filter** creates a triangulated mesh fulfilling the Delaunay condition from a collection of points.

The filter 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) (<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
```

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```
    }  
]
```

Options

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.greedyprojection

The **Greedy Projection Filter** creates a mesh (triangulation) in an attempt to reconstruct the surface of an area from a collection of points.

`GreedyProjectionTriangulation` is an implementation of a greedy triangulation algorithm for 3D points based on local 2D projections. It assumes locally smooth surfaces and relatively smooth transitions between areas with different point densities. The algorithm itself is identical to that used in the [PCL](http://www.pointclouds.org/documentation/tutorials/greedy_projection.php) (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  
  },
```

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

Options

multiplier Nearest neighbor distance multiplier. [Required]

radius Search radius for neighbors. [Required]

num_neighbors Number of nearest neighbors to consider. [Required]

min_angle Minimum angle for created triangles. [Default: 10 degrees]

max_angle Maximum angle for created triangles. [Default: 120 degrees]

eps_angle Maximum normal difference angle for triangulation consideration. [Default: 45 degrees]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If **true**, the skipped points are added to the first point view returned by the skipped filter. If **false**, skipped points are placed in their own point view. If **auto**, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: **auto**]

filters.poisson

The **Poisson Filter** passes data Mischa Kazhdan's poisson surface reconstruction algorithm. [Kazhdan2006] It creates a watertight surface from the original point set by creating an entirely new point set representing the imputed isosurface. The algorithm requires normal vectors to each point in order to run. If the x, y and z normal dimensions are present in the input point set, they will be used by the algorithm. If they don't exist, the poisson filter will invoke the PDAL normal filter to create them before running.

The poisson algorithm will usually create a larger output point set than the input point set. Because the algorithm constructs new points, data associated with the original points set will be lost, as the algorithm has limited ability to impute associated data. However, if color

dimensions (red, green and blue) are present in the input, colors will be reconstructed in the output point set.

This 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]

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]



Fig. 9: Point cloud (800,000 points)



Fig. 10: Reconstruction (1.8 million vertices, 3.7 million faces)

[`filters.delaunay`](#) (page 271) Create mesh using Delaunay triangulation.

[`filters.greedyprojection`](#) (page 272) Create mesh using the Greedy Projection Triangulation approach.

[`filters.poisson`](#) (page 273) Create mesh using the Poisson surface reconstruction algorithm [Kazhdan2006].

7.5.9 Languages

PDAL has three filters than can be used to pass point clouds to other languages. These filters will invalidate an existing KD-tree.

filters.matlab

The **Matlab Filter** allows Matlab (<https://www.mathworks.com/products/matlab.html>) software to be embedded in a [*Pipeline*](#) (page 47) that interacts with a struct array of the data and allows you to modify those points. Additionally, some global [*Metadata*](#) (page 469) 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 47) exited.

See also:

[`writers.matlab`](#) (page 130) can be used to write .mat files.

Note: [`filters.matlab`](#) (page 277) 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"
```

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```
},
{
  "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)

(<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) (<https://www.mathworks.com/products/matlab.html>) code to execute, when the script option is not being used.

add_dimension The name of a dimension to add to the pipeline that does not already exist.

struct Array structure name to read [Default: “PDAL”]

where An expression that limits points passed to a filter. Points that don’t pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.python

The **Python Filter** allows [Python](http://python.org/) (<http://python.org/>) software to be embedded in a *Pipeline* (page 47) that allows modification of PDAL points through a [NumPy](http://www.numpy.org/) (<http://www.numpy.org/>) array. Additionally, some global [Metadata](#) (page 469) is also available that Python functions can interact with.

The function must have two [NumPy](http://www.numpy.org/) (<http://www.numpy.org/>) arrays as arguments, `ins` and `outs`. The `ins` array represents the points before the `filters.python` filter and the `outs`

array represents the points after filtering.

Warning: Make sure NumPy (<http://www.numpy.org/>) is installed in your Python (<http://python.org/>) environment.

```
$ python3 -c "import numpy; print(numpy.__version__)"
1.18.1
```

Warning: Each array contains all the *Dimensions* (page 289) 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 47) exited.
- 2) If you want write a dimension that might not be available, you can specify it with the *add_dimension* (page 284) option:

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

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

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

You can also specify the *type* (page 295) of the dimension using an `=`.

```
"add_dimension": "NewDimensionOne:uint8"
```

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']
```

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```

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 250) 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 278) is the tool you can use for prototyping point stream processing operations.

See also:

If you want to read a *Pipeline* (page 47) 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"
    }
]
```

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```
    }  
]
```

Module Globals

Three global variables are added to the Python module as it is run to allow you to get *Dimensions* (page 289), *Metadata* (page 469), and coordinate system information. Additionally, the `metadata` object can be set by the function to modify metadata for the in-scope *filters.python* (page 278) `pdal::Stage` (page 559).

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

Setting stage metadata

Note: The name of the output metadata variable has changed from `metadata` to `out_metadata`.

Stage metadata can be created by using the `out_metadata` dictionary **global** variable. The `name` key must be set. The type of the `value` can usually be inferred, but can be set to one of `integer`, `nonNegativeInteger`, `double`, `bounds`, `boolean`, `spatialreference`, `uuid` or `string`.

Children may be set using the `children` key whose value is a list of dictionaries.

```
def myfunc(ins,outs):  
    global out_metadata  
    out_metadata = {'name': 'root', 'value': 'a string', 'type': 'string',  
    ↵ 'description': 'a description', 'children': [{name: 'somekey',  
    ↵ value: 52, type: 'integer', description: 'a filter description',  
    ↵ children: []}, {'name': 'readers.faux', 'value': 'another string',  
    ↵ type: 'string', description: 'a reader description', 'children':  
    ↵ []}]}  
    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 35) with substitutions.

If we needed to be able to provide the Z scaling factor of [Example Pipeline](#) (page 281) 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",  
        "script": "arguments.py",  
        "pdalargs": "{\"factor\":0.3048, \"an_argument\":42, \"another\":  
        ↪\"a string\"}"  
    },  
    "output.las"  
]
```

With that option set, you can now fetch the [pdalargs](#) (page 284) 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.

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a ‘*where*’ option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

filters.julia

The **Julia Filter** allows [Julia](https://julialang.org/) (<https://julialang.org/>) software to be embedded in a *Pipeline* (page 47) that allows modification of PDAL points through a [TypedTables](https://github.com/JuliaData/TypedTables.jl) (<https://github.com/JuliaData/TypedTables.jl>) datatype.

The supplied julia function must take a [TypedTables](https://github.com/JuliaData/TypedTables.jl) (<https://github.com/JuliaData/TypedTables.jl>) FlexTable as an argument and return the same object (with modifications).

Warning: The returned Table contains all the [Dimensions](#) (page 289) of the incoming `in` Table

Dynamic Plugin

This stage requires a dynamic plugin to operate

```

module MyModule
  using TypedTables

  function multiply_z(ins)
    for n in 1:length(ins)
      ins[n] = merge(ins[n], (; :Z => row.Z * 10.0))
    end
    return ins
  end
end

```

If you want write a dimension that might not be available, you can
 ↵specify
 it with the `add_dimension_` option:

```

:::

  "add_dimension": "NewDimensionOne"

```

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

```

:::

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

```

You can also specify the `:ref:`type <types>`` of the dimension **using** an
 ↵` `` = `` .
 :::

```

  "add_dimension": "NewDimensionOne:uint8"

```

Filter Example

```

[
  "file-input.las",
  {
    "type": "filters.smrf"
  },
  {

```

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```
"type": "filters.julia",
"script": "filter_z.jl",
"function": "filter_z",
"module": "MyModule"
},
{
  "type": "writers.las",
  "filename": "file-filtered.las"
}
]
```

The JSON pipeline file referenced the external `filter_z.jl` Julia (<https://julialang.org/>) script, which removes points with the Z coordinate by less than 420.

```
module MyModule
  using TypedTables

  function filter_z(ins)
    return filter(p -> p.Z > 420, ins)
  end
end
```

Modification Example

```
[
  "file-input.las",
  {
    "type": "filters.smrf"
  },
  {
    "type": "filters.julia",
    "script": "multiply_z.jl",
    "function": "multiply_z",
    "module": "MyModule"
  },
  {
    "type": "writers.las",
    "filename": "file-modified.las"
  }
]
```

The JSON pipeline file referenced the external `multiply_z.jl` Julia (<https://julialang.org/>) script,

which scales the Z coordinate by a factor of 10.

```
module MyModule
    using TypedTables

    function multiply_z(ins)
        for n in 1:length(ins)
            ins[n] = merge(ins[n], (; :Z => row.Z * 10.0))
        end
        return ins
    end
end
```

Options

script When reading a function from a separate [Julia](https://julialang.org/) (<https://julialang.org/>) file, the file name to read from.

source The literal [Julia](https://julialang.org/) (<https://julialang.org/>) code to execute, when the script option is not being used.

module The Julia module that is holding the function to run. [Required]

function The function to call. [Required]

add_dimension A dimension name or an array of dimension names to add to the pipeline that do not already exist.

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

[*filters.matlab* \(page 277\)](#) Embed MATLAB software in a pipeline.

[*filters.python* \(page 278\)](#) Embed Python software in a pipeline.

[*filters.julia* \(page 284\)](#) Embed Julia software in a pipeline.

7.5.10 Other

`filters.streamcallback`

The **Stream Callback Filter** provides a simple hook for a user-specified action to occur for each point. The stream callback filter is for use by C++ programmers extending PDAL functionality and isn't useful to end users.

Default Embedded Stage

This stage is enabled by default

Streamable Stage

This stage supports streaming operations

Options

where An expression that limits points passed to a filter. Points that don't pass the expression skip the stage but are available to subsequent stages in a pipeline. [Default: no filtering]

where_merge A strategy for merging points skipped by a '*where*' option when running in standard mode. If `true`, the skipped points are added to the first point view returned by the skipped filter. If `false`, skipped points are placed in their own point view. If `auto`, skipped points are merged into the returned point view provided that only one point view is returned and it has the same point count as it did when the filter was run. [Default: `auto`]

`filters.streamcallback` (page 288) Provide a hook for a simple point-by-point callback.

CHAPTER
EIGHT

DIMENSIONS

8.1 Dimensions

All point data in PDAL is stored as a set of dimensions. Dimensions have a name and a data type. The data type is determined at runtime, but a default data type for each dimension is listed below, along with the name of the dimension and its description.

The following table provides a list of known dimension names you can use in *Filters* (page 150), *Writers* (page 115), and *Readers* (page 57).

Note: Types are default types. Stage developers should set the dimension type explicitly if the default dimension isn't suitable.

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
Anisotropy	double	Anisotropy of a point; larger values indicate strong variance in multiple dimensions.
Azimuth	double	Scanner azimuth
Back-groundRadiation	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.
ClusterID	int64_t	ID assigned to a point by a point-clustering algorithm.

continues on next page

Table 1 – continued from previous page

Name	Type	Description
Coplanar	uint8	Indicator of whether or not a point is part of a coplanar neighborhood.
Curvature	double	Curvature of surface at this point
DemantkeVerticality	double	Verticality of a point; larger values indicate vertical structure (Demantke's variation).
Density	double	Estimate of point density
Deviation	float	Difference between the shape of the reference pulse and the return pulse. A larger value for deviation indicates larger distortion.
EchoRange	double	Echo Range
EdgeOfFlight-Line	uint8	Indicates the end of scanline before a direction change with a value of 1 - 0 otherwise
Eigenentropy	double	Eigenentropy of a point; small values indicate more ordered regions, while large values indicate disorder.
Eigenvalue0	double	Smallest eigenvalue obtained form covariance of XYZ coordinates in k-neighborhood.
Eigenvalue1	double	Middle eigenvalue obtained form covariance of XYZ coordinates in k-neighborhood.
Eigenvalue2	double	Largest eigenvalue obtained form covariance of XYZ coordinates in k-neighborhood.
Eigenvalue-Sum	double	Sum of computed eigenvalues.
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
HeightAbove-Ground	double	Height Above Ground
Infrared	uint16	Infrared
Intensity	uint16	Representation of the pulse return magnitude
InternalTime	double	Scanner's internal time when the point was acquired, in seconds

continues on next page

Table 1 – continued from previous page

Name	Type	Description
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
Linearity	double	Linearity of a point; larger values indicate more linear regions.
LocalOutlierFactor	double	Outlier factor based on the LocalReachabilityDistance of a point's nearest neighbors.
LocalReachabilityDistance	double	Reachability metric based on the NNDistance of a point's nearest neighbors.
LongitudeCentroid	double	Longitude Centroid
LongitudeHigh	double	Longitude High
LongitudeLow	double	Longitude Low
LvisLfid	uint64	LVIS_LFID
Mark	uint8	Mark
Miniball	double	Metric capturing distance from a point to the center of the smallest enclosing ball encapsulating k-nearest neighbors, scaled by radius of the ball.
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	uint8	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
Omnivariance	double	Omnivariance of a point; cube root of the product of all eigenvalues.

continues on next page

Table 1 – continued from previous page

Name	Type	Description
OptimalKNN	uint64	Optimal number of k nearest neighbors, such that eigenentropy is minimized.
OptimalRadius	double	Radius corresponding to optimal k nearest neighbors, such that eigenentropy is minimized.
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
Planarity	double	Planarity of a point; larger values indicate more planar regions.
PlaneFit	double	Metric capturing current point's point to plane distance compared to those in the same k-neighborhood used to estimate the plane.
PointId	uint32	An explicit representation of point ordering within a file, which allows this usually-implicit information to be preserved when reordering 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)
RadialDensity	double	Estimate of radial point density
Rank	uint8	Estimated rank of neighborhood of points.
Reciprocity	double	Metric capturing percentage of k-nearest neighbors that also contain the current point in their k-neighborhood.
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.
Reflected-Pulse	int32	Relative reflected pulse signal strength
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

continues on next page

Table 1 – continued from previous page

Name	Type	Description
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
Scattering	double	Scattering of a point; larger values indicate complex (scattered) 3D regions.
ShotNumber	uint64	Shot Number
StartPulse	int32	Relative pulse signal strength
SurfaceVariation	double	Surface variation of a point; larger values indicate higher surface variation.
TextureU	double	U component of a texture location at this point
TextureV	double	V component of a texture location at this point
TextureW	double	W component of a texture location at this point
UserData	uint8	Unspecified user data
Verticality	double	Verticality of a point; larger values indicate vertical structure.
W	double	W coordinate
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

continues on next page

Table 1 – continued from previous page

Name	Type	Description
YBodyAn-gRate	double	Y Body Angle Rate
YVelocity	double	Y Velocity
Z	double	Z coordinate
ZBodyAccel	double	Z Body Acceleration
ZBodyAn-gRate	double	Z Body Angle Rate
ZVelocity	double	Z Velocity

CHAPTER
NINE

TYPES

9.1 Types

PDAL supports the standard integral and floating point types for [dimensions](#) (page 289). This table lists the types and associated strings that can be used to describe the types in options.

Type	Size in Bits	Text Representations
Signed Integer	8	<code>int8, int8_t, char</code>
Signed Integer	16	<code>int16, int16_t, short</code>
Signed Integer	32	<code>int32, int32_t, int</code>
Signed Integer	64	<code>int64, int64_t, long</code>
Unsigned Integer	8	<code>uint8, uint8_t, uchar</code>
Unsigned Integer	16	<code>uint16, uint16_t, ushort</code>
Unsigned Integer	32	<code>uint32, uint32_t, uint</code>
Unsigned Integer	64	<code>uint64, uint64_t, ulong</code>
Floating Point	32	<code>float, float32</code>
Floating Point	64	<code>double, float64</code>

**CHAPTER
TEN**

PYTHON

10.1 Python

PDAL provides Python support in two significant ways. First it [embeds](https://docs.python.org/3/extending/embedding.html) Python to allow you to write Python programs that interact with data using [*filters.python*](#) (page 278) filter. Second, it [extends](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.

10.1.1 Versions

PDAL supports both Python 3.5+. [*Continuous Integration*](#) (page 522) tests Python Linux, OSX, and Windows.

10.1.2 Embed

PDAL allows users to embed Python functions inline with other [*Pipeline*](#) (page 47) 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.

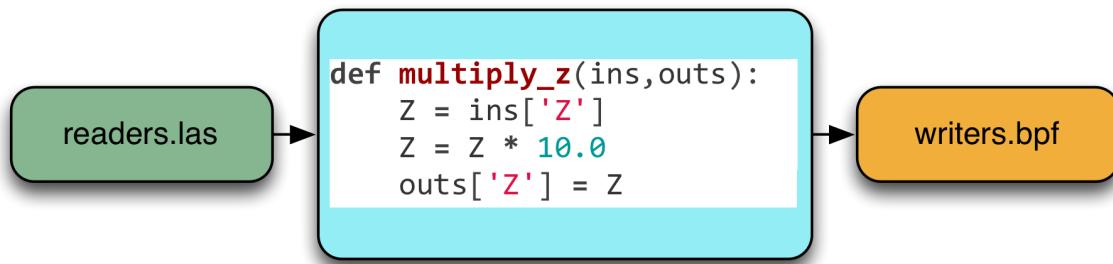


Fig. 1: Embedding a Python function to take Z values read from a *readers.las* (page 73) and then output them to a *writers.bpf* (page 115).

10.1.3 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 47) 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 47) 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)
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.

Note: Previous to PDAL 2.1, Python support was spread across the embedded stages (*readers.numpy* (page 83) and *filters.python* (page 278)) which were installed by PDAL itself and the PDAL extension that was installed from PyPI. As of PDAL 2.1 and PDAL/python 2.3, both the embedded stages and the extension are installed from PyPI.

Installation Using pip

As administrator, you can install PDAL using pip:

```
pip install PDAL
```

Note: To install pip please read [here](https://pip.pypa.io/en/stable/installing/) (<https://pip.pypa.io/en/stable/installing/>)

Installation from Source

PDAL Python support is hosted in a separate repository than PDAL itself at [GitHub](https://github.com/PDAL/python) (<https://github.com/PDAL/python>). If you have a working PDAL installation and a working Python installation, you can install the extension using the following procedure on Unix. The procedure on Windows is similar

```
$ git clone https://github.com/PDAL/python pdalextension  
$ cd pdalextension  
$ pip install .
```

Install using Conda

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

JAVA

11.1 Java

PDAL provides [Java bindings to use PDAL on JVM](https://github.com/PDAL/java) (<https://github.com/PDAL/java>). It is released independently from PDAL itself as of PDAL 1.7. Native binaries are prebuilt for Linux and MacOS and delivered in a jar, so there is no need in building PDAL with a special flag or building JNI binaries manually.

The project consists of the following modules:

- `pdal-native` - with packed OS specific libraries to link PDAL to JNI proxy classes. Dependency contains bindings for `x86_64-darwin` and `x86_64-linux`, other versions are not supported yet.
- `pdal` - with the core bindings functionality.
- `pdal-scala` - a Scala API package that simplifies PDAL Pipeline construction.

11.1.1 Versions

PDAL JNI major version usually follows PDAL versioning i.e. `pdal-java 1.8.x` was built and tested against PDAL `1.8.x` and `pdal-java 2.1.x` against PDAL `2.x.x`.

11.1.2 Using PDAL Java bindings

PDAL provides [JNI bindings](https://docs.oracle.com/javase/8/docs/technotes/guides/jni/index.html)

(<https://docs.oracle.com/javase/8/docs/technotes/guides/jni/index.html>) that gives users access to executing [`pipeline`](#) (page 47) instantiations and capturing the results in Java interfaces. This mode of operation is useful if you are looking to have PDAL simply act as your data format and processing handler.

Users are expected to construct their own PDAL [`pipeline`](#) (page 47), execute it, and retrieve points into Java memory:

```

import io.pdal._

val json =
"""
| {
|   "pipeline": [
|     {
|       "filename": "1.2-with-color.las",
|       "spatialreference": "EPSG:2993"
|     },
|     {
|       "type": "filters.reprojection",
|       "out_srs": "EPSG:3857"
|     },
|     {
|       "type": "filters.delaunay"
|     }
|   ]
| }
""".stripMargin

val pipeline = Pipeline(json)
pipeline.validate() // check if our JSON and options were good
pipeline.setLogLevel(8) // make it really noisy
pipeline.execute() // execute the pipeline
val metadata: String      = pipeline.getMetadata() // retrieve metadata
val pvs: PointViewIterator = pipeline.getPointViews() // iterator over
                           // PointViews
val pv: PointView         = pvs.next() // let's take the first PointView

// load all points into JVM memory
// PointCloud provides operations on PDAL points that
// are loaded in this case into JVM memory as a single Array[Byte]
val pointCloud: PointCloud = pv.getPointCloud()
val x: Double = pointCloud.getDouble(0, DimType.X) // get a point with
                           // PointId = 0 and only a single dimensions

// in some cases it is not necessary to load everything into JVM memory
// so it is possible to get only required points directly from the
// PointView
val y: Double = pv.getDouble(0, DimType.Y)

// it is also possible to get access to the triangular mesh generated
// via PDAL

```

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```

val mesh: TriangularMesh      = pv.getTriangularMesh()
// the output is an Array of Triangles
// Each Triangle contains PointIds from the PDAL point table
val triangles: Array[Triangle] = mesh.asList

pv.close()
pipeline.close()

```

11.1.3 Using PDAL Scala

PDAL Scala project introduces a DSL to simplify PDAL Pipeline construction (this is the same pipeline from the section above):

```

import io.pdal._
import io.pdal.pipeline._

val expression =
  ReadLas("1.2-with-color.las", spatialreference = Some("EPSG:2993")) ~
  FilterReprojection("EPSG:3857") ~
  FilterDelaunay()

val pipeline = expression.toPipeline
pipeline.validate() // check if our JSON and options were good
pipeline.setLogLevel(8) // make it really noisy
pipeline.execute() // execute the pipeline
val metadata: String      = pipeline.getMetadata() // retrieve metadata
val pvs: PointViewIterator = pipeline.getPointViews() // iterator over
→PointViews
val pv: PointView        = pvs.next() // let's take the first PointView

// load all points into JVM memory
// PointCloud provides operations on PDAL points that
// are loaded in this case into JVM memory as a single Array[Byte]
val pointCloud: PointCloud = pv.getPointCloud()
val x: Double = pointCloud.getDouble(0, DimType.X) // get a point with
→PointId = 0 and only a single dimensions

// in some cases it is not necessary to load everything into JVM memory
// so it is possible to get only required points directly from the
→PointView
val y: Double = pv.getDouble(0, DimType.Y)

```

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```
// it is also possible to get access to the triangular mesh generated  
// via PDAL
val mesh: TriangularMesh      = pv.getTriangularMesh()
// the output is an Array of Triangles
// Each Triangle contains PointIds from the PDAL point table
val triangles: Array[Triangle] = mesh.asArray

pv.close()
pipeline.close()
```

It covers PDAL 2.0.x, but to use any custom DSL that is not covered by the current Scala API you can use RawExpr type to build a Pipeline Expression:

```
import io.pdal._
import io.pdal.pipeline._
import io.circe.syntax._

val pipelineWithRawExpr =
  ReadLas("1.2-with-color.las") ~
  RawExpr(Map("type" -> "filters.crop").asJson) ~
  WriteLas("1.2-with-color-out.las")
```

Installation

PDAL Java artifacts are cross published for Scala 2.13, 2.12 and 2.11. However, if it is not required, a separate artifact that has no Scala specific artifact postfix is published as well.

```
// pdal is published to maven central, but you can use following repos
// in addition
resolvers ++= Seq(
  Resolver.sonatypeRepo("releases"),
  Resolver.sonatypeRepo("snapshots") // for snapshots
)

libraryDependencies ++= Seq(
  "io.pdal" %% "pdal" % "x.x.x",           // core library
  "io.pdal" % "pdal-native" % "x.x.x", // jni binaries
  "io.pdal" %% "pdal-scala" % "x.x.x"   // if scala core library (if
// required)
)
```

The latest version is: [maven central 2.2.0](https://search.maven.org/search?q=g:io.pdal) (<https://search.maven.org/search?q=g:io.pdal>)

There is also an [example SBT PDAL Demo project](#) (<https://github.com/PDAL/java/tree/master/examples/pdal-jni>) in the bindings repository, that can be used for a quick start.

Compilation

Development purposes (including binaries) compilation:

1. Install PDAL (using brew / package managers (unix) / build from sources / etc)
2. Build native libs `./sbt native/nativeCompile` (optionally, binaries would be built during tests run)
3. Run `./sbt core/test` to run PDAL tests

Only Java development purposes compilation:

1. Provide `$LD_LIBRARY_PATH` or `$DYLD_LIBRARY_PATH`
2. If you don't want to provide global variable you can pass `-Djava.library.path=<path>` into sbt:
`./sbt -Djava.library.path=<path>`
3. Set `PDAL_DEPEND_ON_NATIVE=false` (to disable native project build)
4. Run `PDAL_DEPEND_ON_NATIVE=false ./sbt`

If you would like to use your own bindings binary, it is necessary to set `java.library.path`:

```
// Mac OS X example with manual JNI installation
// cp -f native/target/resource_managed/main/native/x86_64-darwin/
// libpdaljni.2.1.dylib /usr/local/lib/libpdaljni.2.1.dylib
// place built binary into /usr/local/lib, and pass java.library.path
// to your JVM
javaOptions += "-Djava.library.path=/usr/local/lib"
```

You can use `pdal-native` dep in case you don't have installed JNI bindings and to avoid steps described above. Dependency contains bindings for `x86_64-darwin` and `x86_64-linux`, other versions are not supported yet.

CHAPTER TWELVE

TUTORIALS

12.1 Tutorials

This section provides a collection of tutorials on how to use the PDAL *Applications* (page 25) and *Pipelines* (page 47) to process data.

Note: Users looking for documentation on how to contribute to PDAL should look [here](#) (page 447) and users looking to use the PDAL API in their own applications should look [here](#) (page 523).

12.1.1 Reading with PDAL

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- *Reading with PDAL* (page 307)
 - *A basic inquiry example* (page 308)
 - *A conversion example* (page 309)
 - * *Metadata* (page 309)
 - *A Pipeline Example* (page 310)
 - * *Simple conversion* (page 310)
 - * *Loop a directory and filter it through a pipeline* (page 310)

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)

(<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/) (<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  
    }  
  }  
}
```

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}

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 289) 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) header fields, such as [UUID](#) (http://en.wikipedia.org/wiki/Universally_unique_identifier). You may need to preserve some more information as part of your conversion to make it useful down the road.

Metadata

PDAL carries *metadata* (page 469) for each stage through the PDAL *processing pipeline* (page 47). The metadata can be written in JSON form using the pdal [info](#) (page 31) 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 35) 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 47), for more detailed exposition of the topic.

The *pipeline* (page 35) 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) 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"
```

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```
get-childitem $indir |  
foreach-object {  
    if ($.extension -ne ".las") {  
        continue  
    }  
    $outname = $outdir + "\\" + $.name  
    pdal pipeline -i \path\to\proj.json $_.fullname $outname  
}
```

12.1.2 Reading data from EPT

Introduction

This tutorial describes how to use [Conda](https://conda.io) (<https://conda.io>), [Entwine](https://entwine.io) (<https://entwine.io>), [PDAL](https://pdal.io) (<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.html) (<https://pdal.io/stages/readers.ept.html>) to fetch data, we will filter it for noise using [filters.outlier](https://pdal.io/stages/filters.outlier.html) (<https://pdal.io/stages/filters.outlier.html>), we will classify the data as ground/not-ground using [filters.smrf](https://pdal.io/stages/filters.smrf.html) (<https://pdal.io/stages/filters.smrf.html>), and we will write out a digital terrain model with [writers.gdal](#) (page 121). 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. Ensure 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.

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/ept.json",
      "type": "readers.ept",
      "tag": "readdata"
    },
    {
      "limits": "Classification! [7:7]"
    }
  ]
}
```

(continues on next page)

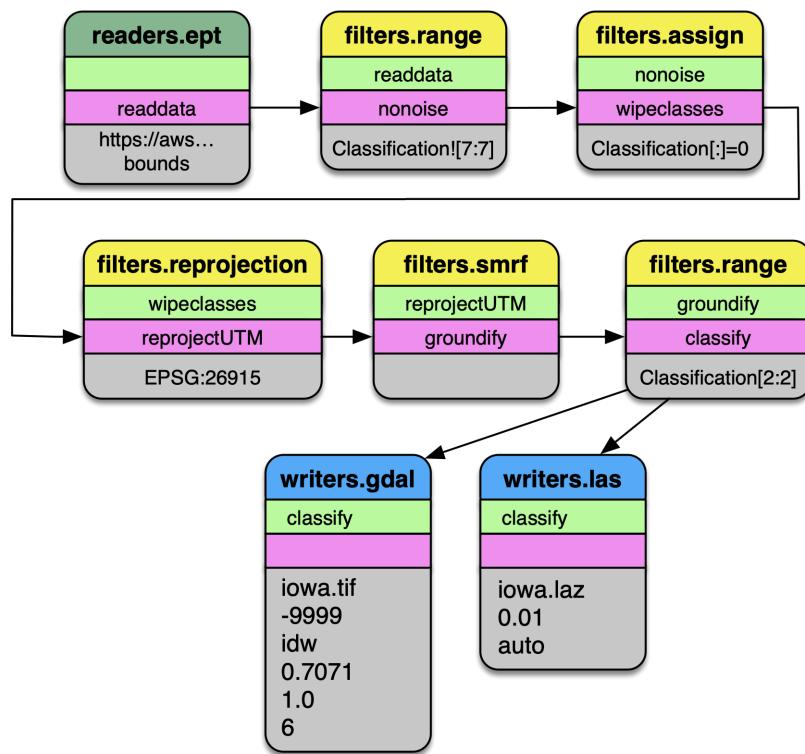


Fig. 1: Pipeline diagram. The data are read from the Entwine Point Tile (<https://entwine.io/entwine-point-tile.html>) resource at <https://usgs.entwine.io> for Iowa using `readers.ept` (page 59) and filtered through a number of steps until processing is complete. The data are then written to an `iowa.laz` and `iowa.tif` file.

(continued from previous page)

```
        "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 59) reads the point cloud data from the EPT resource on AWS. We give it a URL to the root of the resource in the `filename` option, and we also give it a `bounds` object to define the window in which we should select data from.

Note: The full URL to the EPT root file (`ept.json`) must be given to the `filename` parameter for PDAL 2.2+. This was a change in behavior of the `readers.ept` (page 59) driver.

The `bounds` object is in the form `([minx, maxx], [miny, maxy])`.

Warning: If you do not define a `bounds` option, PDAL will try to read the data for the entire state of Iowa, which is about 160 billion points. Maybe you have enough memory for this...

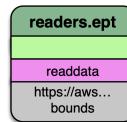


Fig. 2: The EPT reader reads data from an EPT resource with PDAL. Options available in PDAL 1.9+ allow users to select data at or above specified resolutions.

`filters.range`

The data we are selecting may have noise properly classified, and we can use `filters.range` (page 250) to keep all data that does not have a `Classification Dimensions` (page 289) value of 7.

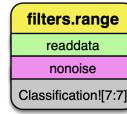


Fig. 3: The `filters.range` (page 250) filter utilizes range selection to allow users to select data for processing or removal. The `filters.mongoexpression` filter can be used for even more complex logic operations.

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 205) takes the expression `Classification[:]=0` and assigns the Classification for each point to 0.

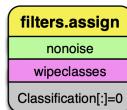


Fig. 4: [*filters.assign*](#) (page 205) can also take in an option to apply assignments based on a conditional. If you want to assign values based on a bounding geometry, use [*filters.overlay*](#) (page 207).

filters.reprojection

The data on the AWS 3DEP Public Dataset are stored in [Web Mercator](#) (https://en.wikipedia.org/wiki/Web_Mercator_projection) coordinate system, which is not suitable for many operations. We need to reproject them into an appropriate UTM coordinate system ([EPSG:26915](#) (<https://epsg.io/32615>)).

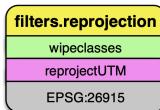


Fig. 5: [*filters.reprojection*](#) (page 222) can also take override the incoming coordinate system using the `a_srs` option.

filters.smrf

The Simple Morphological Filter ([*filters.smrf*](#) (page 155)) classifies points as ground or not-ground.

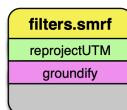


Fig. 6: [*filters.smrf*](#) (page 155) provides a number of tuning options, but the defaults tend to work quite well for mixed urban environments on flat ground (ie, Iowa).

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. 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 121). 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 121) for more options.



Fig. 8: Output a DTM at 1m resolution.

writers.las

We can also write a LAZ file containing the same points that were used to make the elevation model in the section above. See `writers.las` (page 126) for more options.



Fig. 9: Also output the LAZ file as part of our processing pipeline.

Execute the Pipeline

1. Save the PDAL pipeline in *Pipeline* (page 312) to a file called `iowa.json`
2. Invoke the **PDAL pipeline** (<https://pdal.io/pipeline.html>) command

```
pdal pipeline iowa.json
```

Add the `--debug` option if you would like information about how PDAL is fetching and processing the data.

```
pdal pipeline iowa.json --debug
```

3. Save a color scheme to `dem-colors.txt`

```
# 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

12.1.3 LAS Reading and Writing with PDAL

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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 73) and *writers.las* (page 126) 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 126) 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 126) is not used to carry along a version from a previously read file.

Spatial Reference System

LAS 1.0 to 1.3 use [GeoTIFF](#) (<https://trac.osgeo.org/geotiff/>) keys for storing coordinate system information, while LAS 1.4 uses [Well Known Text](#) (https://en.wikipedia.org/wiki/Well-known_text#Coordinate_reference_systems). GeoTIFF is well-supported by most software that read LAS, but it is not possible to express some coordinate system specifics with GeoTIFF. WKT is supports more coordinate systems than GeoTIFF, but vendor-specific and later versions (WKT 2) may not be handled well.

Assignment Example

The PDAL [writers.las](#) (page 126) 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 126) to EPSG:4326.

```
1  [
2    {
```

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```

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 328) 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). In [Well Known Text](#) (https://en.wikipedia.org/wiki/Well-known_text#Coordinate_reference_systems), this coordinate system is described by:

\$ gdalsrsinfo "EPSG:4326+3855"

```

COMP_CS["WGS 84 + EGM2008 geoid height",
  GEOGCS["WGS 84",
    DATUM["WGS_1984",
      SPHEROID["WGS 84",6378137,298.257223563,
        AUTHORITY["EPSG","7030"]],
      AUTHORITY["EPSG","6326"]],
```

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```

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 320), 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) 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) (<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 222).

```
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 222). `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 289) 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 289) stored for each point in a LAS file. All point formats specify the following dimensions as part of a point record:

Table 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>) 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 289) a file must store, but programs are allowed to store extra data beyond that fixed set. This feature of the format was regularized in LAS 1.4 as something called “extra bytes” or “extra dims”, but previous versions can also store these extra per-point attributes.

Extra Dimension Example

LAS 1.4 provides for the storage of dimensions not part of the chosen point format by appending them to each point record. PDAL supports this feature when writing files with the “extra_dims” option. The following example will store all source dimensions in the output file and place a description of the dimensions that aren’t part of the point format in an “extra bytes” VLR:

```
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 126) 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 152) to reassign them. During this scenario, we’d like to keep all of the other LAS header information, such as *Variable Length Records* (page 328), 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) (<http://laszip.org>) is an open source, lossless compression technique for [ASPRS LAS](http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html) (<http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html>) data. It is supported by two different software libraries, and it can be used in both the C/C++ and the JavaScript execution environments. LAZ support is provided by both *readers.las* (page 73) and *writers.las* (page 126). 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 126) `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 126) driver supports an option, `pdal_metadata`, that writes two *PDAL* VLRs to LAS files. The first is the equivalent of [info](#) (page 31)'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 469) 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.

12.1.4 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 auxiliary data sources such as [OGR](#) (<http://www.gdal.org>)-readable [Shapefiles](#) (<https://en.wikipedia.org/wiki/Shapefile>). This tutorial describes how to construct a pipeline that takes in geometries and clips out point cloud data inside geometries with matching attributes.

Contents

- [*Clipping with Geometries*](#) (page 330)
 - [*Introduction*](#) (page 331)
 - [*Example Data*](#) (page 331)
 - [*Stage Operations*](#) (page 331)
 - [*Data Preparation*](#) (page 332)
 - [*Pipeline*](#) (page 333)
 - [*Processing*](#) (page 334)
 - [*Conclusion*](#) (page 335)

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 207) stage, which allows you to assign point values based on polygons read from [OGR](#) (<http://www.gdal.org>). The second is [*filters.range*](#) (page 250), which allows you to keep or reject points from the set that match given criteria.

See also:

[*filters.python*](#) (page 278) allow you to construct sophisticated logic for keeping or rejecting points in a more expressive environment.

Data Preparation

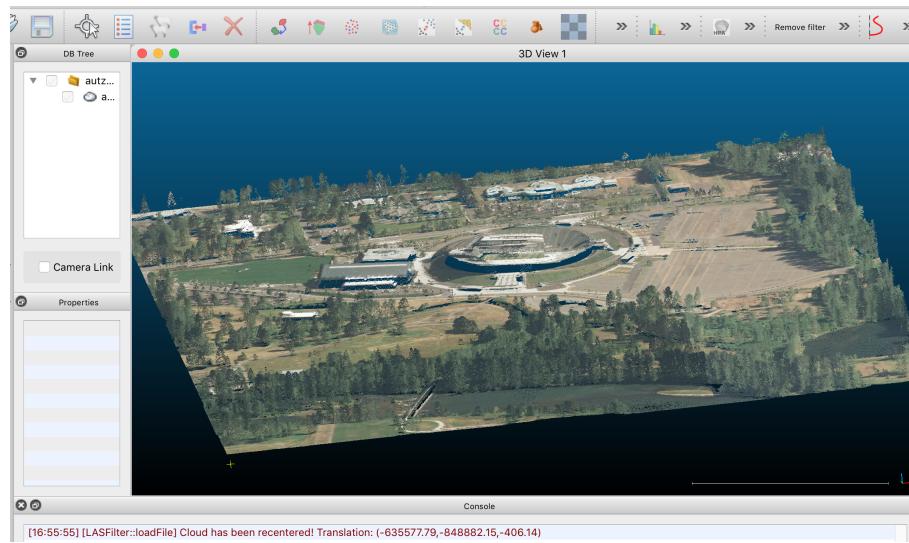


Fig. 10: Autzen Stadium, a 100 million+ point cloud file.

The data are mixed in two different coordinate systems. The [LAZ](#) (page 73) file is in [Oregon State Plane Ft.](#)

(<http://www.oregon.gov/DAS/CIO/GEO/pages/coordination/projections/projections.aspx>) and the [GeoJSON](#) (<http://geojson.org>) defining the polygons is in [EPSG:4326](#) (<http://epsg.io/4326>). We have two options – project the point cloud into the coordinate system of the attribute polygons, or project the attribute polygons into the coordinate system of the points. The latter is preferable in this case because it will be less math and therefore less computation. To make it convenient, we can utilize [OGR](#) (<http://www.gdal.org>)’s [VRT](#) (http://www.gdal.org/drv_vrt.html) capability to reproject the data for us on-the-fly:

```
<OGRVRTDataSource>
  <OGRVRTWarpedLayer>
    <OGRVRTLayer name="OGRGeoJSON">
      <SrcDataSource>attributes.json</SrcDataSource>
      <LayerSRS>EPSG:4326</LayerSRS>
    </OGRVRTLayer>
    <TargetSRS>+proj=lcc +lat_1=43 +lat_2=45.5 +lat_0=41.75 +lon_0=-120.5 +x_0=399999.9999999999 +y_0=0 +ellps=GRS80 +units=ft +no_defs</TargetSRS>
  </OGRVRTWarpedLayer>
</OGRVRTDataSource>
```

Note: The GeoJSON file does not have an externally-defined coordinate system, so we are explicitly setting one with the LayerSRS parameter. If your data does have coordinate system

information, you don't need to do that.

Save this VRT definition to a file, called `attributes.vrt` in the same location where you stored the `autzen.laz` and `attributes.json` files.

The attribute GeoJSON file has a couple of features with different attributes. For our scenario, we want to clip out the yellow-green polygon, marked number “5”, in the upper right hand corner.

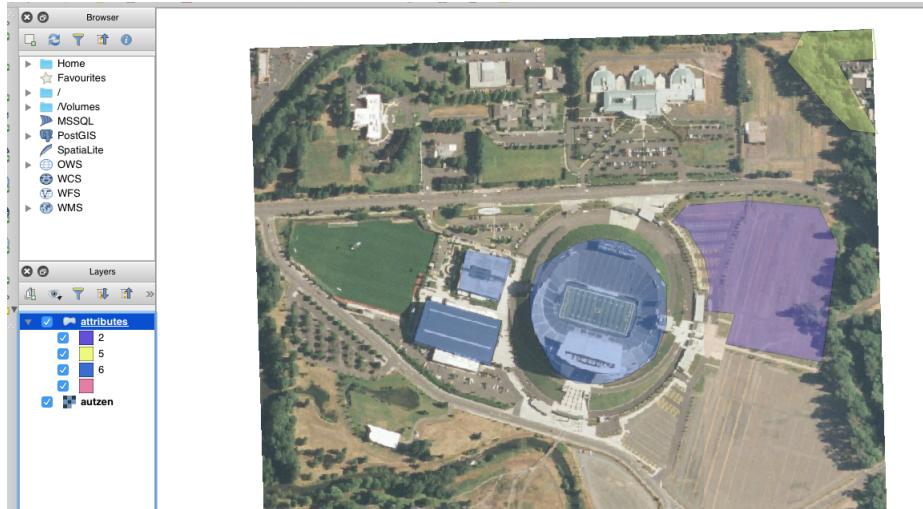


Fig. 11: We want to clip out the polygon in the upper right hand corner. We can view the GeoJSON (<http://geojson.org>) geometry using something like QGIS (<http://qgis.org>)

Pipeline

A PDAL *pipeline* (page 47) 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]"  
    }]
```

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```
    },
    "output.las"
]
```

- *readers.las* (page 73): 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 207): Using the VRT we defined in *Data Preparation* (page 332), read attribute polygons out of the data source and assign the values from the **CLS** column to the **Classification** field.
- *filters.range* (page 250): 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 126): write our content out using an **ASPRS LAS** (<http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html>) writer.

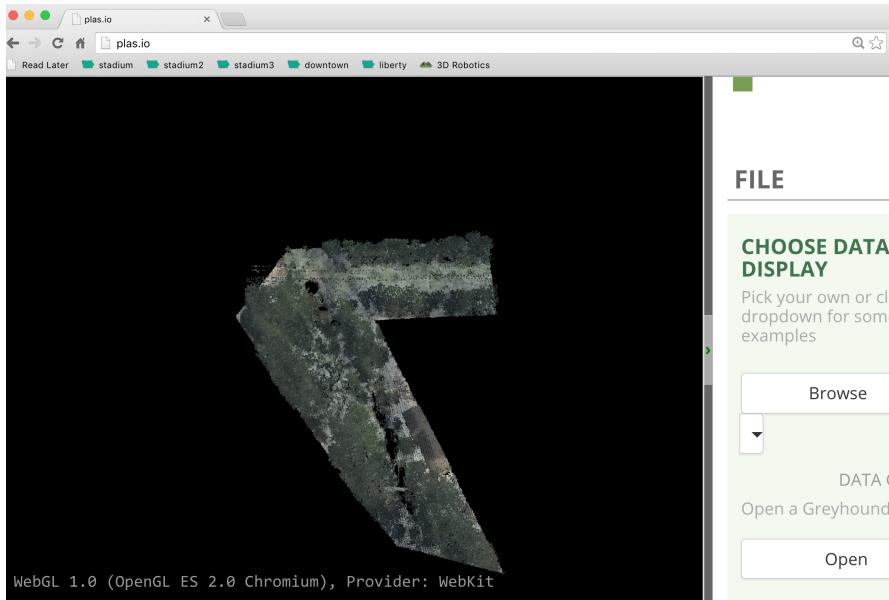
Note: You don't have to use only **Classification** to set the attributes with *filters.overlay* (page 207). Any valid dimension name could work, but most LiDAR softwares will display categorical coloring for the **Classification** field, and we can leverage that behavior in this scenario.

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/>) should do the trick.



Conclusion

PDAL allows the composition of point cloud operations. This tutorial demonstrated how to use the [filters.overlay](#) (page 207) and [filters.range](#) (page 250) stages to clip points with shapefiles.

12.1.5 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 152), a [ground kernel](#) (page 30) to simplify command-line access to PMF, and a filter for [removing outliers](#) (page 159).

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     }
  ]
```

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```
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 42) 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 205) 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 205) and [filters.overlay](#) (page 207).

Extended Local Minimum

The [Extended Local Minimum \(ELM\) method](#) (page 157) helps to identify low noise points that can adversely affect ground segmentation algorithms. ELM was first published in [Chen2012] as part of the upward-fusion method of DTM generation. Noise points are **classified** with a value of 7 in keeping with the LAS specification.

```
11  {
12      "type": "filters.elm"
13 }
```

Outliers

PDAL's [outlier filter](#) (page 159) 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 155) [Pingel2013] is a newer addition to PDAL that has quietly existed in an alpha state since v1.3. With the release of PDAL v1.5, our SMRF implementation is much more complete, although it only implements nearest neighbor void filling and not the authors' preferred "Springs" algorithm.

The changes to SMRF between PDAL v1.3 and v1.5 are substantial. The original version had actually drifted quite far from the authors' published approach, namely in the area of filling voids. We have reverted the code to match the published work, but for now are only using the nearest neighbors approach to filling voids. The morphological operations are also accelerated by moving to an iterative approach and using a diamond structuring element.

```

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 252), 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 152) [Zhang2003]. Rather, it is offered as an alternative. PMF has been a part of PDAL since v1.0, first as part of the PCL plugin and now as `filters.pmf`. Since PDAL v1.4, we have fixed a number of bugs, and have accelerated the approximate mode by implementing iterative morphological operations and using a diamond structuring element.

Extracting Ground Returns

Any time we have points classified as ground, we may wish to extract just these points, e.g., to create a *digital terrain model* (DTM). In this case, we use a [range filter](#) (page 250) as shown.

```
26  {
27      "type": "filters.range",
28      "limits": "Classification[2:2]"
29  }
```

The [range filter](#) (page 250) accepts a `limits` option that identifies the dimension(s) on which to filter and the [range](#) (page 252) 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 152) and [SMRF](#) (page 155) 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 42) `input.las` to `output.las`.

```
$ pdal translate input.las output.las --json pipeline.json
```

12.1.6 Applying a grid shift to point clouds

Introduction

This tutorial first appeared on Land Information New Zealand's [On-Location Blog](#) (<https://medium.com/on-location>).

It describes how to use [Conda](#) (<https://conda.io>), [PDAL](#) (<https://pdal.io>), and [GDAL](#) (<https://gdal.org>) to apply a grid shift to point cloud files. It uses PDAL's [readers.las](#) (<https://pdal.io/stages/readers.las.html>) to fetch the data, [filters.reprojection](#) (<https://pdal.io/stages/filters.reprojection.html>) to apply the grid shift, and [writers.las](#) (<https://pdal.io/stages/writers.las.html>) to write the reprojected point cloud.

The data used in this tutorial is available for free under a CC-BY 4.0 license on Land Information New Zealand's [LINZ Data Service](#) (<https://data.linz.govt.nz>).

The tutorial will be reprojecting point cloud files from:

- A New Zealand local vertical datum to the New Zealand Vertical Datum 2016 (NZVD2016).
- New Zealand Geodetic Datum 2000 (NZGD2000) to NZVD2016.
- Finally, NZVD2016 to NZGD2000 or to a local vertical datum.

Background

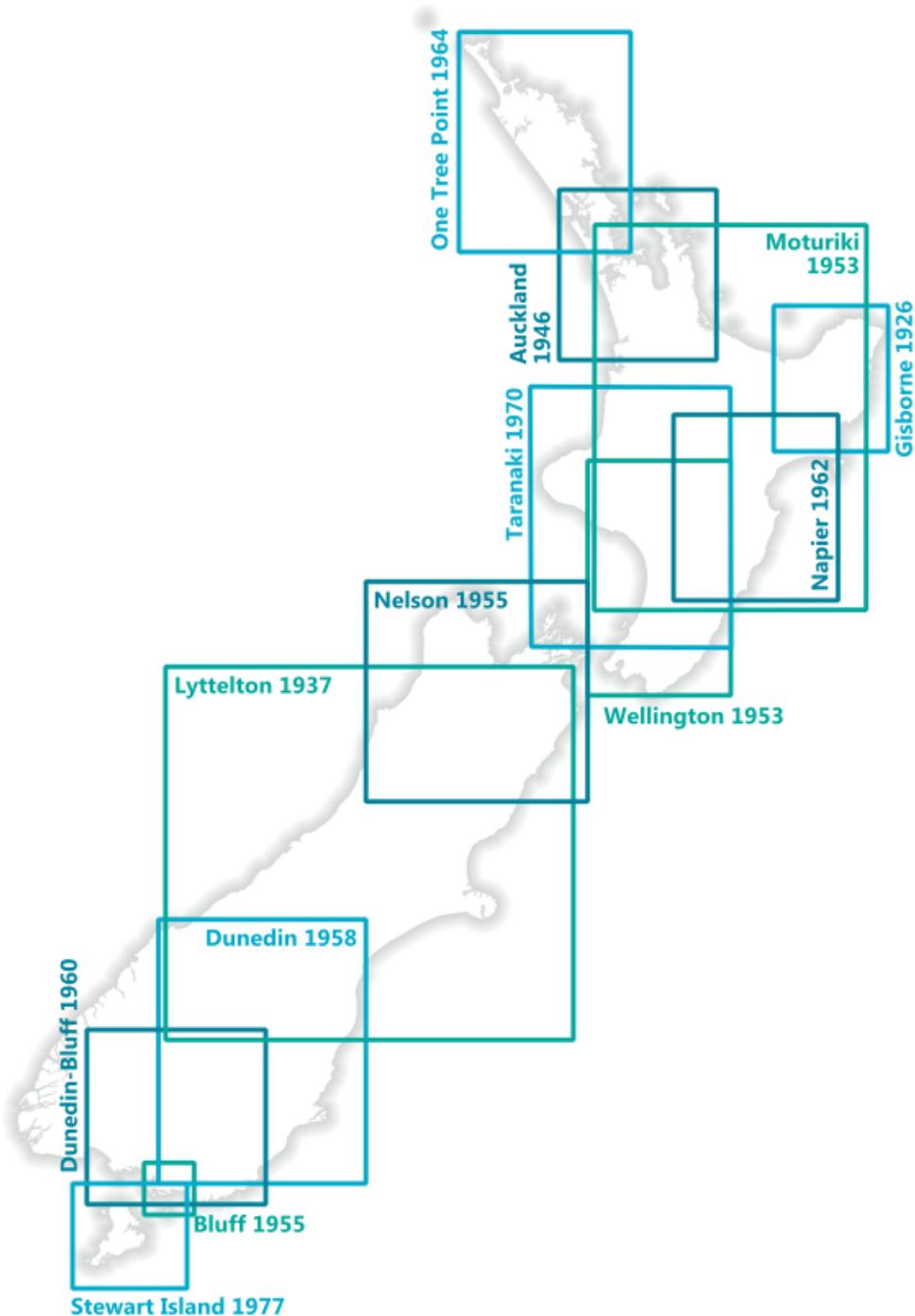
Historically in New Zealand, heights were defined in terms of 13 local vertical datums (LVD) referenced to an estimate of the local mean sea level (MSL).

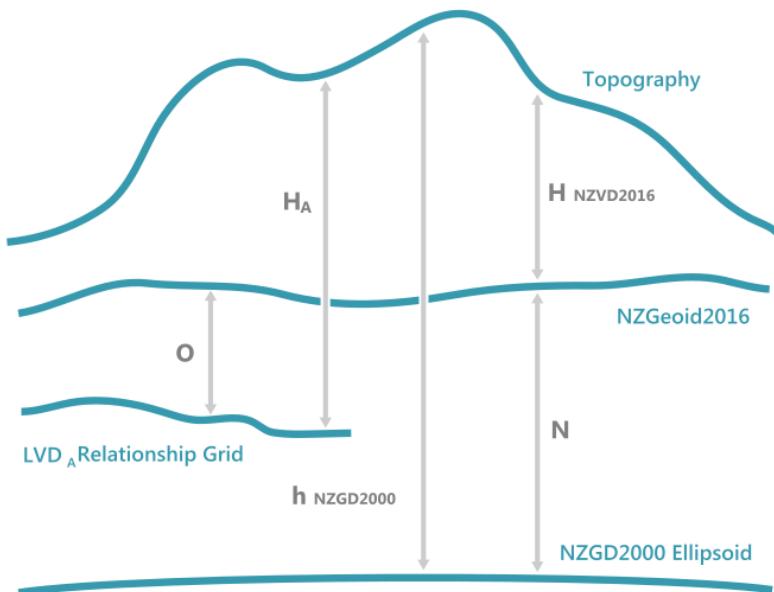
In 2016, New Zealand Vertical Datum 2016 (NZVD2016), which is defined by the NZGeoid2016 geoid, became the official national vertical datum for New Zealand. The general relationship between the different datums is shown in the diagram below.

Available on the [LINZ Data Service](#) (<https://data.linz.govt.nz>) (LDS) are [relationship grids](#) (<https://data.linz.govt.nz/search/category/geodetic/vertical-datum-2016/?q=NZVD2016+Conversion+Raster>) which model the difference between the local vertical datums and NZVD2016 (O in the above diagram).

The [NZ Quasigeoid 2016](#) (<https://data.linz.govt.nz/layer/53447-nz-quasigeoid-2016-raster/>), also a relationship grid, models the difference between the NZGD2000 ellipsoid and NZVD2016 (N in the above diagram).

The equations to transform heights using the published values in the relationship grids are:





LVD to NZVD2016

$$H_{NZVD2016} = H_A - O$$

For the 13 local vertical datums in New Zealand the published value (O) will always be a negative number. Which means the NZVD2016 height will always be less than the LVD height.

NZVD2016 to NZGD2000

$$h_{NZGD2000} = H + N$$

Before we begin

We will be using multiple tools to perform the reprojection. To retrieve these tools and have them all accessible in a nice self-contained environment we will be using a system called Conda. Conda is an open source package and environment management system that runs on Windows, macOS, and Linux. Essentially we will create an environment within Conda which will contain the packages we need: PDAL, GDAL and Python.

Install Conda

Download [Miniconda](https://docs.conda.io/en/latest/miniconda.html) (<https://docs.conda.io/en/latest/miniconda.html>), selecting the 64-bit installer for your platform and install it as directed.

Create a Conda Environment

1. After installing, open the Anaconda Prompt from your start menu.
2. When you begin using conda, you already have a default environment named `base`. We don't want to put programs into our base environment so we'll create a separate environment just for doing this reprojection. To do this, type:

```
conda create --name vd-reproject
```

3. It will check for the additional packages/dependencies that are needed, and will ask if you want to proceed. Say yes.

```
Proceed ([y]/n)? y
```

4. To start to use the new environment and install our required packages within it, we need to activate the environment first:

```
conda activate vd-reproject
```

Note: After the environment is activated the name of the environment appears as `(vd-reproject)` at the beginning of the command line. This indicates that you're now inside the environment.

5. Finally, we need to install the tools/packages we will be using.

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

When these packages are installed, they will also install the packages they're dependent on to run. Python is one of these dependent packages, so we won't need to install it ourselves as conda would've already done it for us.

Now that the packages are installed, we are ready to begin.

Step 1: Create a Datum Transformation Grid (GTX)

PDAL allows for the use of PROJ.4 strings to define the spatial reference system of the inputted or outputted data. This is great, because it gives us the ability to use +geoidgrid which is an option to add a grid shift file in the format of NOAA Vdatum's GTX file format. But where do we get a GTX file from? We have two options:

Option 1 — LINZ supplied GTX file

LINZ has created GTX files for each of the relationship grids mentioned earlier. They can be downloaded from <https://www.geodesy.linz.govt.nz/download/proj-datumgrid-nz>

Here is a list of which GTX file belongs to which Local Vertical Datum:

- **Auckland 1946:** auckht1946-nzvd2016.gtx
- **Bluff 1955:** blufht1955-nzvd2016.gtx
- **Dunedin 1958:** duneht1958-nzvd2016.gtx
- **Dunedin-Bluff 1960:** dublht1960-nzvd2016.gtx
- **Gisborne 1926:** gisbht1926-nzvd2016.gtx
- **Lyttelton 1937:** lyttht1937-nzvd2016.gtx
- **Moturiki 1953:** motuht1953-nzvd2016.gtx
- **Napier 1962:** napiht1962-nzvd2016.gtx
- **Nelson 1955:** nelsht1955-nzvd2016.gtx
- **One Tree Point 1964:** ontphht1964-nzvd2016.gtx
- **Stewart Island 1977:** stisht1977-nzvd2016.gtx
- **Taranaki 1970:** taraht1970-nzvd2016.gtx
- **Wellington 1953:** wellht1953-nzvd2016.gtx

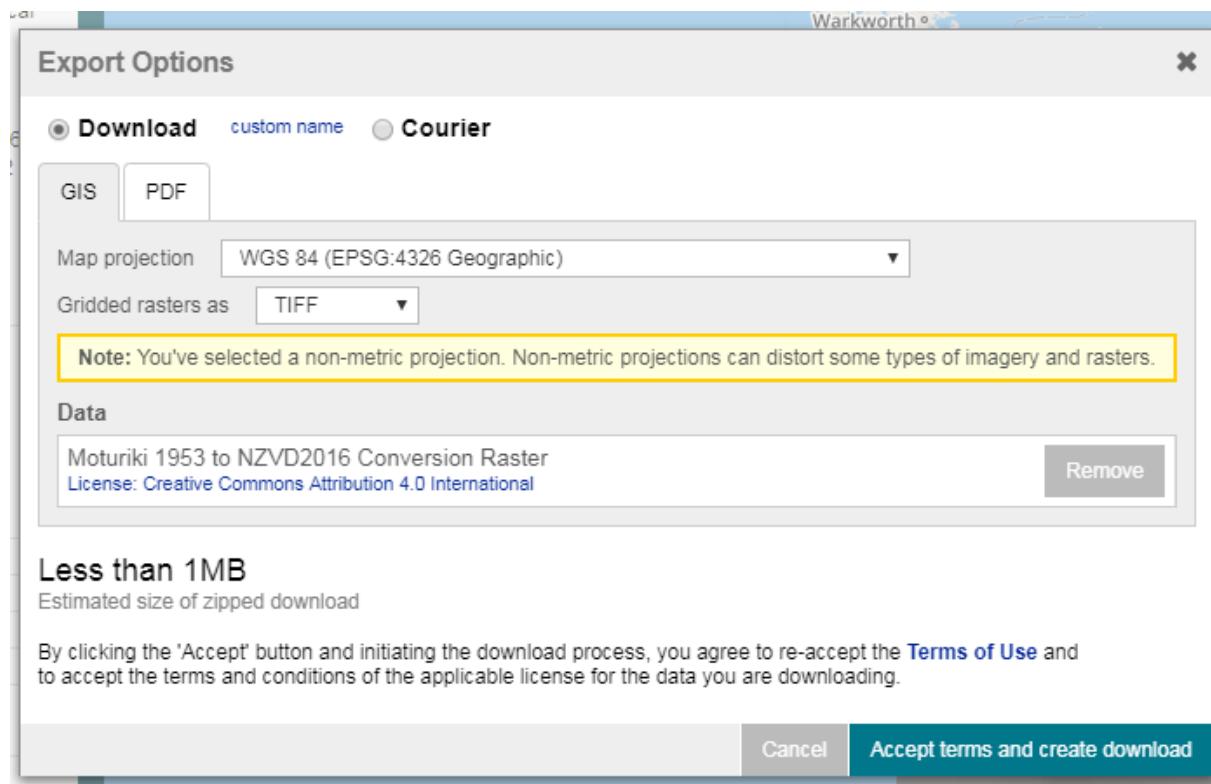
There is also a GTX file for the Quasigeoid which would be used if converting between NZVD2016 and the NZGD2000 ellipsoid.

- **New Zealand Quasigeoid 2016:** nzgeoid2016.gtx

Option two — Create a GTX file

You can create your own GTX file using the relationship grids available on the LDS. For example, if you intend to convert from Moturiki 1953 to NZVD2016, you have to do the following:

1. Download the ‘**Moturiki 1953 to NZVD2016 Conversion Raster**’ as a TIFF from the LDS in ‘**WGS 84 (EPSG:4326 Geographic)**’ Map projection.
<https://data.linz.govt.nz/layer/103959-moturiki-1953-to-nzvd2016-conversion-raster/>.



2. Open the Anaconda Prompt from the start menu and activate the environment we created earlier:

```
conda activate vd-reproject
```

3. Navigate to the location of the downloaded TIFF file and execute gdal_translate to convert the TIFF file to a GTX file:

```
cd path/to/TIFF/file  
gdal_translate -ot Float32 "moturiki-1953-to-nzvd2016-conversion-  
raster.tif" "moturiki-1953-to-nzvd2016-conversion-raster.gtx"
```

Note: -ot Float32 indicates the data type of the output image's bands. GTX files only

support Float32.

Step 2: Prepare a JSON Pipeline file

We will be using a PDAL pipeline (<https://pdal.io/pipeline.html>) to transmit a chain of processing elements into PDAL. These elements will be represented in a JSON file.

Using a text editor, create a JSON file named pipeline.json containing the contents as below.

```
{  
  "pipeline": [  
    {  
      "type": "readers.las",  
      "filename": "#"  
    },  
    {  
      "type": "filters.reprojection",  
      "in_srs": "EPSG:2193",  
      "out_srs": "EPSG:2193"  
    },  
    {  
      "type": "writers.las",  
      "filename": "#",  
      "a_srs": "EPSG:2193",  
      "forward": "all"  
    }  
  ]  
}
```

Update the srs details for `in_srs`, `out_srs` and `a_srs` to the EPSG code of the horizontal map projection your source LAS files are in. In the example above we are using New Zealand Transverse Mercator 2000 (EPSG:2193).

Warning: Be aware "`forward": "all"` under the `writers.las` section represents the header fields whose values should be preserved from the source LAS file. `all` will transfer all header fields, including scale and offset values, as well as VLRs. If you desire to transfer only specific header fields, refer to <https://pdal.io/stages/writers.las.html> for more information about this option.

Step 3: Use PDAL to reproject

Reprojecting one file from LVD to NZVD2016

Using the Anaconda Prompt, activate the vd-reproject environment:

```
conda activate vd-reproject
```

Then issue the following command to reproject one file (of course, replace the files and paths to suit your needs).

```
pdal pipeline "path/to/your/pipeline.json" - readers.las.filename="path/
 ↪to/source_las_file.las" - writers.las.filename="path/to/reprojected_
 ↪las_file.las" - filters.reprojection.out_srs="+init=EPSG:2193
 ↪+geoidgrids=path/to/your/gtx_file.gtx"
```

Reprojecting multiple files from LVD to NZVD2016

Below is a python script which executes multiple LAS files. Save to your computer as lvd_to_nzvd2016.py, then open in a text editor and update src_directory, gtxfile, jsonfile, horizontal_srs with the necessary information.

Note: The file is also available from
<https://gist.github.com/rclarkelinz/d48de5c0432f5c00d02a452e6d1d3bc3>

To execute the script, open the Anaconda Prompt, activate the vd-reproject environment and then navigate to where you have saved the script and issue this command:

```
python lvd_to_nzvd2016.py
```

This script creates a new directory called ‘reprojected’ in the same location as the LAS files. On completion the reprojected LAS files will be located in this directory, ready for your GIS needs.

You can spot check the accuracy of the conversion by using the LINZ Online converter:
www.geodesy.linz.govt.nz/concord

Reprojecting from NZGD2000 to NZVD2016

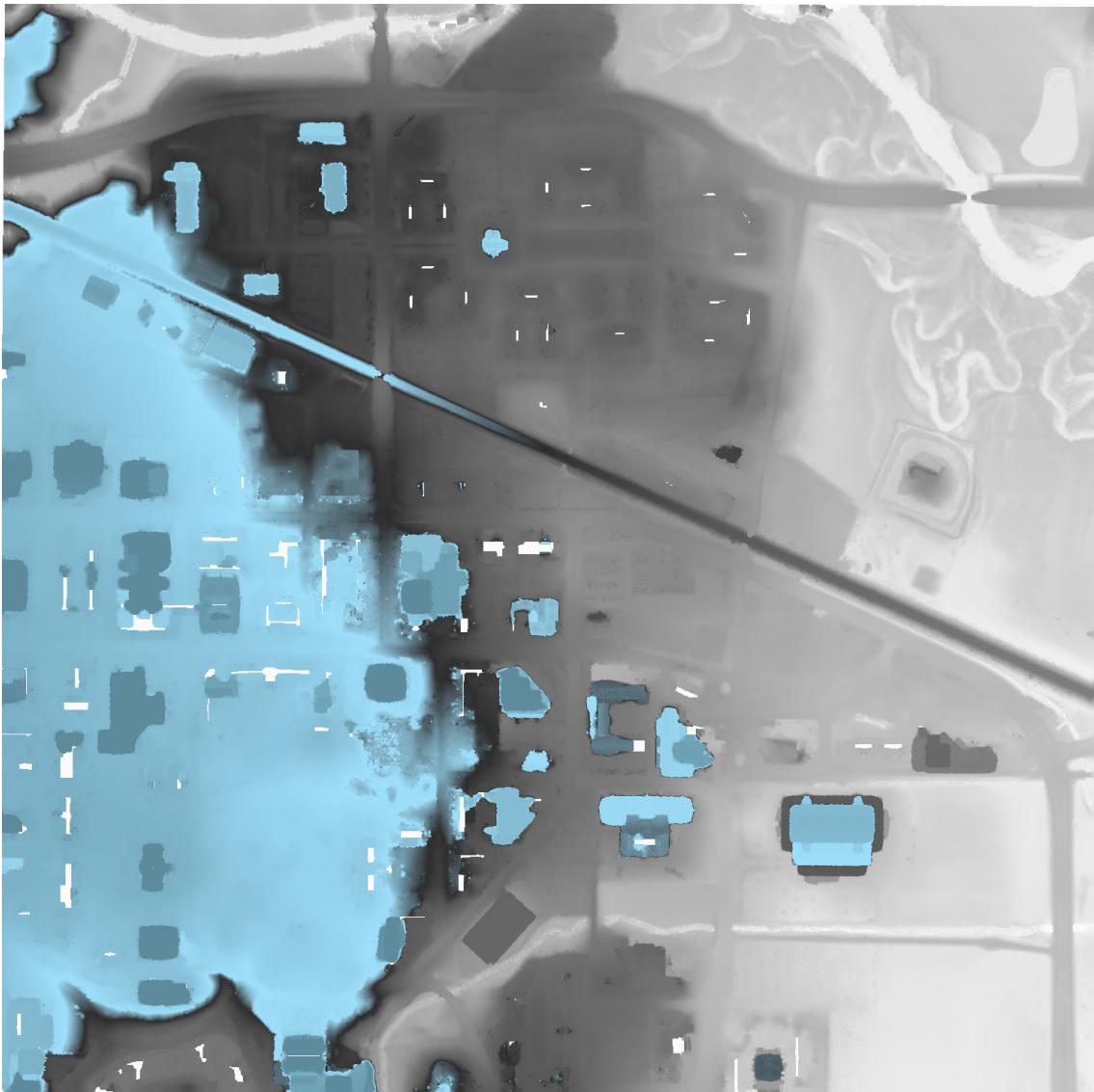
The steps to do this reprojection are the same as above except for one change:

In **Step 1**, for option one, the GTX file required will be `nzgeoid2016.gtx`. Or, if you are following option two, the relationship grid on the LDS is the [NZ Quasigeoid 2016](#) (<https://data.linz.govt.nz/layer/53447-nz-quasigeoid-2016-raster/>).

NZVD2016 to NZGD2000 or LVD

Previously, the grid values are being *subtracted* from the point cloud value in **Step 3**. To reproject to NZGD2000 or an LVD, the grid values need to be *added* to the NZVD2016 value.

To accommodate this change in PDAL, you need to alter the following text in the PDAL command from `filters.reprojection.out_srs` to `filters.reprojection.in_srs`.



CHAPTER
THIRTEEN

WORKSHOP

13.1 Point Cloud Processing and Analysis with PDAL

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Date 08/26/2019

13.1.1 Introduction

1. *Introduction to LiDAR* (page 353)
2. *Introduction to PDAL* (page 5)
3. *Software Installation* (page 358)
4. *Basic Information* (page 359)
5. *Translation* (page 365)
6. *Analysis* (page 372)
7. *Georeferencing* (page 432)

Materials

Slides

- Slides (<https://pdal.s3.amazonaws.com/workshop/slides.zip>)

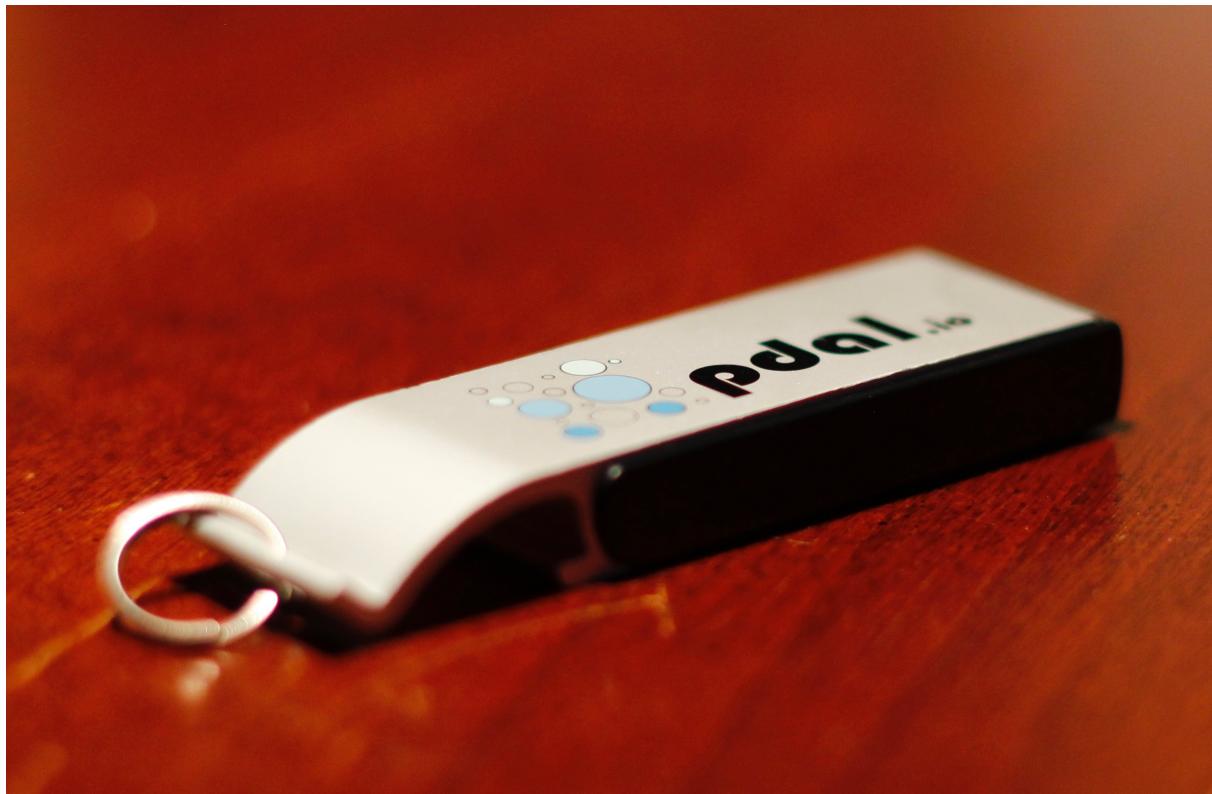
Workshop Materials

These materials are available as a PDF and an HTML website.

- **PDF download** (<https://pdal.s3.amazonaws.com/workshop/PDAL-workshop.pdf>)
- **HTML** (<https://pdal.s3.amazonaws.com/workshop/PDAL-workshop-html.zip>)

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://pdal.s3.amazonaws.com/workshop/PDAL-Workshop-complete.zip>

13.1.2 Introduction to LiDAR

LiDAR is a remote sensing technique that uses visible or near-infrared laser energy to measure the distance between a sensor and an object. LiDAR sensors are versatile and (often) mobile; they help autonomous cars avoid obstacles and make detailed topographic measurements from space. Before diving into LiDAR data processing, we will spend a bit of time reviewing some LiDAR fundamentals and discussing some terms of art.

Types of LiDAR

LiDAR systems, generally speaking, come in one of three types:

- **Pulse-based**, or **linear-mode**, systems emit a pulse of laser energy and measure the time it takes for that energy to travel to a target, bounce off the target, and be returned to the sensor. These systems are called linear-mode because they (generally) only have a single aperture, and so can only measure distance along a single vector at any point in time. Pulse-based systems are very common, and are usually what you would think of when you think of LiDAR.
- **Phase-based** LiDAR systems measure distance via *interferometry*, that is, by using the phase of a modulated laser beam to calculate a distance as a fraction of the modulated signal's wavelength. Phase-based systems can be very precise, on the order of a few millimeters, but since they require comparatively more energy than the other two types they are usually used for short-range (e.g. indoor) scanning.
- **Geiger-mode**, or **photon-counting**, systems use extremely sensitive detectors that can be triggered by a single photon. Since only a single photon is required to trigger a measurement, these systems can operate at much 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]:

$$\mathbf{p}_G^l = \mathbf{p}_{GPS}^l + \mathbf{R}_b^l (\mathbf{R}_s^b \mathbf{r}^s - \mathbf{l}^b) \quad (13.1)$$

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)

- r^s is the coordinates of the laser point in the scanner's frame
- 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 (13.1) to create a final, georeferenced point cloud.

Note: While lever-arm offsets are usually taken from the schematic drawings of the LiDAR mounting system, the boresight matrix cannot be reliably determined from drawings alone. The boresight matrix must therefore be determined either via manual or automated boresight calibration using actual LiDAR data of planar surfaces, such as the roof and sides of buildings. The process for determining a boresight calibration from LiDAR data is beyond the scope of this class.

Discrete-Return vs. Full-Waveform

Pulse-based LiDAR systems use the round-trip travel time of a pulse of laser energy to measure distances. The outgoing pulse of a LiDAR system is roughly (but not exactly) a Gaussian:

This pulse can interact with multiple objects in a scene before it is returned to the sensor. Here is an example of a LiDAR return:

As you can see, this return pulse can be very complicated. While there is more information contained in the “full waveform” picture displayed above, many LiDAR consumers are only interested in detecting the presence or absence of an object — simplistically, the peaks in that waveform.

Full waveform data is used only in specialized circumstances. If you have or receive LiDAR data, it will usually be discrete return (point clouds). Processing full waveform data is beyond the scope of this class.

Note: PDAL is a discrete-return point cloud processing library. It does not have any functionality to analyze or process full waveform data.

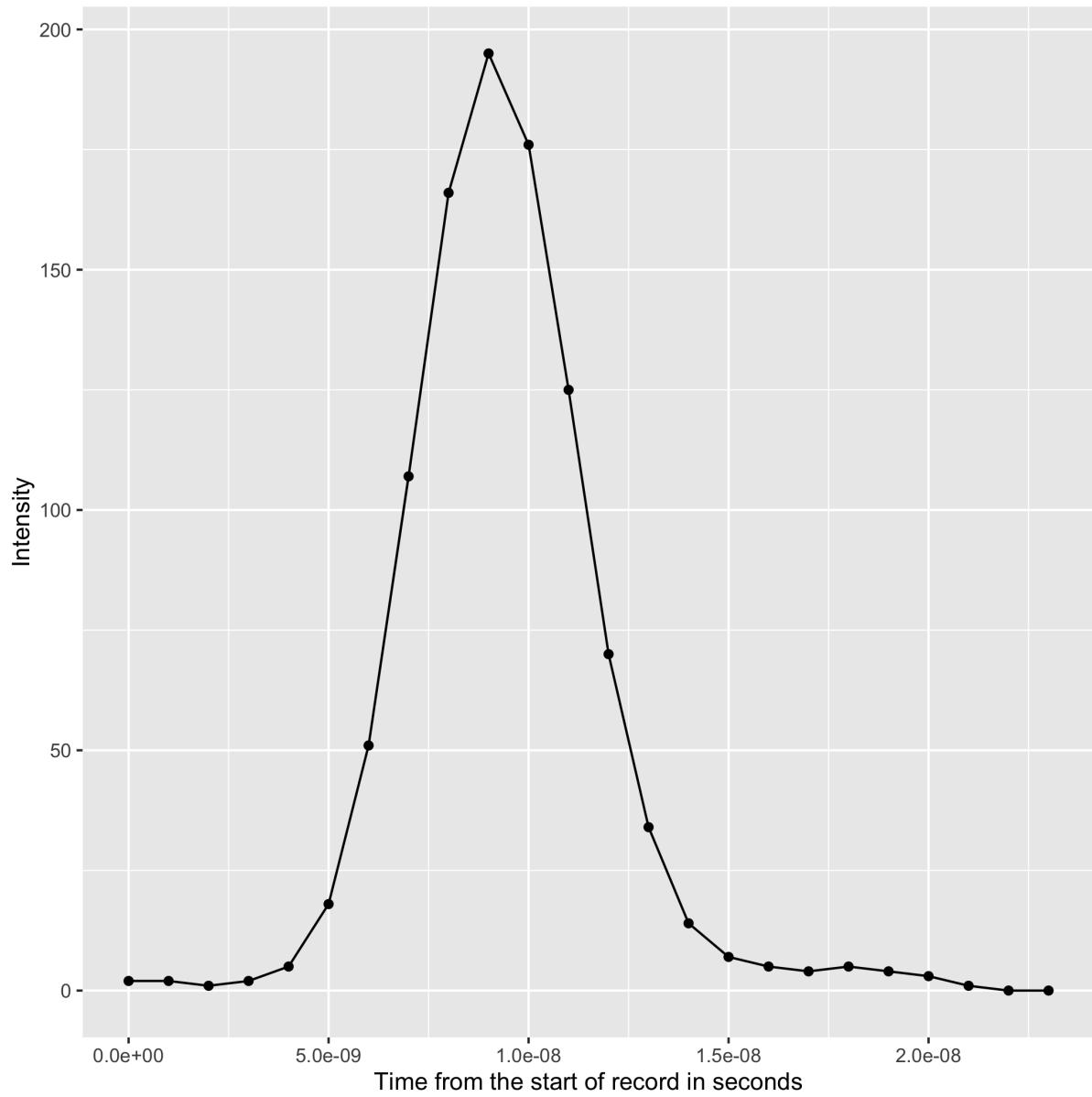


Fig. 1: A real-world outgoing LiDAR pulse.

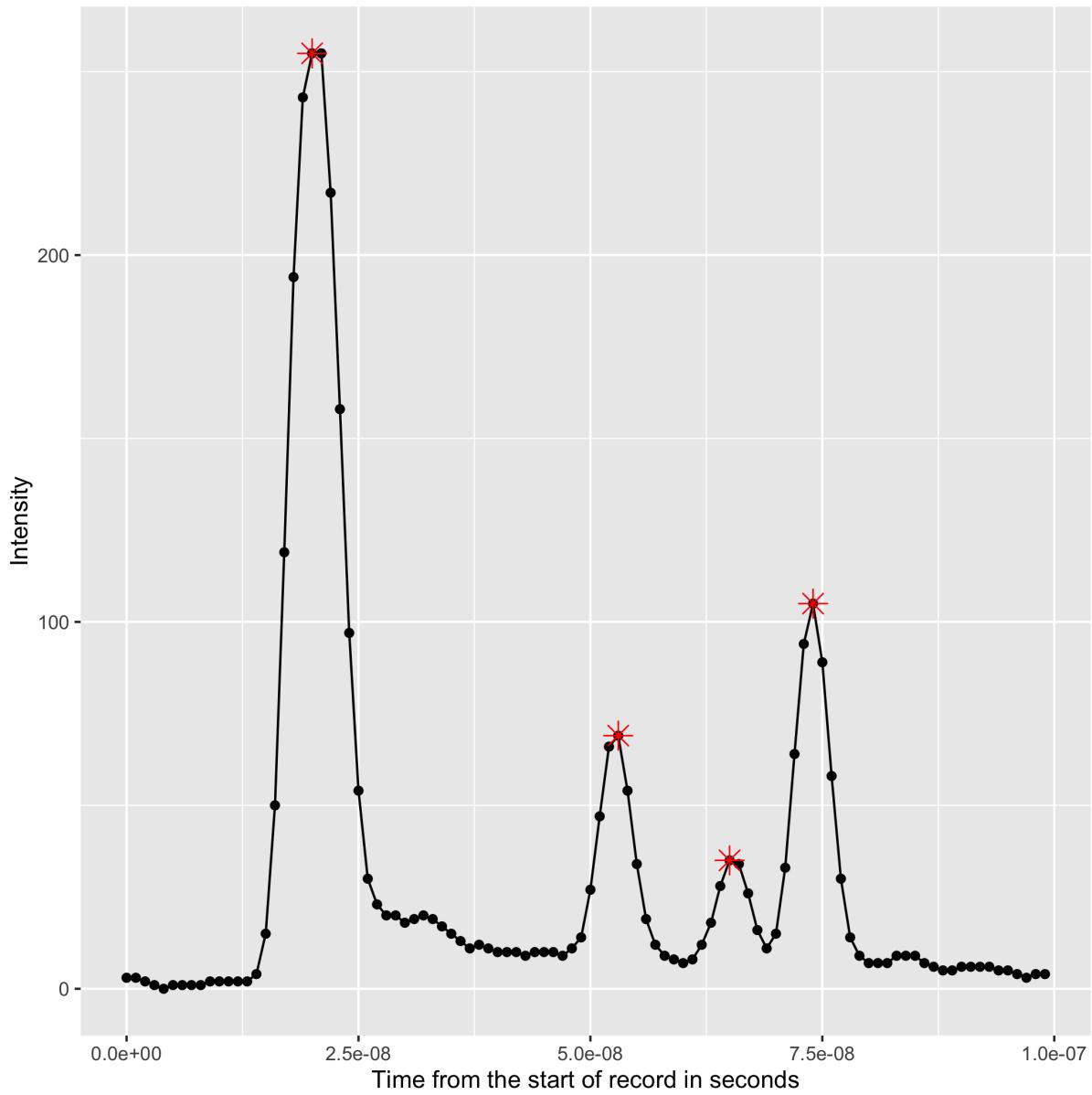


Fig. 2: A real-world incoming LiDAR return. Potential discrete-return peaks are marked in red.

13.1.3 Software Installation

Conda

What is Conda

Conda is an open source package management system and environment management system that runs on Windows, macOS and Linux. Conda quickly installs, runs, and updates packages and their dependencies. Conda easily creates, saves, loads and switches between environments on your local computer. It was created for Python programs, but it can package and distribute software for any language..

How will we use Conda?

PDAL stands on the shoulders of giants. It uses GDAL, GEOS, and *many other dependencies* (page 458). Because of this, it is very challenging to build it yourself. We could easily burn an entire workshop learning the esoteric build mysteries of PDAL and all of its dependencies. Fortunately, Conda provides us a fully-featured known configuration to run our examples and exercises without having to suffer so much, and provides it for Windows, Linux, and macOS.

Note: Not everyone uses Conda. Another alternative to get a known configuration is to go through the workshop using docker as your platform. A previous edition of the workshop was provided using Docker, but it was found to be a bit too difficult to follow.

Installing Conda

1. Copy the entire contents of your workshop USB key to a PDAL directory in your home directory (something like C:\Users\hobu\PDAL) or the equivalent for your OS. We will refer to this location for the rest of the workshop materials.
2. Download the Conda installer for your OS setup.
<https://docs.conda.io/en/latest/miniconda.html>
3. After installing Conda, create an environment for PDAL with:

```
conda create --name pdalworkshop
```

4. Then *activate* the new environment:

```
conda activate pdalworkshop
```

5. Install PDAL, Entwine, and GDAL, and install it from **conda-forge**:

```
conda install -c conda-forge pdal python-pdal gdal entwine  
→matplotlib
```

13.1.4 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 *Conda Shell*.

```
pdal info ./exercises/info/interesting.las -p 0
```

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

1. `pdal`: The `pdal` application :)
2. `info`: We want to run `info` (page 31) on the data. All commands are run by the `pdal` application.
3. `./exercises/info/interesting.las`: The file we are running the command on. PDAL will be able to identify this file is an [ASPRS LAS](#) (<http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html>) file from the extension, `.las`, but not every file type is easily identified. You can use a `pipeline` (page 35) to override which `reader` (page 57) 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).

```
(pdalworkshop) $pdal info ./exercises/info/interesting.las -p 0
{
  "filename": "./exercises/info/interesting.las",
  "pdal_version": "1.9.1 (git-version: Release)",
  "points":
  {
    "point":
    {
      "Blue": 88,
      "Classification": 1,
      "EdgeOfFlightLine": 0,
      "GpsTime": 245380.7825,
      "Green": 77,
      "Intensity": 143,
      "NumberOfReturns": 1,
      "PointId": 0,
      "PointSourceId": 7326,
      "Red": 68,
      "ReturnNumber": 1,
      "ScanAngleRank": -9,
      "ScanDirectionFlag": 1,
      "UserData": 132,
      "X": 637012.24,
      "Y": 849028.31,
      "Z": 431.66
    }
  }
}
```

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 31). 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 146) 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 *Conda Shell*.

```
1 pdal info ./exercises/info/interesting.las --metadata
```

```
(pdalworkshop) $ pdal info ./exercises/info/interesting.las --metadata
{
  "filename": "./exercises/info/interesting.las",
  "metadata": {
    "comp_spatialreference": "PROJCS[\"NAD_1983_Oregon_Statewide_Lambert_Feet_Intl\",GEOGCS[\"GCS_North_American_1983\",DATUM[\"D_North_American_1983\",SPHEROID[\"GRS_1980\",6378137,298.257222101]],PRIMEM[\"Greenwich\",0],UNIT[\"degree\",0.017453295199433]],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\",4000000],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,
    "minz": 406.59,
    "offset_x": 0,
    "offset_y": 0,
    "offset_z": 0,
    "point_length": 34,
    "project_id": "00000000-0000-0000-0000-000000000000",
    "scale_x": 0.01000000000000000208,
    "scale_y": 0.01000000000000000208,
    "scale_z": 0.01000000000000000208,
    "software_id": "HOBU-GENERATING",
  }
}
```

Note: PDAL *metadata* (page 469) 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` command output used in conjunction with a JSON parsing tool like `jq` provide a powerful inspection combination.

For example, we might only care about the `system_id` and `compressed` flag for this particular file. Our simple `pdal info --metadata` command gives us that, but it also gives us a bunch of other stuff we don't need at the moment. Let's focus on extracting what we want using the `jq` command.

```
1 pdal info ./exercises/info/interesting.las --metadata \
2 | jq ".metadata.compressed, .metadata.system_id"
```

```
1 pdal info ./exercises/info/interesting.las --metadata ^
2 | jq ".metadata.compressed, .metadata.system_id"
```

```
(pdalworkshop) $ pdal info ./exercises/info/interesting.las --metadata | jq ".metadata.compressed, .metadata.system_id"
false
"HOBUSYSTEMID"
(pdalworkshop) $
```

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) (<https://en.wikipedia.org/wiki/JSON>) as the exchange format when printing information from `info` (page 31). JSON provides human and machine-readable text data.
2. The PDAL *metadata document* (page 469) 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 57) produce same-named values where possible, but it is common that variables are different. *Filters* (page 150) and even *writers* (page 115) 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 ./exercises/info/interesting.las --all | jq .stats.bbox.  
→native.bbox
```

```
(pdalworkshop) $pdal info ./exercises/info/interesting.las --all | jq .stats.bbox.native.bbox  
{  
    "maxx": 638982.55,  
    "maxy": 853535.43,  
    "maxz": 586.38,  
    "minx": 635619.85,  
    "miny": 848899.7,  
    "minz": 406.59  
}  
(pdalworkshop) $
```

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 ./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.

```
(pdalworkshop) $ pdal info ./exercises/info/interesting.las --query "637301.20, 851217.57, 496.49/3"
{
  "filename": "./exercises/info/interesting.las",
  "pdal_version": "1.9.1 (git-version: Release)",
  "points":
  [
    {
      "point":
      [
        {
          "Blue": 221,
          "Classification": 1,
          "EdgeOffFlightLine": 0,
          "GpsTime": 247565.2203,
          "Green": 211,
          "Intensity": 169,
          "NumberOfReturns": 1,
          "PointId": 762,
          "PointSourceId": 7330,
          "Red": 228,
          "ReturnNumber": 1,
          "ScanAngleRank": -4,
          "ScanDirectionFlag": 0,
          "UserData": 124,
          "X": 637323.56,
          "Y": 851555.64,
          "Z": 586.38
        },
        {
          "Blue": 243,
          "Classification": 1,
          "EdgeOffFlightLine": 0,
          "GpsTime": 247564.4991,
          "Green": 234,
          "Intensity": 249,
          "NumberOfReturns": 1,
          "PointId": 757,
          "PointSourceId": 7330,
          "Red": 241,
          "ReturnNumber": 1,
          "ScanAngleRank": -8,
          "ScanDirectionFlag": 1,
          "UserData": 128,
        }
      ]
    }
  ]
}
```

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 31). 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 31) constructs a [KD-tree](#) (https://en.wikipedia.org/wiki/K-d_tree) of the entire set of points in memory. If you have really large data sets, this isn't going to work so well, and you will need to come up with a different solution.

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 *Conda Shell*.

```
pdal translate ./exercises/translation/interesting.laz \
./exercises/translation/interesting.las
```

```
pdal translate ./exercises/translation/interesting.laz ^
./exercises/translation/interesting.las
```

LAS is a very fluffy binary format. Because of the way the data are stored, there is ample redundant information, and [LASzip](#) (<http://laszip.org>) is an open source solution for compressing this information. Note that we are actually inflating the data here. Its laz from the workshop and we are converting it to las.

2. Verify that the laz data is compressed over the las:

```
ls -alh ./exercises/translation/interesting.laz
```

```
ls -alh ./exercises/translation/interesting.las
```

```
dir ./exercises/translation/interesting.laz
```

```
dir ./exercises/translation/interesting.las
```

```
(pdal19) C:\>dir C:\Users\hobu\PDAL\exercises\info\interesting.laz
Volume in drive C has no label.
Volume Serial Number is 162A-5F2D

Directory of C:\Users\hobu\PDAL\exercises\info

08/04/2019  05:12 PM           18,786 interesting.laz
               1 File(s)        18,786 bytes
               0 Dir(s)   11,142,668,288 bytes free

(pdal19) C:\>dir C:\Users\hobu\PDAL\exercises\info\interesting.las
Volume in drive C has no label.
Volume Serial Number is 162A-5F2D

Directory of C:\Users\hobu\PDAL\exercises\info

08/04/2019  02:44 PM           37,698 interesting.las
               1 File(s)        37,698 bytes
               0 Dir(s)   11,142,668,288 bytes free

/pdal19\ C:\>
```

See also:

LAS Reading and Writing with PDAL (page 318) 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 *Conda Shell*:

```
1 pdal translate ./exercises/analysis/ground/CSite1_orig-utm.laz \
2   ./exercises/translation/csite-dd.laz reprojection \
3   --filters.reprojection.out_srs="EPSG:4326"
```

```
1 pdal translate ./exercises/analysis/ground/CSite1_orig-utm.laz ^
2   ./exercises/translation/csite-dd.laz reprojection ^
3   --filters.reprojection.out_srs="EPSG:4326"
```

```
(pdalworkshop) 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"
(pdalworkshop) C:\>_
```

Unfortunately this doesn't produce the intended results for us. Issue the following `pdal info` command to see why:

```
pdal info ./exercises/translation/csite-dd.laz --all \
| jq .stats.bbox.native.bbox
```

```
pdal info ./exercises/translation/csite-dd.laz --all ^
| jq .stats.bbox.native.bbox
```

```
(pdalworkshop) C:\>pdal info c:/Users/hobu/PDAL/exercises/translation/csite-dd.laz --all | jq .stats.bbox.native.bbox
{
  "maxx": 9.18,
  "maxy": 48.79,
  "maxz": 426.91,
  "minx": 9.16,
  "miny": 48.78,
  "minz": 99.43
}
```

--all dumps all *info* (page 31) 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:

```
(pdalworkshop) 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": "1.9.1 (git-version: Release)",
  "points":
  {
    "point":
    {
      "Blue": 0,
      "Classification": 0,
      "EdgeOfFlightLine": 0,
      "GpsTime": 0,
      "Green": 0,
      "Intensity": 100,
      "NumberOfReturns": 2,
      "PointId": 0,
      "PointSourceId": 0,
      "Red": 0,
      "ReturnNumber": 1,
      "ScanAngleRank": 0,
      "ScanDirectionFlag": 0,
      "UserData": 0,
      "X": 9.17,
      "Y": 48.78,
      "Z": 316.88
    }
  }
}
```

Some formats, like *writers.las* (page 126) 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 ./exercises/analysis/ground/CSite1_orig-utm.laz \
3 ./exercises/translation/csite-dd.laz reprojection \
4 --filters.reprojection.out_srs="EPSG:4326" \
5 --writers.las.scale_x=0.0000001 \
6 --writers.las.scale_y=0.0000001 \
7 --writers.las.offset_x="auto" \
8 --writers.las.offset_y="auto"
```

```
1 pdal translate ^
2 ./exercises/analysis/ground/CSite1_orig-utm.laz ^
3 ./exercises/translation/csite-dd.laz reprojection ^
4 --filters.reprojection.out_srs="EPSG:4326" ^
5 --writers.las.scale_x=0.0000001 ^
6 --writers.las.scale_y=0.0000001 ^
7 --writers.las.offset_x="auto" ^
8 --writers.las.offset_y="auto"
```

```
(pdalworkshop) $pdal translate \
> ./exercises/analysis/ground/CSite1_orig-utm.laz \
> ./exercises/translation/csite-dd.laz reprojection \
> --filters.reprojection.out_srs="EPSG:4326" \
> --writers.las.scale_x=0.0000001 \
> --writers.las.scale_y=0.0000001 \
> --writers.las.offset_x="auto" \
> --writers.las.offset_y="auto"
(pdal translate writers.las Warning) Auto offset for Xrequested in stream mode. Using value of 9.16789.
(pdal translate writers.las Warning) Auto offset for Yrequested in stream mode. Using value of 48.7835.
(pdalworkshop) $
```

Run the *pdal info* command again to verify the X, Y, and Z dimensions:

```
(pdalworkshop) $pdal info ./exercises/translation/csite-dd.laz --all \
> | jq .stats.bbox.native.bbox
{
  "maxx": 9.179032939,
  "maxy": 48.78976523,
  "maxz": 426.91,
  "minx": 9.164037839,
  "miny": 48.78345443,
  "minz": 99.43
}
(pdalworkshop) $
```

Notes

1. *filters.reprojection* (page 222) will use whatever coordinate system is defined by the point cloud file, but you can override it using the `in_srs` option. This is useful in situations where the coordinate system is not correct, not completely specified, or your system doesn't have all of the required supporting coordinate system dictionaries.
2. PDAL uses Proj.4 (<http://proj4.org>) library for reprojection. This library includes the capability to do both vertical and horizontal datum transformations.

Entwine

Exercise

This exercise uses PDAL to fetch data from an Entwine index stored in an Amazon Web Services object store (bucket). Entwine is a point cloud indexing strategy, which rearranges points into a lossless octree structure known as EPT, for Entwine Point Tiles. The structure is described here: <https://entwine.io/entwine-point-tile.html>.

EPT indexes can be used for visualization as well as analysis and data manipulation at any scale.

Examples of Entwine usage can be found from very fine photogrammetric surveys to continental scale lidar management.

US Geological Survey (USGS) example data is here: <https://usgs.entwine.io/>

We will use a sample data set from Dublin, Ireland

<http://potree.entwine.io/data/view.html?r=%22http://na-c.entwine.io/dublin/ept.json%22>

1. View the `entwine.json` file in your editor. If the file does not exist, create it and paste the following JSON into it:

```
{  
  "pipeline": [  
    {  
      "type": "readers.ept",  
      "filename": "ept://https://na-c.entwine.io/  
      ↵dublin/ept.json",  
      "resolution": 5  
    },  
    {  
      "type": "writers.las",  
      "compression": "true",  
      "minor_version": "2",  
      "dataformat_id": "0",  
    }  
  ]  
}
```

(continues on next page)

(continued from previous page)

```
        "filename": "dublin.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 EPT resource at <http://na-c.entwine.io/dublin/ept.json>

-
- Issue the following command in your *Conda Shell*.

```
pdal pipeline ./excercises/translation/entwine.json -v 7
```

```
(pdal19) C:\Users\hobu\PDAL\exercises\translation>pdal pipeline entwine.json -v 7
(PDAL Debug) Debugging...
(pdal pipeline readers.upt Debug) GDAL debug: OGRSpatialReference::Validate: No root pointer.
(pdal pipeline readers.upt Debug) GDAL debug: OGRSpatialReference::Validate: No root pointer.
(pdal pipeline readers.upt Debug) GDAL debug: OGRSpatialReference::Validate: No root pointer.
(pdal pipeline readers.upt Debug) Endpoint: https://na-c.entwine.io/dublin/
Got EPT info
SRS: PROJCS["WGS 84 / Pseudo-Mercator",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"]],PROJECTION["Mercator_1SP"],PARAMETER["central_meridian",0],PARAMETER["scale_factor",1],PARAMETER["false_easting",0],PARAMETER["false_northing",0],UNIT["metre",1,AUTHORITY["EPSG","9001"]],AXIS["X",EAST],AXIS["Y",NORTH],EXTENSION["PROJ4","+proj=merc +a=6378137 +b=6378137 +lat_ts=0.0 +lon_0=0.0 +x_0=0.0 +y_0=0 +k=1.0 +units=m +nadgrids=null +wktext +no_defs"],AUTHORITY["EPSG","3857"]]
Root resolution: 21.3828
Query resolution: 5
Actual resolution: 2.67285
Depth end: 4
Query bounds: [-1.797693134862316e+308, 1.797693134862316e+308], [-1.797693134862316e+308, 1.797693134862316e+308], [-1.797693134862316e+308, 1.797693134862316e+308]
Threads: 4
(pdal pipeline readers.upt Debug) Registering dim X: double
(pdal pipeline readers.upt Debug) Registering dim Y: double
(pdal pipeline readers.upt Debug) Registering dim Z: double
(pdal pipeline readers.upt Debug) Registering dim Intensity: uint16_t
(pdal pipeline readers.upt Debug) Registering dim ReturnNumber: uint8_t
(pdal pipeline readers.upt Debug) Registering dim NumberOfReturns: uint8_t
(pdal pipeline readers.upt Debug) Registering dim ScanDirectionFlag: uint8_t
(pdal pipeline readers.upt Debug) Registering dim EdgeOfFlightLine: uint8_t
(pdal pipeline readers.upt Debug) Registering dim Classification: uint8_t
(pdal pipeline readers.upt Debug) Registering dim ScanAngleRank: float
(pdal pipeline readers.upt Debug) Registering dim UserData: uint8_t
(pdal pipeline readers.upt Debug) Registering dim PointSourceId: uint16_t
(pdal pipeline readers.upt Debug) Registering dim GpsTime: double
(pdal pipeline readers.upt Debug) Registering dim OriginId: uint32_t
(pdal pipeline Debug) Executing pipeline in standard mode.
(pdal pipeline readers.upt Debug) Overlap nodes: 78
(pdal pipeline readers.upt Debug) Overlap points: 8934506
(pdal pipeline readers.upt Debug) Data 1/78: 0-0-0-0
(pdal pipeline readers.upt Debug) Data 2/78: 1-0-0-0
(pdal pipeline readers.upt Debug) Data 3/78: 1-0-0-1
(pdal pipeline readers.upt Debug) Data 4/78: 1-0-1-0
(pdal pipeline readers.upt Debug) Data 5/78: 1-0-1-1
(pdal pipeline readers.upt Debug) Data 6/78: 1-1-0-0
```

- Verify that the data look ok:

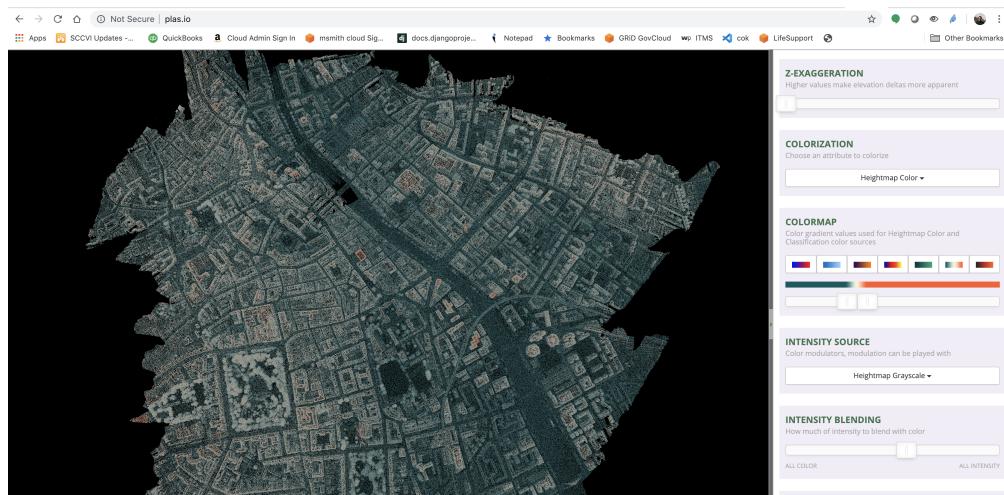
```
pdal info dublin.laz | jq .stats.bbox.native.bbox

pdal info dublin.laz -p 0
```

```
(pdal19) C:\Users\hobu\PDAL\exercises\translation>pdal info dublin.laz | jq .stats.bbox.native.bbox
{
  "maxx": -694128.96,
  "maxy": 7049938.84,
  "maxz": 385.37,
  "minx": -699477.88,
  "miny": 7044490.98,
  "minz": -144.24
}

(pdal19) C:\Users\hobu\PDAL\exercises\translation>pdal info dublin.laz -p 0
{
  "filename": "dublin.laz",
  "pdal_version": "1.9.1 (git-version: Release)",
  "points":
  {
    "point":
    {
      "Classification": 4,
      "EdgeOfFlightLine": 0,
      "Intensity": 7,
      "NumberOfReturns": 2,
      "PointId": 0,
      "PointSourceId": 0,
      "ReturnNumber": 2,
      "ScanAngleRank": -33,
      "ScanDirectionFlag": 1,
      "UserData": 0,
      "X": -697907.12,
      "Y": 7045474.25,
      "Z": 27.5
    }
  }
}
```

4. Visualize the data in <http://plas.io>



Notes

1. *readers.ept* (page 59) contains more detailed documentation about how to use PDAL's EPT reader .

Analysis

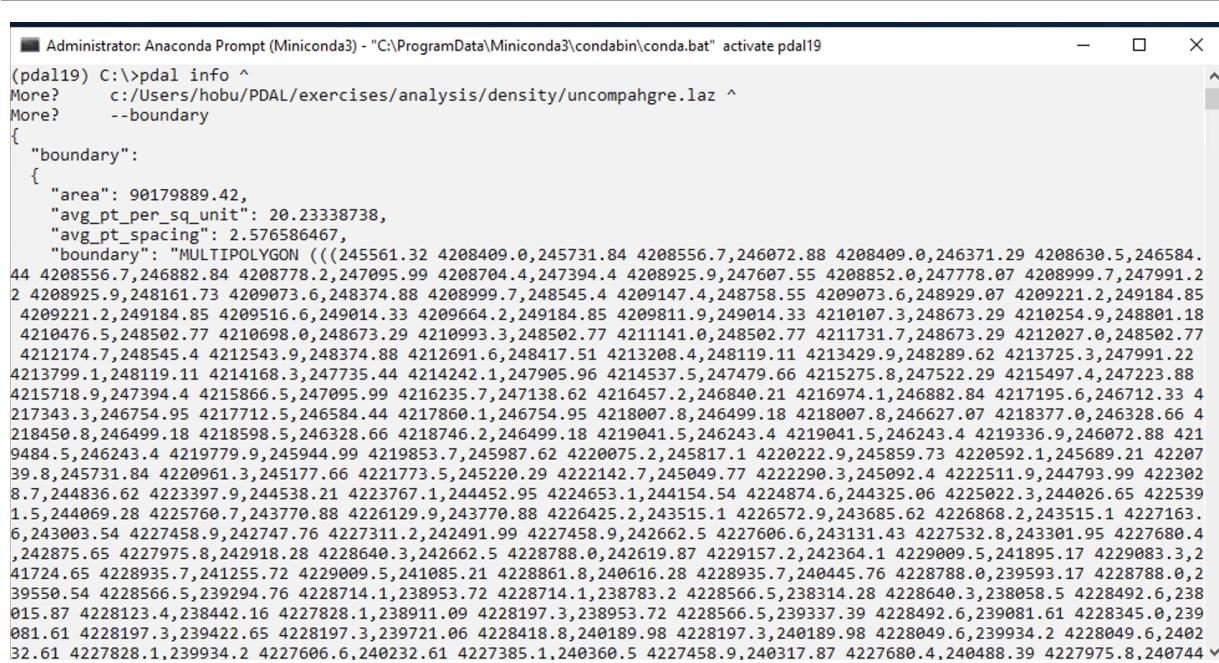
Finding the boundary

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 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 ./exercises/analysis/density/uncompahgre.laz --boundary
```



```
Administrator: Anaconda Prompt (Miniconda3) - "C:\ProgramData\Miniconda3\condabin\conda.bat" activate pdal19
(pdal19) C:\>pdal info ^
More?      c:/Users/hobu/PDAL/exercises/analysis/density/uncompahgre.laz ^
More?      --boundary
{
  "boundary": {
    "area": 90179889.42,
    "avg_pt_per_sq_unit": 20.23338738,
    "avg_pt_spacing": 2.576586467,
    "boundary": "MULTIPOLYGON (((245561.32 4208409.0, 245731.84 4208556.7, 246072.88 4208409.0, 246371.29 4208630.5, 246584.4208556.7, 246882.84 4208778.2, 247095.99 4208704.4, 247394.4 4208925.9, 247607.55 4208852.0, 247778.07 4208999.7, 247991.22 4208925.9, 248161.73 42089073.6, 248374.88 4208999.7, 248545.4 4209147.4, 248758.55 4209073.6, 248929.07 4209221.2, 249184.85 4209221.2, 249184.85 4209516.6, 249014.33 4209664.2, 249184.85 4209811.9, 249014.33 4210107.3, 248673.29 4210254.9, 248801.18 4218476.5, 248502.77 4210698.0, 248673.29 4210993.3, 248502.77 4211141.0, 248502.77 4211731.7, 248673.29 4212027.0, 248502.77 4212174.7, 248545.4 4212543.9, 248374.88 4212691.6, 248417.51 4213208.4, 248119.11 4213429.9, 248289.62 4213725.3, 247991.22 4213799.1, 248119.11 4214168.3, 247735.44 4214242.1, 247985.96 4214537.5, 247479.66 4215275.8, 247522.29 4215497.4, 247223.88 4215718.9, 247394.4 4215866.5, 247095.99 4216235.7, 247138.62 4216457.2, 246840.21 4216974.1, 246882.84 4217195.6, 246712.33 4217343.3, 246754.95 4217712.5, 246584.44 4217860.1, 246754.95 4218007.8, 246499.18 4218007.8, 246627.07 4218377.0, 246328.66 4218450.8, 246499.18 4218598.5, 246328.66 4218746.2, 246499.18 4219041.5, 246243.4 4219041.5, 246243.4 4219336.9, 246672.88 421948.5, 246243.4 4219779.9, 245944.99 4219853.7, 245987.62 4220075.2, 245817.1 4220222.9, 245859.73 4220592.1, 245689.21 4220739.8, 245731.84 4220961.3, 245177.66 4221773.5, 245220.29 4222142.7, 245049.77 4222290.3, 245092.4 4222511.9, 244793.99 4223028.7, 244836.62 4223397.9, 244538.21 4223767.1, 244452.95 4224653.1, 244154.54 4224874.6, 244325.06 4225022.3, 244026.65 4225391.5, 244069.28 4225760.7, 243770.88 4226129.9, 243770.88 4226425.2, 243515.1 4226572.9, 243685.62 4226868.2, 243515.1 4227163.6, 243003.54 4227458.9, 242747.76 4227311.2, 242491.99 4227458.9, 242662.5 4227606.6, 243131.43 4227532.8, 243301.95 4227680.4, 242875.65 4227975.8, 242918.28 4228640.3, 242662.5 4228788.0, 242619.87 4229157.2, 242364.1 4229009.5, 241895.17 4229083.3, 241724.65 4228935.7, 241255.72 4229009.5, 241085.21 4228861.8, 240616.28 4228935.7, 240445.76 4228788.0, 239593.17 4228788.0, 239550.54 4228566.5, 239294.76 4228714.1, 238953.72 4228714.1, 238783.2 4228566.5, 238314.28 4228640.3, 238058.5 4228492.6, 238015.87 4228123.4, 238442.16 4227828.1, 238911.09 4228197.3, 238953.72 4228566.5, 239337.39 4228492.6, 239081.61 4228345.0, 239081.61 4228197.3, 239422.65 4228197.3, 239721.06 4228418.8, 240189.98 4228197.3, 240189.98 4228049.6, 239934.2 4228049.6, 240232.61 4227828.1, 239934.2 4227606.6, 240232.61 4227385.1, 240360.5 4227458.9, 240317.87 4227680.4, 240488.39 4227975.8, 240744
```

... 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. 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 265). We can leverage this capability to output a contiguous boundary of the `uncompahgre.laz` file.

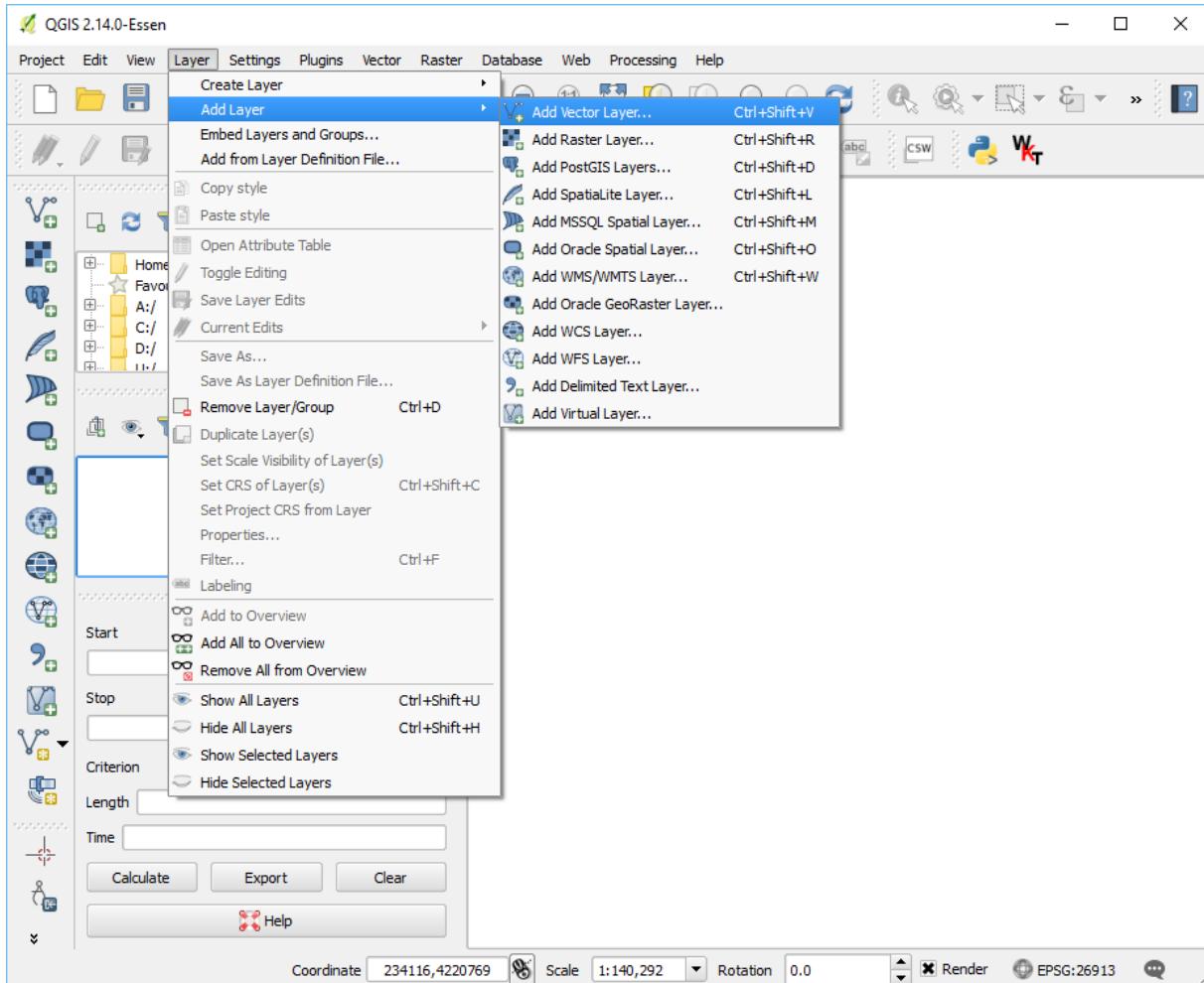
```
1 pdal tindex create --tindex ./exercises/analysis/boundary/boundary.  
2   ↵sqlite \  
3   --filespec ./exercises/analysis/density/uncompahgre.laz \  
4   -f SQLite
```

```
1 pdal tindex create --tindex ./exercises/analysis/boundary/boundary.  
2   ↵sqlite ^  
3   --filespec ./exercises/analysis/density/uncompahgre.laz ^  
4   -f SQLite
```

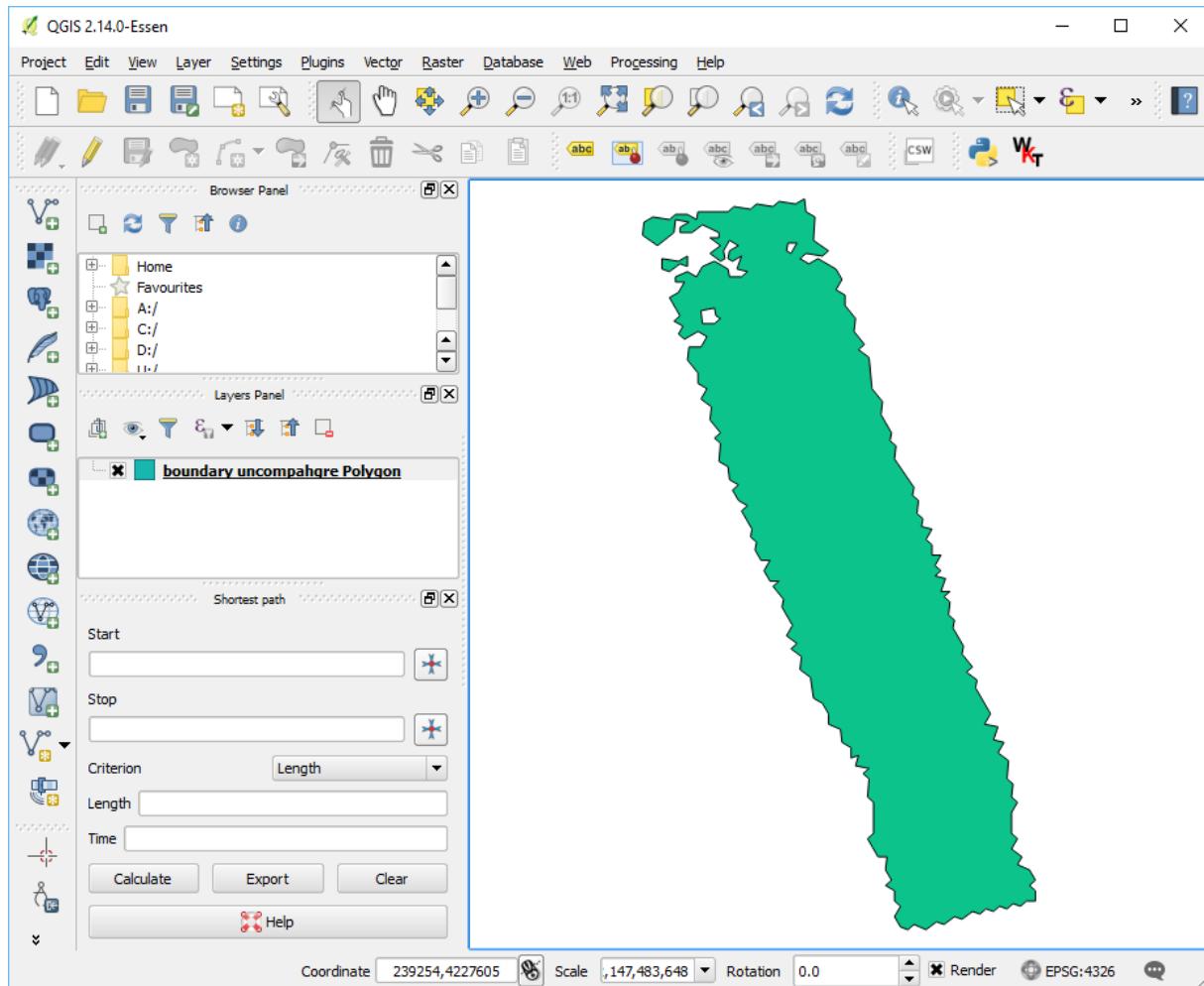
```
(pdalworkshop) $ pdal tindex create --tindex ./exercises/analysis/boundary/boundary.sqlite \  
1 >   --filespec ./exercises/analysis/density/uncompahgre.laz \  
2 >   -f SQLite  
(pdalworkshop) $
```

Once we've run the `tindex` (page 40), we can now visualize our output:

Open qgis 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 265) can also be used by the *density* (page 28) to generate a tessellated surface. See the *Visualizing acquisition density* (page 390) example for steps to achieve this.
3. The *tindex* (page 40) 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).

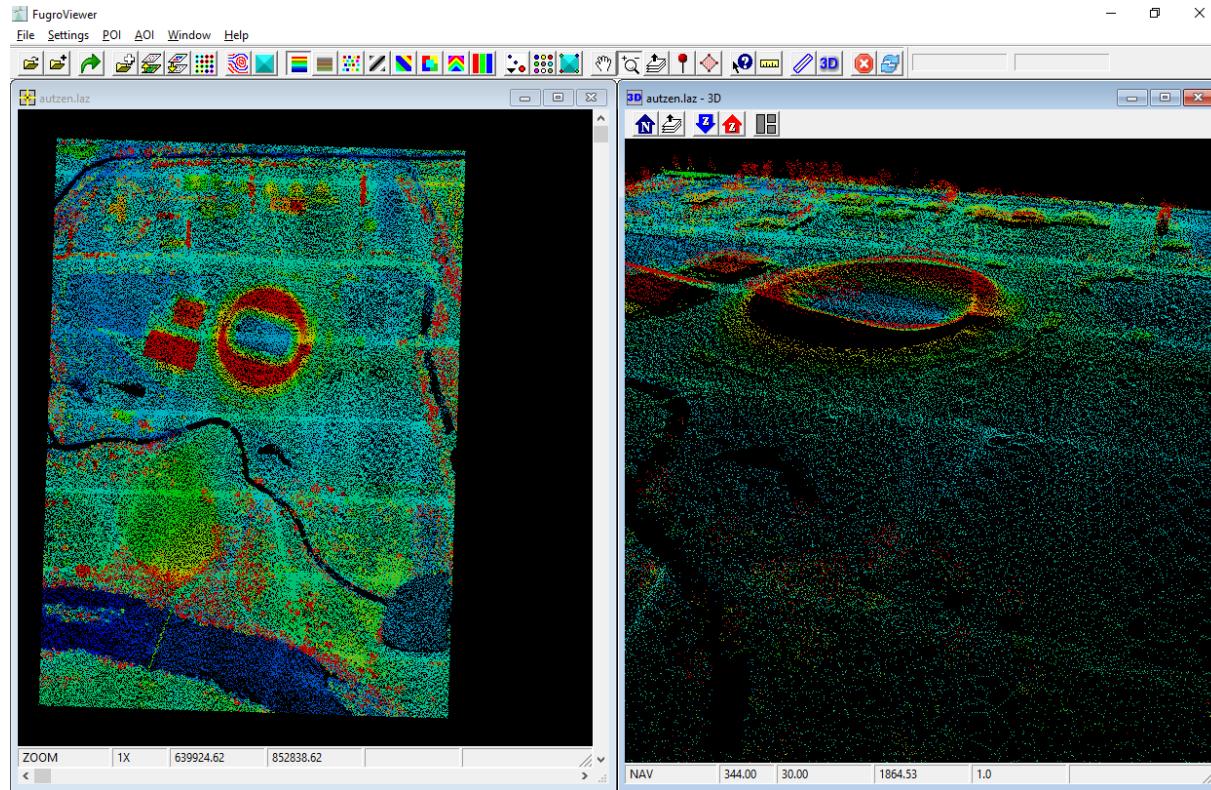
Clipping data with polygons

This exercise uses PDAL to apply to clip data with polygon geometries.

Note: This exercise is an adaption of the *PDAL tutorial* (page 330).

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 73) file is in [Oregon State Plane Ft.](#)

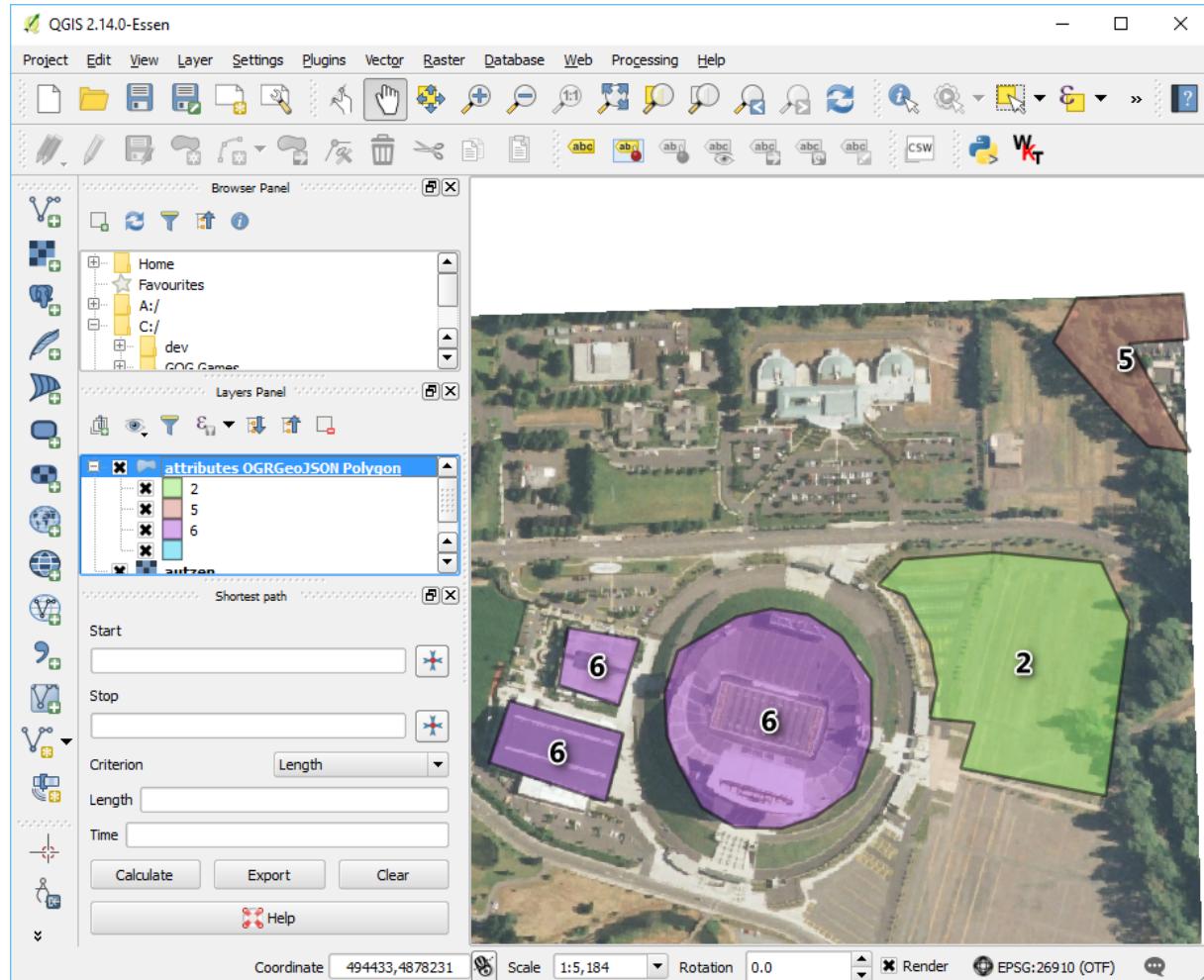
(<http://www.oregon.gov/DAS/CIO/GEO/pages/coordination/projections/projections.aspx>) and the [GeoJSON](#) (<http://geojson.org>) defining the polygons, `attributes.json`, is in [EPSG:4326](#) (<http://epsg.io/4326>). We have two options – project the point cloud into the coordinate system of the attribute 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) (<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>./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 `./` 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) for more details.

Pipeline breakdown

```
{  
    "pipeline": [  
        "./exercises/analysis/clipping/autzen.laz",  
        {  
            "column": "CLS",  
            "datasource": "./exercises/analysis/clipping/attributes.vrt"  
        },  
        ...  
    ]  
}
```

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```
"dimension": "Classification",
"layer": "OGRGeoJSON",
"type": "filters.overlay"
},
{
  "limits": "Classification[6:6]",
  "type": "filters.range"
},
"./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 `.` 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 207) filter allows you to assign values for coincident polygons. Using the VRT we defined in [Data preparation](#) (page 376), `filters.overlay` (page 207) 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 250) to keep points with Classification values in the range of 6:6.

4. Writer

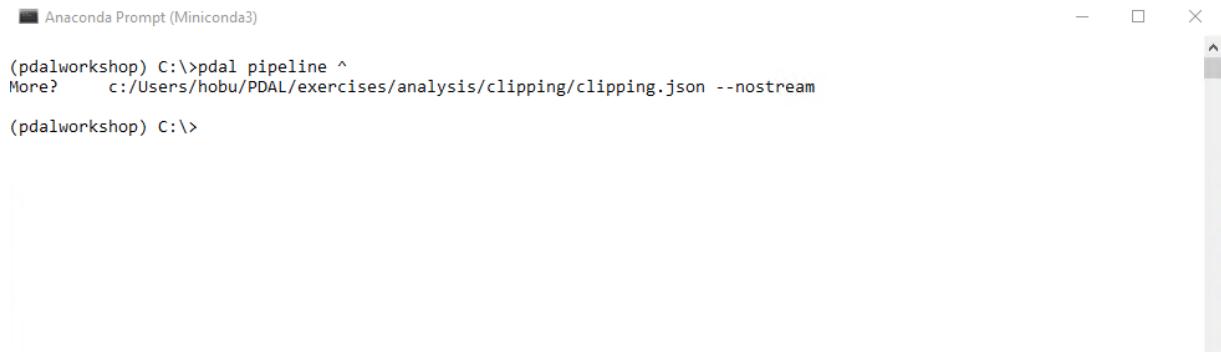
We will write our content back out using a `writers.las` (page 126).

Execution

Invoke the following command, substituting accordingly, in your *Conda Shell*:

The `--nostream` option disables stream mode. The point-in-polygon check (see notes) performs poorly in stream mode currently.

```
1 pdal pipeline ./exercises/analysis/clipping/clipping.json --nostream
```

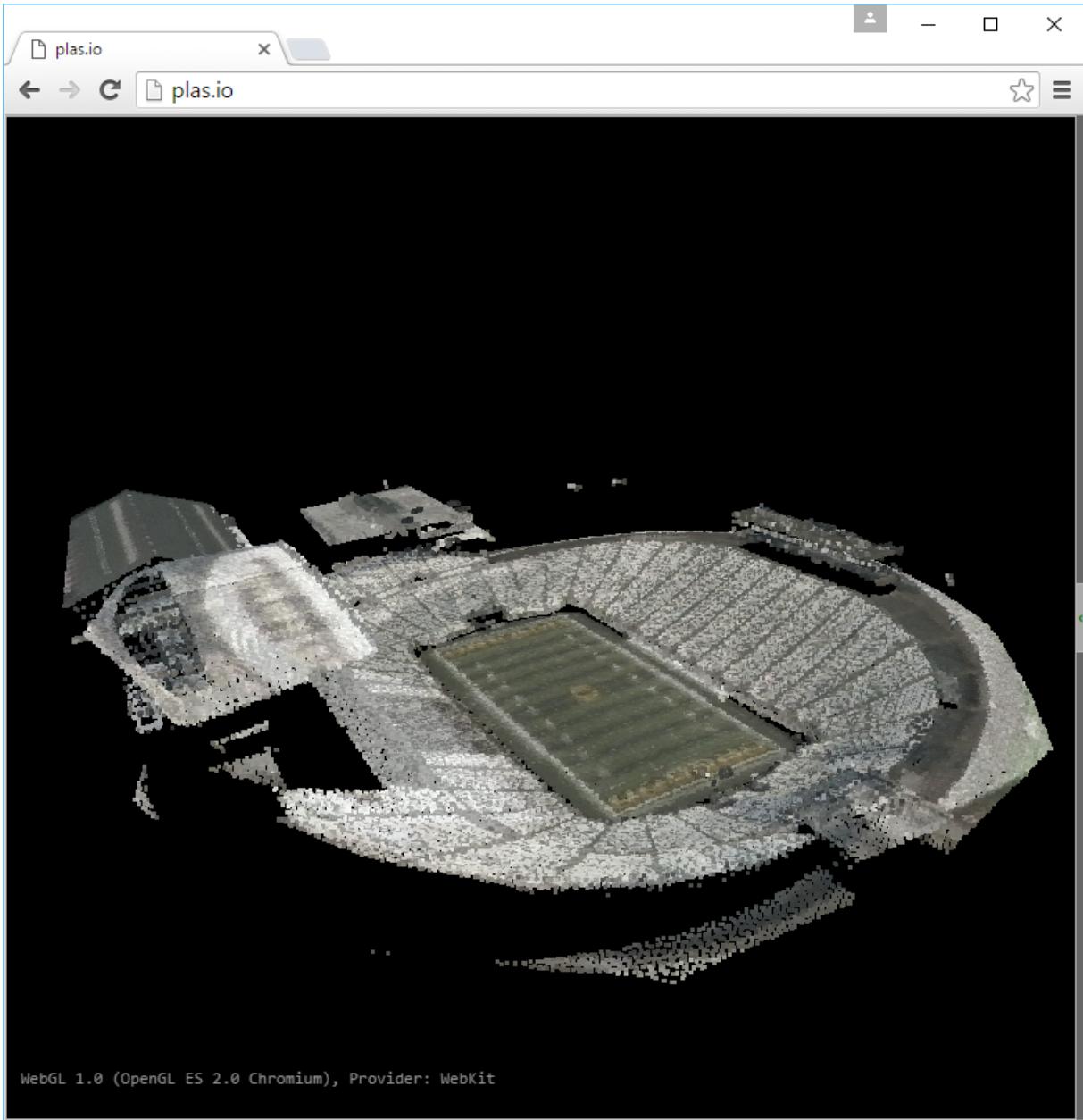


Anaconda Prompt (Miniconda3)

```
(pdalworkshop) C:\>pdal pipeline ^
More?      c:/Users/hobu/PDAL/exercises/analysis/clipping/clipping.json --nostream
(pdalworkshop) C:\>
```

Visualization

Use one of the point cloud visualization tools you installed to take a look at your `./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 207) 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 150) 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          "./exercises/analysis/thinning/uncompahgre.laz",
4          {
5              "type": "filters.colorization",
6              "raster": "./exercises/analysis/colorization/casi-2015-04-
7              ↪29-weekly-mosaic.tif"
8          },
9          {
10             "type": "filters.range",
11             "limits": "Red[1:]"
12         },
13         {
14             "type": "writers.las",
15             "compression": "true",
16             "minor_version": "2",
17             "dataformat_id": "3",
18             "filename": "./exercises/analysis/colorization/uncompahgre-
19             ↪colored.laz"
20         }
21     ]
22 }
```

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 `./` 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.

```
"./exercises/analysis/thinning/uncompahgre.laz",
```

2. filters.colorization

The [filters.colorization](#) (page 178) PDAL filter does most of the work for this operation. We're going to use the default data scaling options. This filter will create PDAL dimensions Red, Green, and Blue.

```
{
  "type": "filters.colorization",
  "raster": "./exercises/analysis/colorization/casi-2015-04-29-weekly-
  ↪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 250) to filter keep any points that have Red ≥ 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",
```

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```
"dataformat_id": "3",
"filename": "./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 126) provides a number of possible options to control how your LAS files are written.

Execution

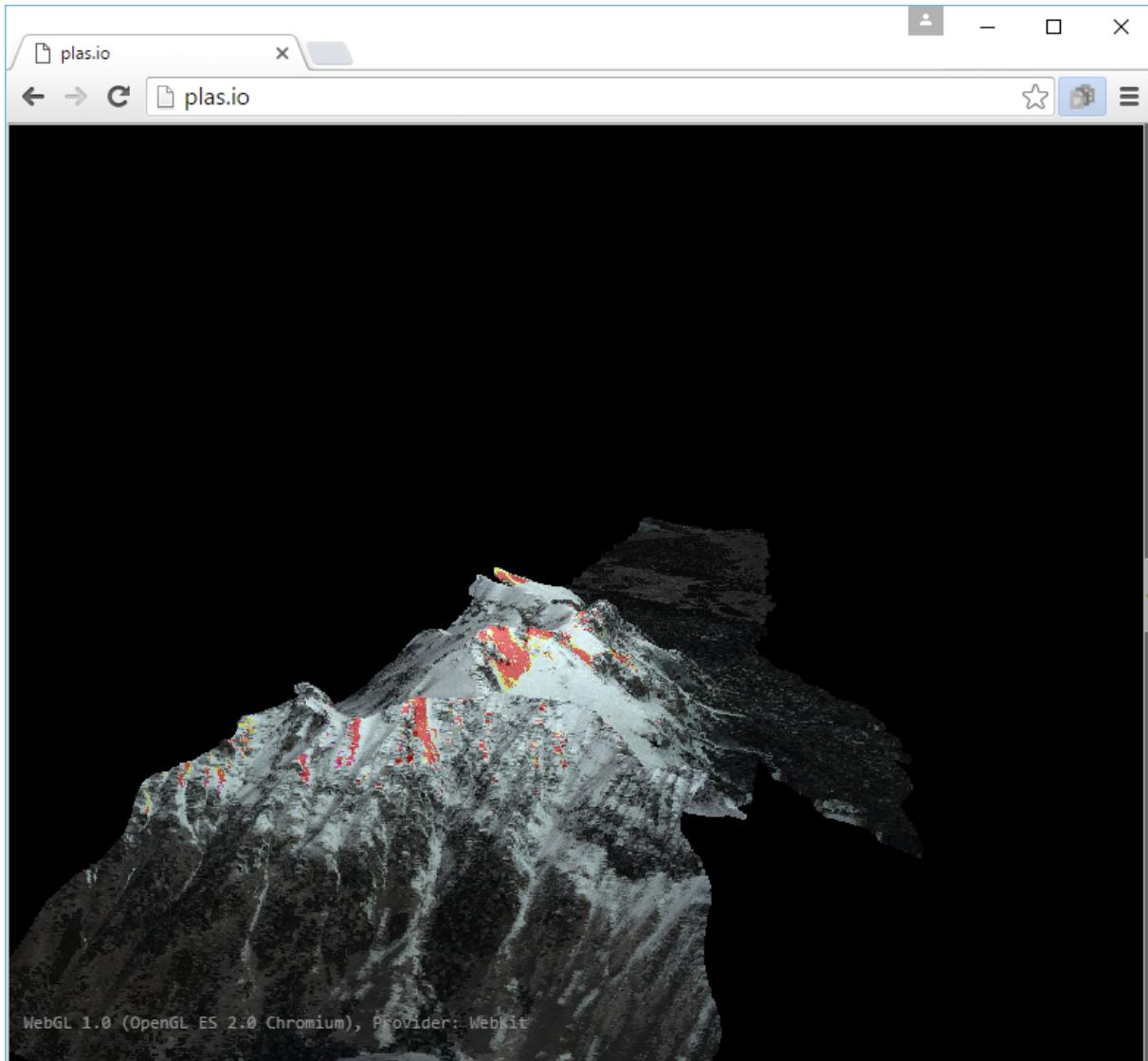
Invoke the following command, substituting accordingly, in your *Conda Shell*:

```
1 pdal pipeline ./exercises/analysis/colorization/colorize.json
```

```
(pdal19) C:\>pdal pipeline ^
More? c:\Users\hobu\PDAL\exercises\analysis\colorization\colorize.json
(pdal19) 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 178) for more information.
4. These data are of [Uncompahgre Basin](#) (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 159) to apply a statistical filter to data.

Because this operation is somewhat complex, we are going to use a pipeline to define it.

```
{  
    "pipeline": [  
        "./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": "./exercises/analysis/denoising/clean.laz"  
        }  
    ]  
}
```

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```
    ]  
}
```

Note: This pipeline is available in your workshop materials in the `./exercises/analysis/denoising/denoise.json` file.

Pipeline breakdown

1. Reader

After our pipeline errata, the first item we define in the pipeline is the point cloud file we're going to read.

```
"./exercises/analysis/denoising/18TWK820985.laz",
```

2. filters.outlier

The PDAL *outlier filter* (page 159) 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 250) can remove these noise points by constructing a *range* (page 252) with the value `Classification![7:7]`, which passes every point with a Classification value **not** equal to 7.

Even with the *filters.outlier* (page 159) 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 252) to keep only points that are within the range $-100 \leq Z \leq 3000$.

Both *ranges* (page 252) are passed as a comma-separated list to the *range filter* (page 250) 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": "./exercises/analysis/denoising/clean.laz"  
}
```

1. **compression**: LASzip (<http://laszip.org>) data is ~6x smaller than ASPRS LAS.
2. **minor_version**: We want to make sure to output LAS 1.2, which will provide the widest compatibility with other softwares that can consume LAS.
3. **dataformat_id**: Format 3 supports both time and color information

Note: *writers.las* (page 126) provides a number of possible options to control how your LAS files are written.

Execution

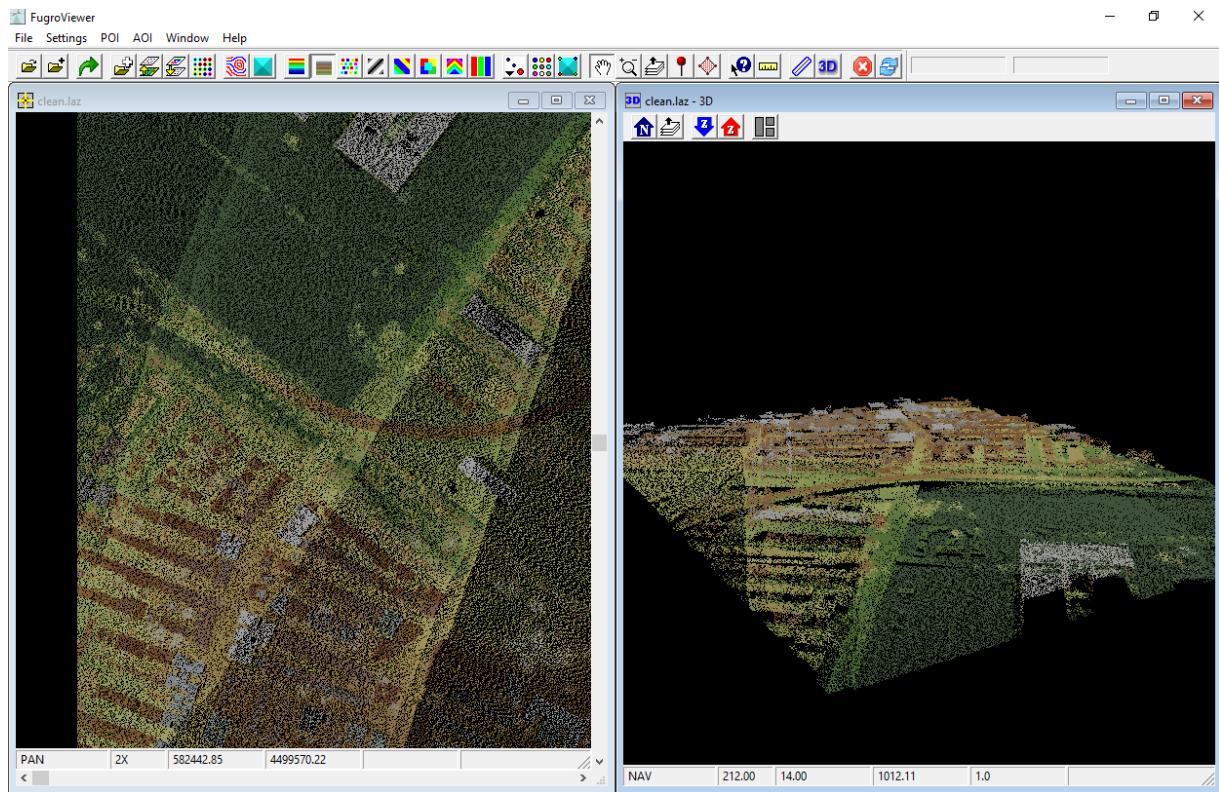
Invoke the following command, substituting accordingly, in your `Shell`:

```
pdal pipeline ./exercises/analysis/denoising/denoise.json
```

```
(pdalworkshop) $ pdal density ./exercises/analysis/density/uncompahgre.laz \
> -o ./exercises/analysis/density/density.sqlite \
> -f SQLite
(pdalworkshop) $
```

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 159) requires the entire set in memory to process. If you have really large files, you are going to need to `split` (page 258) 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 28) to compute a vector field of hexagons computed with *filters.hexbin* (page 265). It is a kind of simple interpolation, which we will use for visualization in **QGIS** (<http://qgis.org>).

Command

Invoke the following command, substituting accordingly, in your `Shell`:

```
1 pdal density ./exercises/analysis/density/uncompahgre.laz \
2 -o ./exercises/analysis/density/density.sqlite \
3 -f SQLite
```

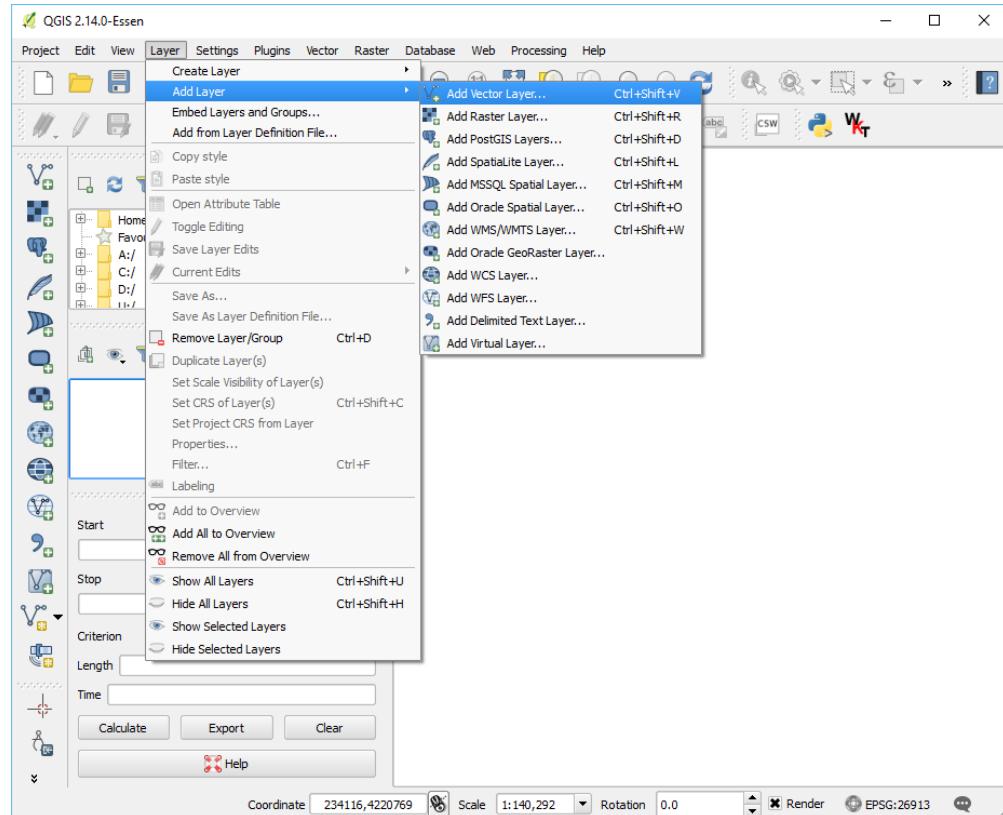
```
1 pdal density ./exercises/analysis/density/uncompahgre.laz ^
2 -o ./exercises/analysis/density/density.sqlite ^
3 -f SQLite
```

```
(pdalworkshop) C:\>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
(pdalworkshop) C:\>_
```

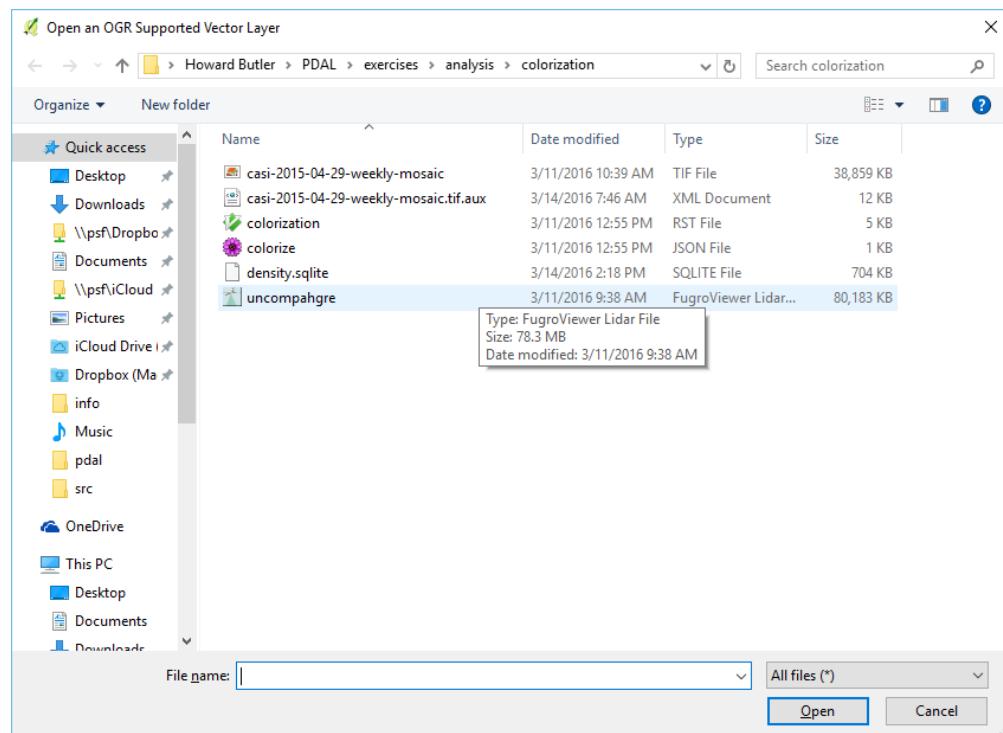
Visualization

The command uses GDAL to output a **SQLite** (<http://sqlite.org>) file containing hexagon polygons. We will now use **QGIS** (<http://qgis.org>) to visualize them.

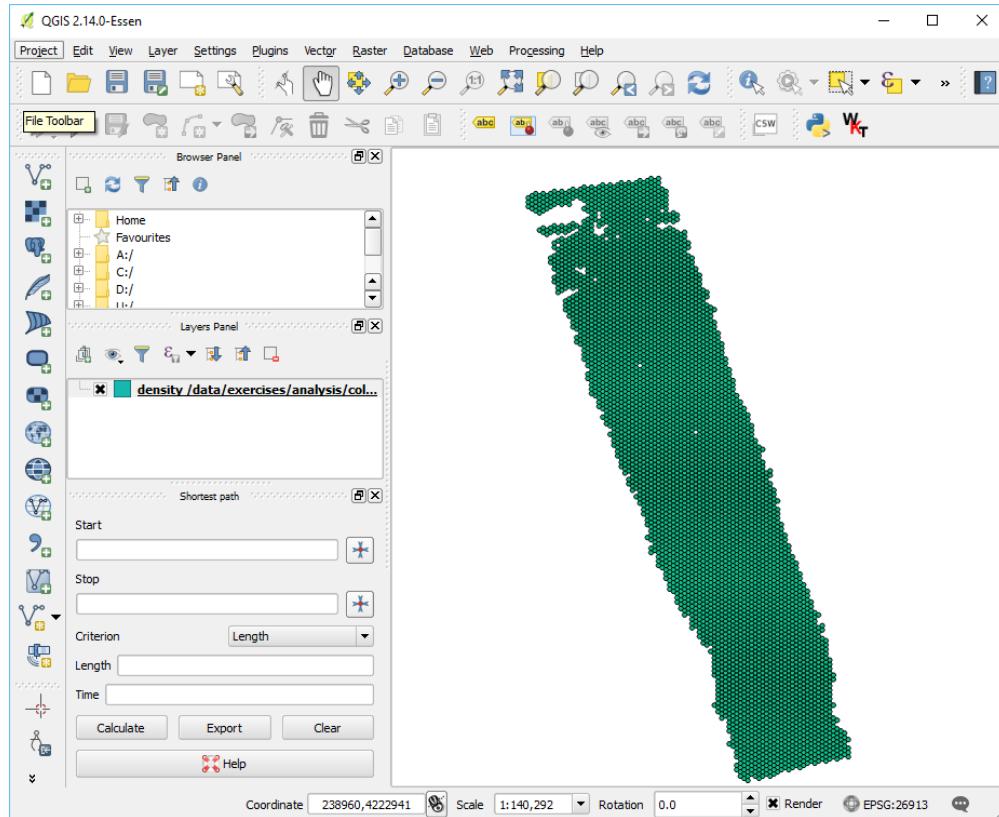
1. Add a vector layer



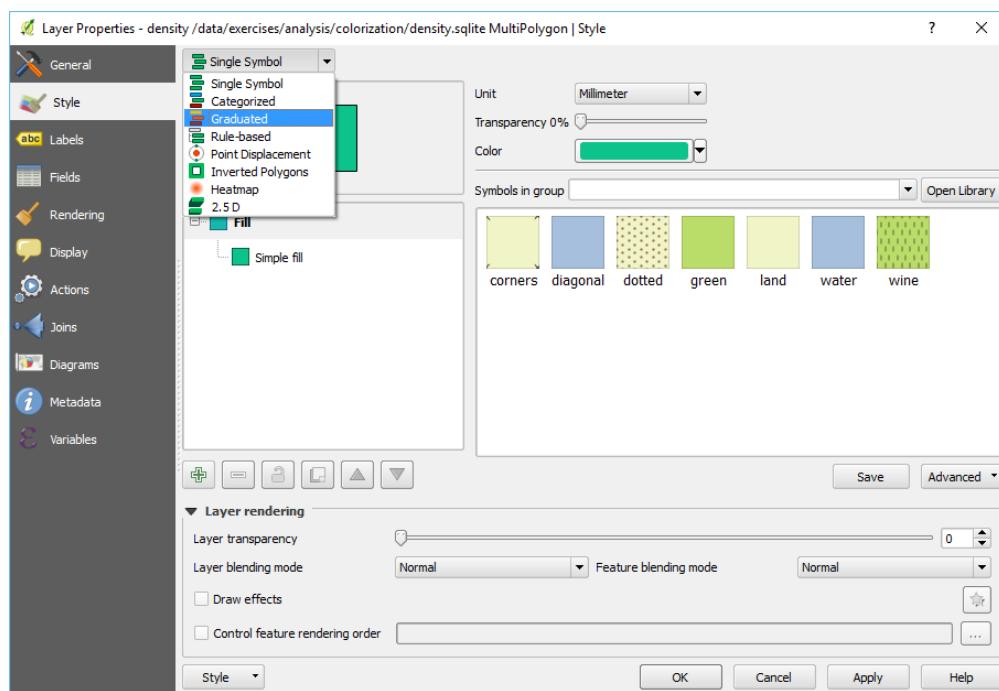
2. Navigate to the output directory



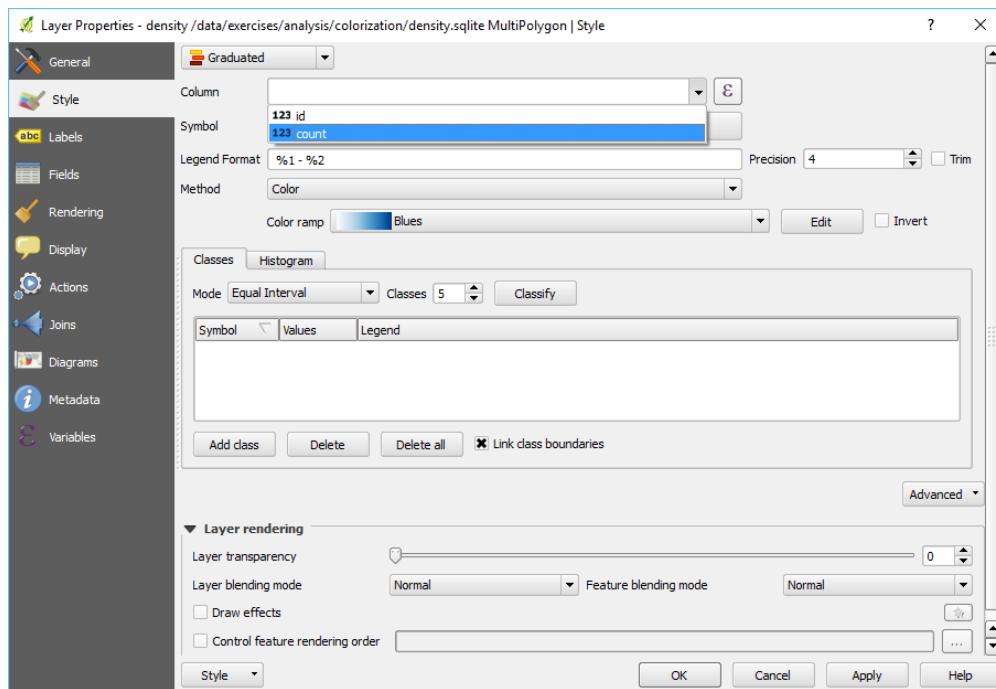
3. Add the density.sqlite file to the view



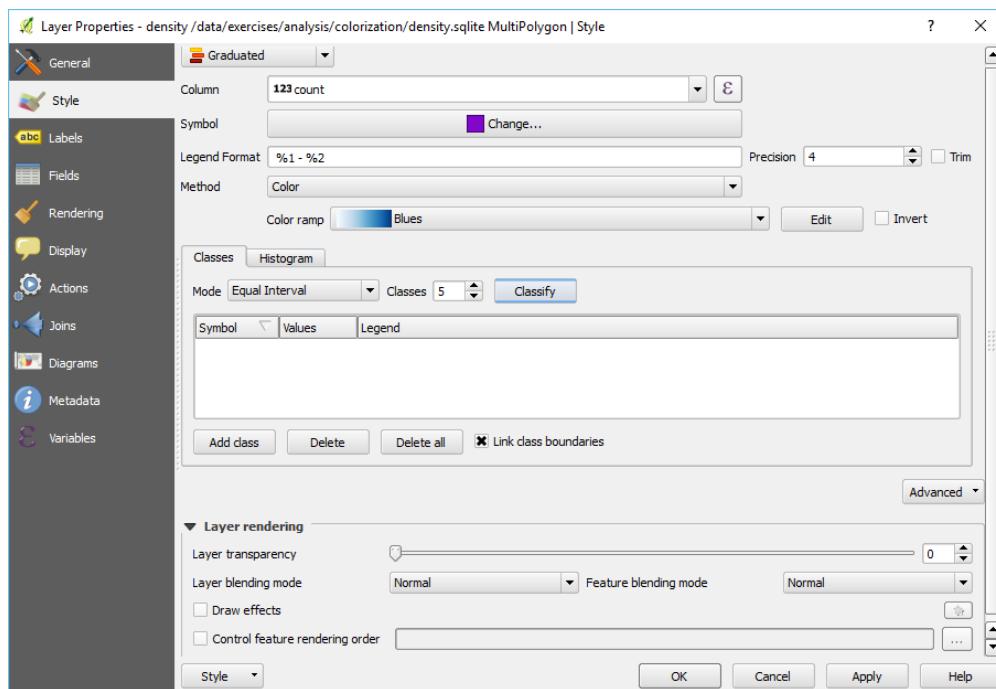
4. Right click on the density.sqlite layer in the *Layers* panel and then choose **Properties**.
5. Pick the **Graduated** drop down



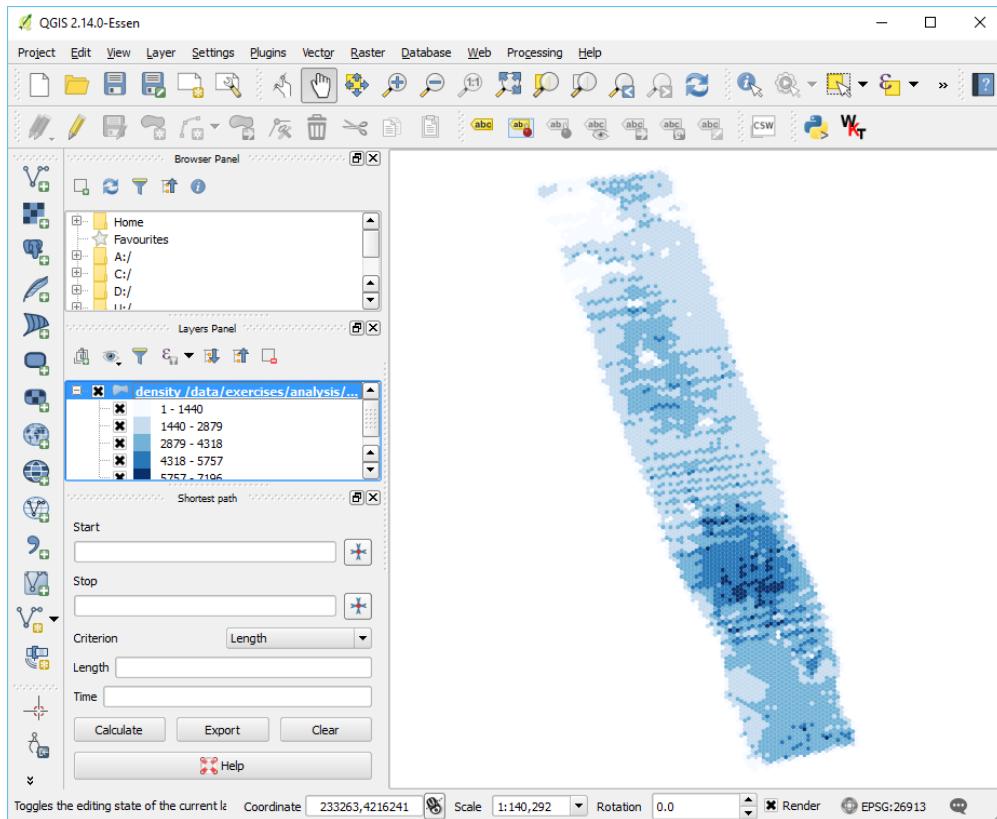
6. Choose the Count column to visualize



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 265).

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 40).

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 390) 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 234)
- Random using a combination of `filters.decimation` (page 231) and `filters.randomize` (page 213)
- Voxel using `filters.voxelgrid`

In this exercise, we are going to thin with the Poisson method, but the concept should operate similarly for the `filters.voxelgrid` approach.

Command

Invoke the following command, substituting accordingly, in your *Conda Shell*:

```
1 pdal translate ./exercises/analysis/density/uncompahgre.laz \
2   ./exercises/analysis/thinning/uncompahgre-thin.laz \
3   sample --filters.sample.radius=20
```

```
1 pdal translate ./exercises/analysis/density/uncompahgre.laz ^
2   ./exercises/analysis/thinning/uncompahgre-thin.laz ^
3   sample --filters.sample.radius=20
```

```
(pdalworkshop) $pdal translate ./exercises/analysis/density/uncompahgre.laz \
> ./exercises/analysis/thinning/uncompahgre-thin.laz \
> sample --filters.sample.radius=20
(pdalworkshop) $
```

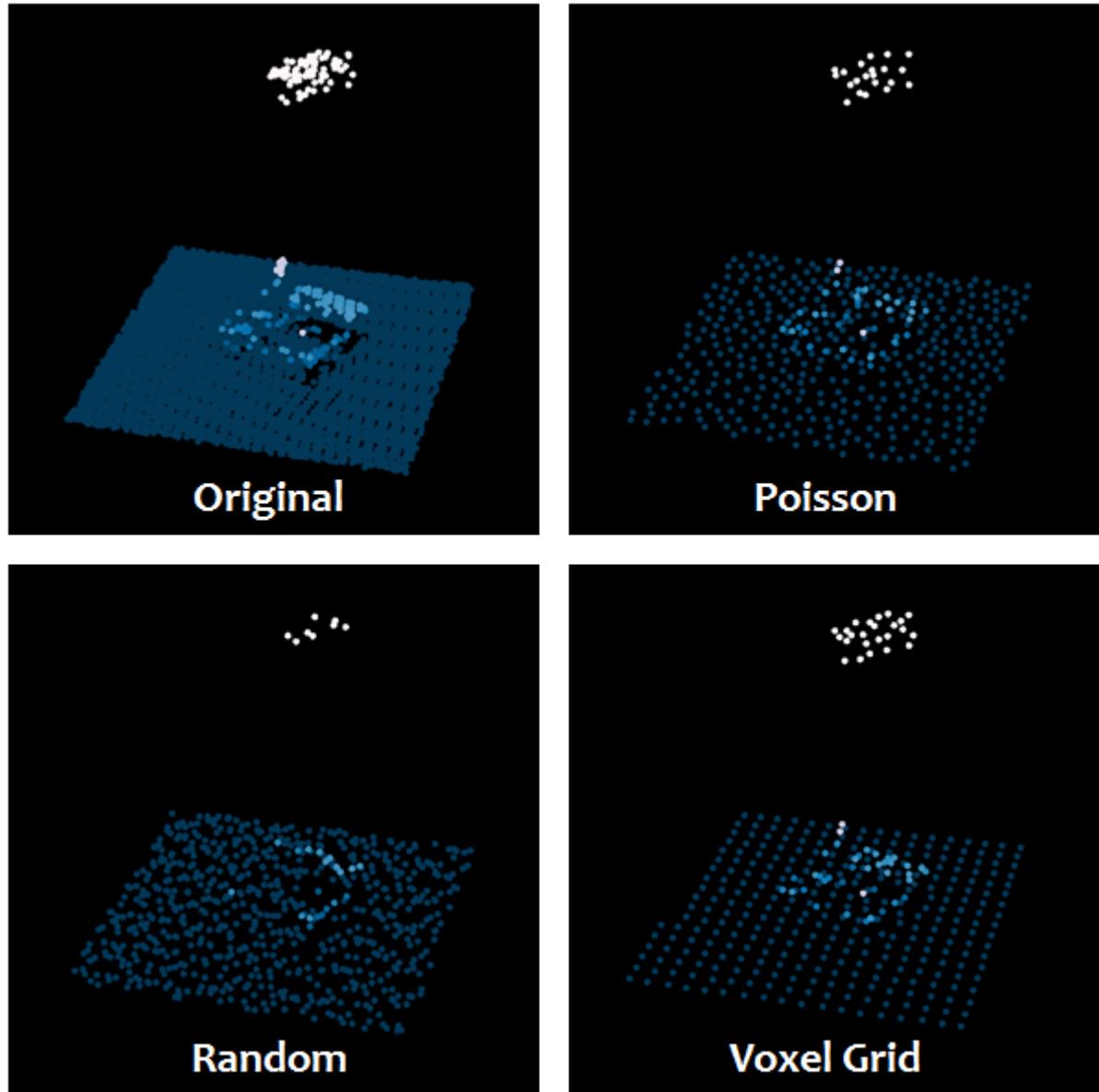


Fig. 3: Thinning strategies available in PDAL

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.

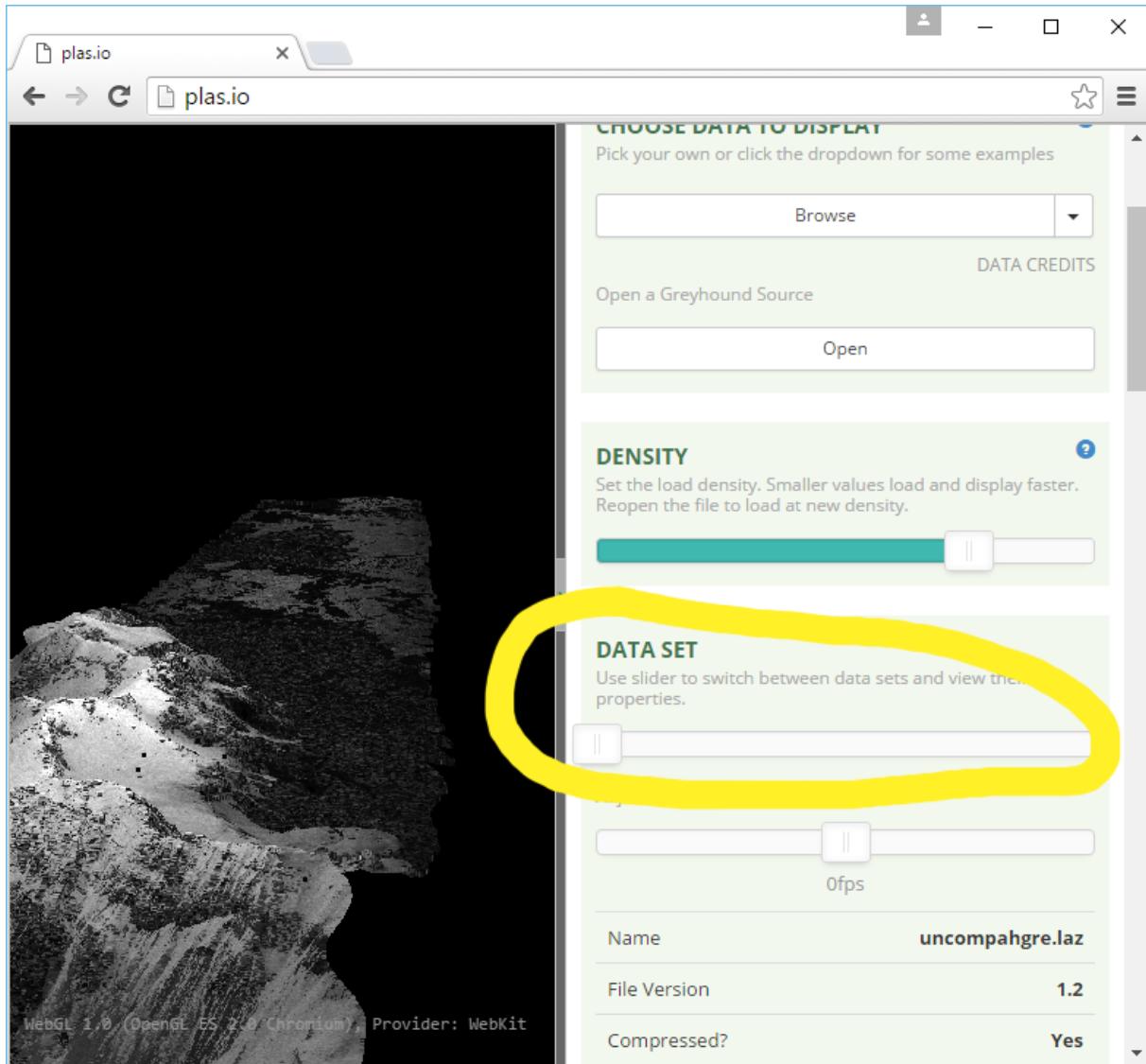


Fig. 4: Selecting multiple data sets in <http://plas.io>

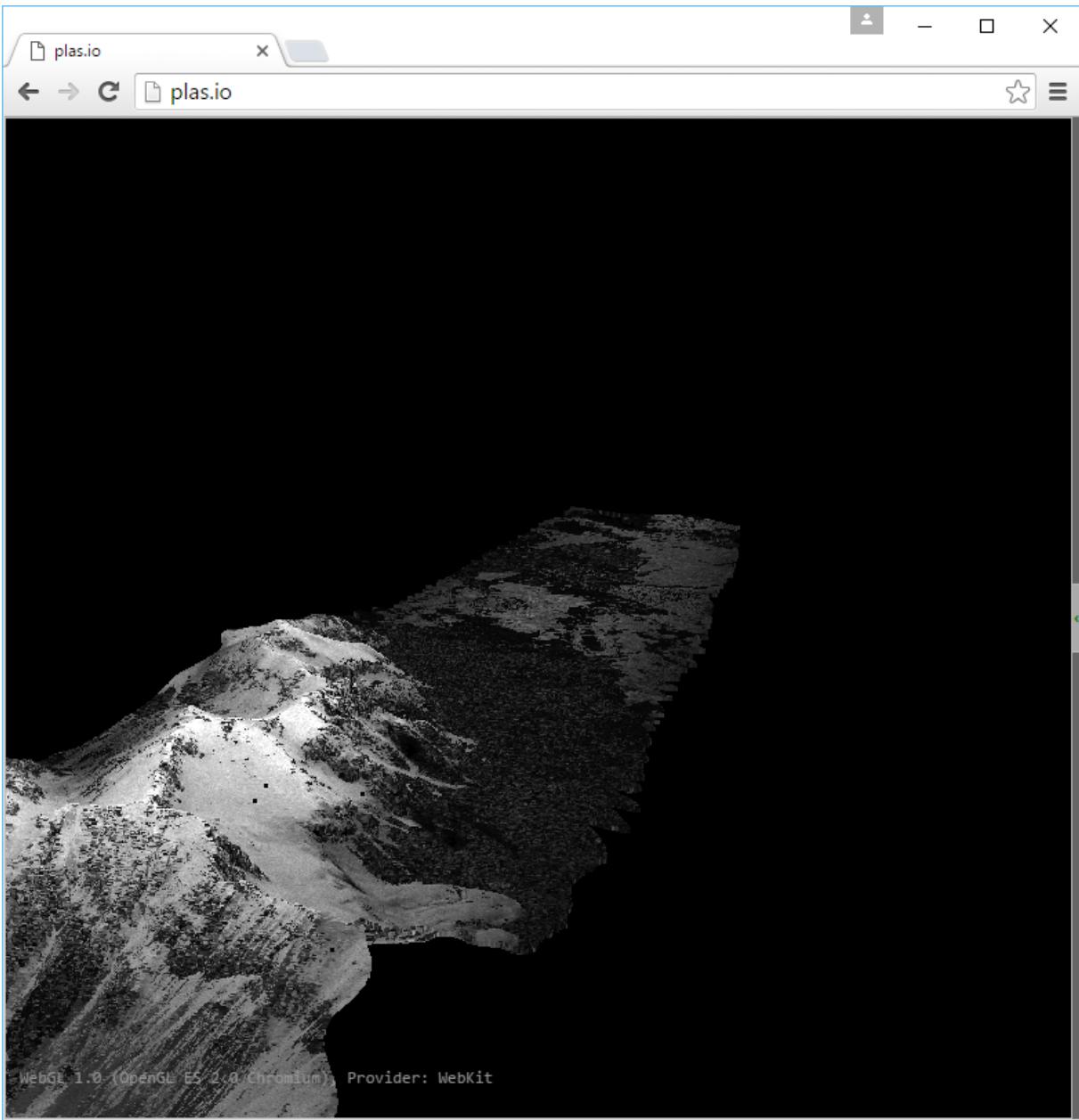


Fig. 5: Full resolution Uncompahgre data set

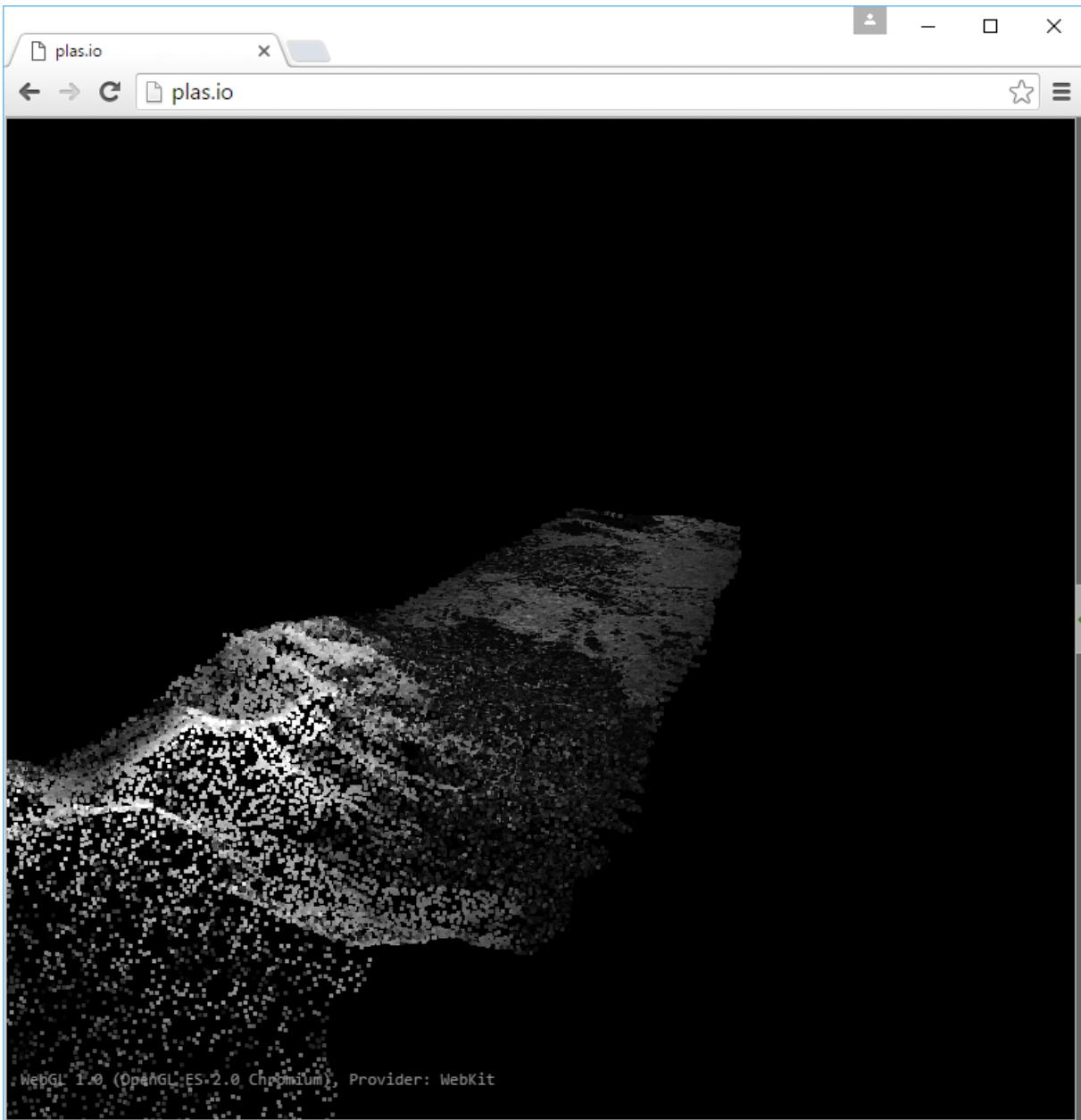


Fig. 6: Uncompahgre thinned at a radius of 20m

Notes

1. Poisson sampling is non-destructive. Points that are filtered with [filters.sample](#) (page 234) 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 `pcl_ground` tutorial on the PDAL website by Brad Chambers. You can find more detail and example invocations there.

Exercise

The primary input for [Digital Terrain Model](#)

(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](#)]

Command

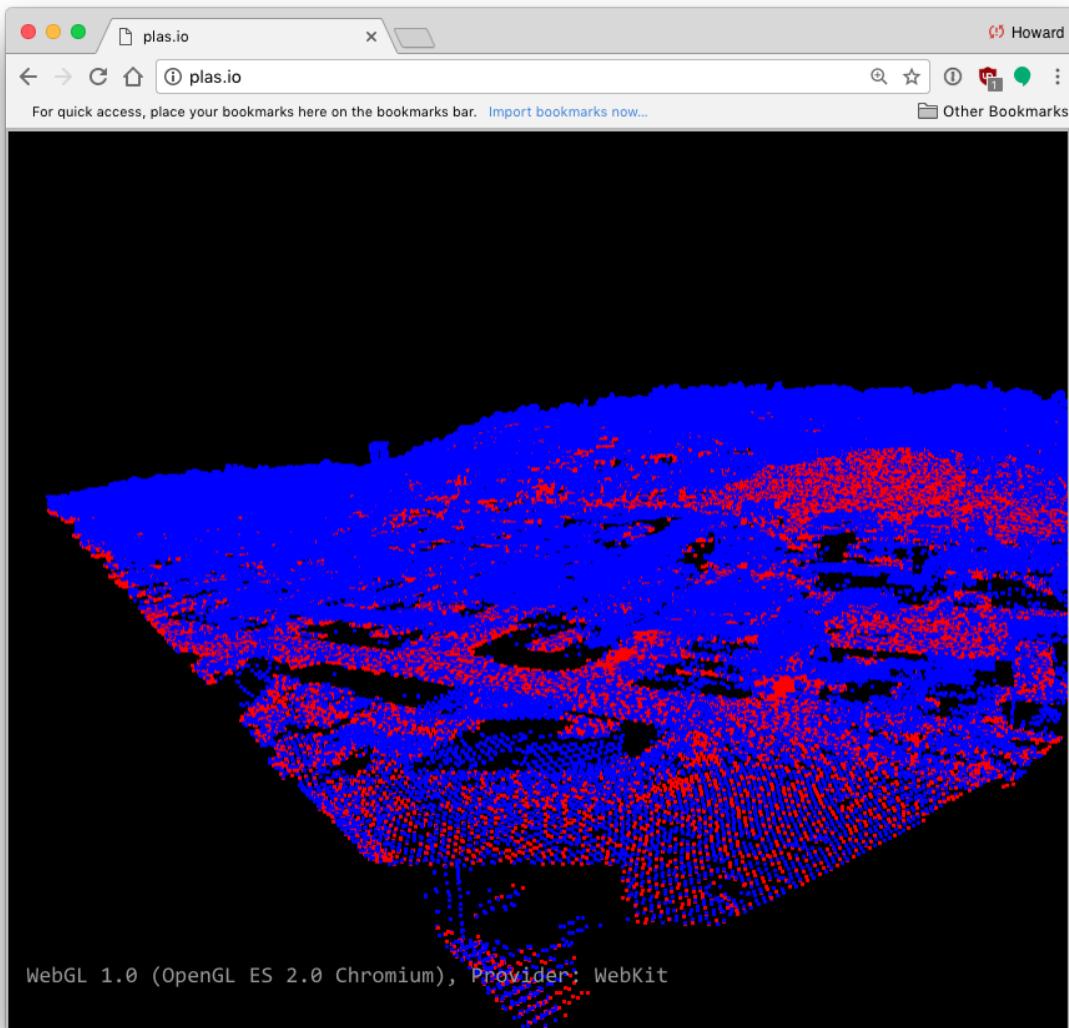
Invoke the following command, substituting accordingly, in your *Conda Shell*:

```
1 pdal translate ./exercises/analysis/ground/CSite1_orig-utm.laz \
2 -o ./exercises/analysis/ground/ground.laz \
3 smrf \
4 -v 4
```

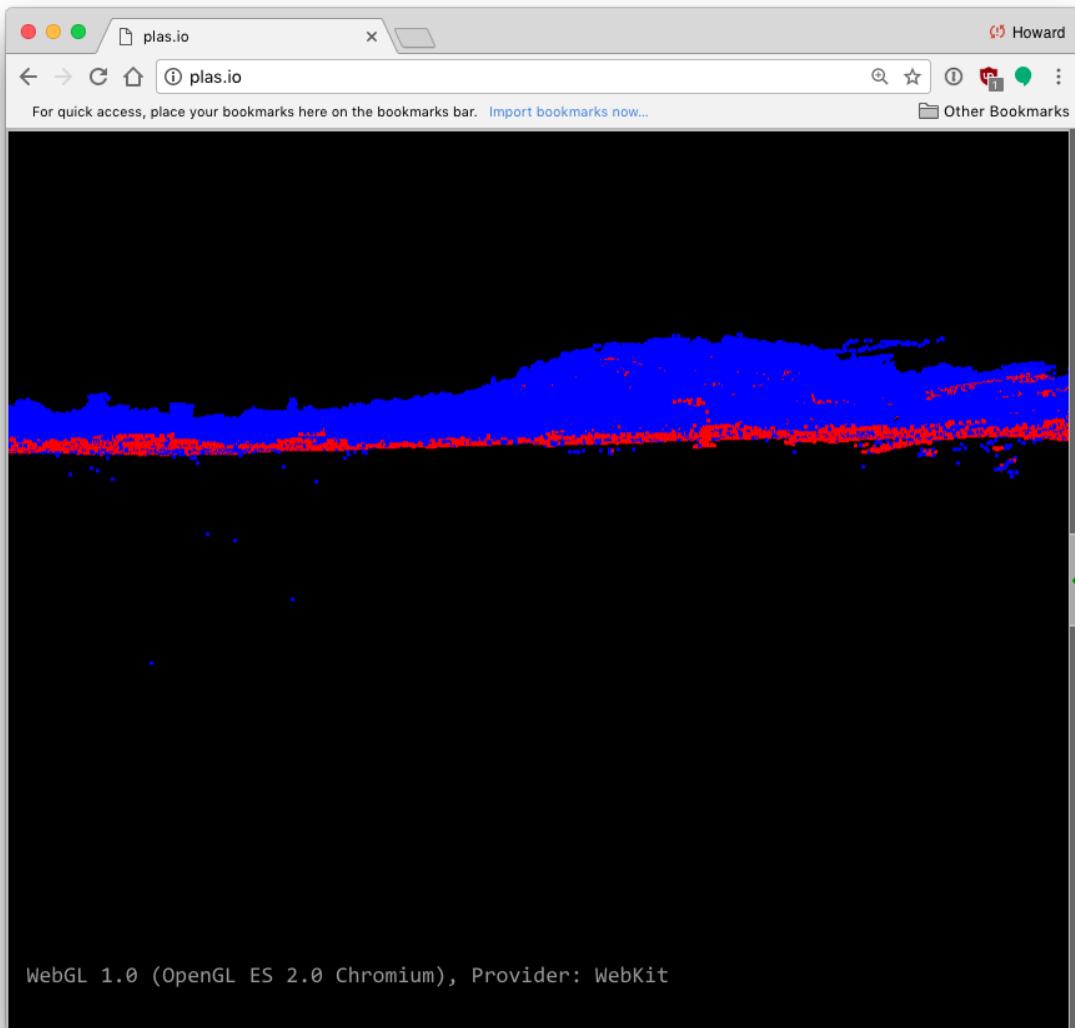
```
1 pdal translate ./exercises/analysis/ground/CSite1_orig-utm.laz ^
2 -o ./exercises/analysis/ground/ground.laz ^
3 smrf ^
4 -v 4
```

```
(pdalworkshop) $pdal translate ./exercises/analysis/ground/CSite1_orig-utm.laz \
> -o ./exercises/analysis/ground/ground.laz \
> smrf \
> -v 4
(PDAL Debug) Debugging...
(pdal translate readers.las Debug) GDAL debug: OGRSpatialReference::Validate: No root pointer.
(pdal translate readers.las Debug) GDAL debug: OGRSpatialReference::Validate: No root pointer.
(pdal translate readers.las Debug) GDAL debug: OGRSpatialReference::Validate: No root pointer.
(pdal translate Debug) Executing pipeline in standard mode.
(pdal translate filters.smrf Debug) progressiveFilter: radius = 1      767170 ground   4631 non-ground (0.60%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 1      576488 ground   195313 non-ground (25.31%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 2      519149 ground   252652 non-ground (32.74%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 3      492155 ground   279646 non-ground (36.23%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 4      473156 ground   298645 non-ground (38.69%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 5      454156 ground   317645 non-ground (41.16%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 6      433943 ground   337858 non-ground (43.78%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 7      414492 ground   357309 non-ground (46.30%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 8      399457 ground   372344 non-ground (48.24%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 9      388449 ground   383352 non-ground (49.67%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 10     382942 ground   388859 non-ground (50.38%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 11     379683 ground   392118 non-ground (50.81%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 12     377098 ground   394703 non-ground (51.14%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 13     374993 ground   396808 non-ground (51.41%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 14     373622 ground   398179 non-ground (51.59%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 15     372487 ground   399314 non-ground (51.74%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 16     372248 ground   399553 non-ground (51.77%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 17     371884 ground   399917 non-ground (51.82%)
(pdal translate filters.smrf Debug) progressiveFilter: radius = 18     371674 ground   400127 non-ground (51.84%)
(pdal translate writers.las Debug) Wrote 1366408 points to the LAS file
(pdalworkshop) $
```

As we can see, the algorithm does a great job of discriminating the points, but there's a few issues.



There's noise underneath the main surface that will cause us trouble when we generate a terrain surface.



Filtering

We do not yet have a satisfactory surface for generating a DTM. When we visualize the output of this ground operation, we notice there's still some noise. We can stack the call to SMRF with a call to a the *filters.outlier* technique we learned about in denoising.

1. Let us start by removing the non-ground data to just view the ground data:

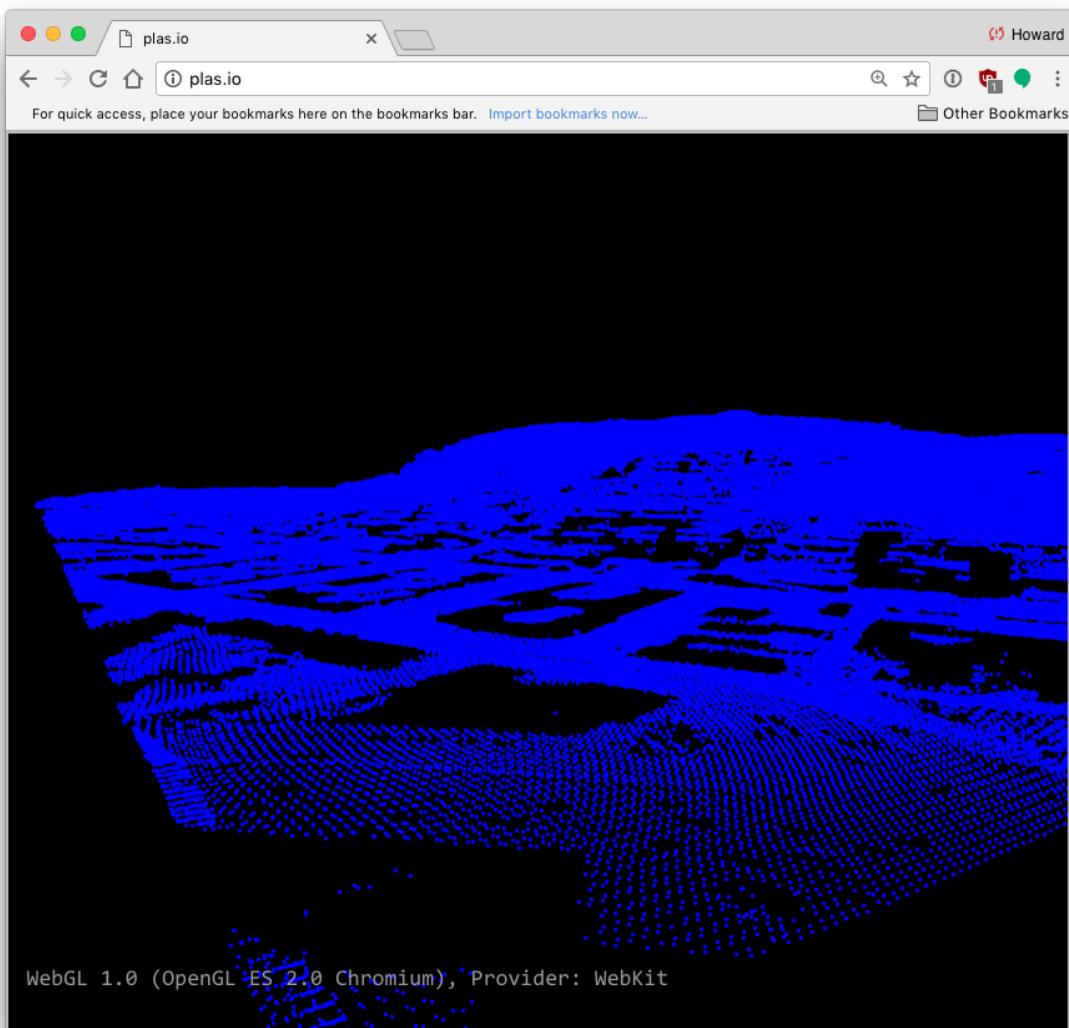
```
1 pdal translate \
2 ./exercises/analysis/ground/CSite1_orig-utm.laz \
3 -o ./exercises/analysis/ground/ground.laz \
4 smrf range \
```

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```
5 --filters.range.limits="Classification[2:2]" \
6 -v 4
```

```
1 pdal translate ^
2 ./exercises/analysis/ground/CSite1_orig-utm.laz ^
3 -o ./exercises/analysis/ground/ground.laz ^
4 Smrf range ^
5 --filters.range.limits="Classification[2:2]" ^
6 -v 4
```



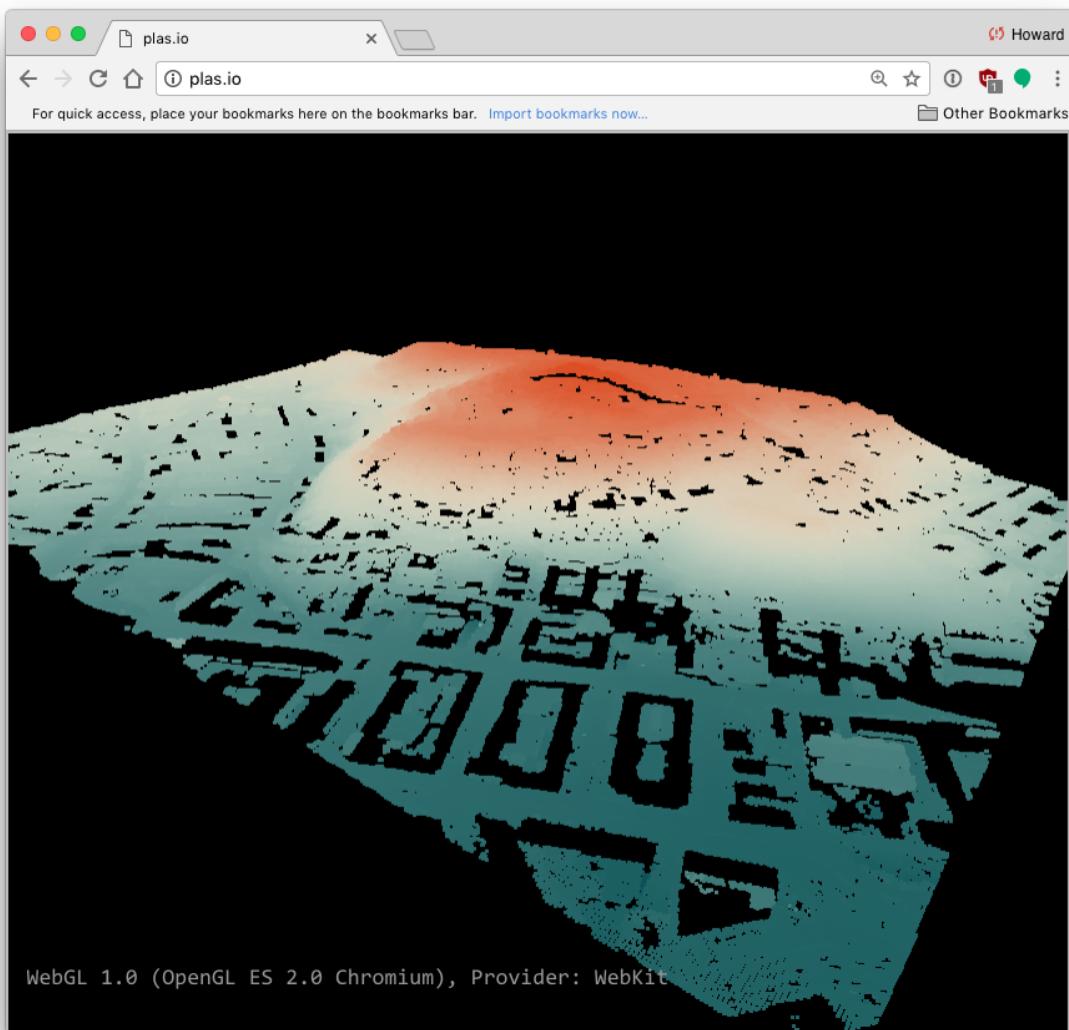
2. Now we will instead use the `translate` (page 42) command to stack the `filters.outlier` (page 159) and `filters.smrf` (page 155) stages:

```
1 pdal translate ./exercises/analysis/ground/CSite1_orig-utm.laz \
2 -o ./exercises/analysis/ground/denoised-ground-only.laz \
3 outlier smrf range \
4 --filters.outlier.method="statistical" \
5 --filters.outlier.mean_k=8 --filters.outlier.multiplier=3.0 \
6 --filters.smrf.ignore="Classification[7:7]" \
7 --filters.range.limits="Classification[2:2]" \
8 --writers.las.compression=true \
9 --verbose 4
```

```
1 pdal translate ./exercises/analysis/ground/CSite1_orig-utm.laz ^
2 -o ./exercises/analysis/ground/denoised-ground-only.laz ^
3 outlier smrf range ^
4 --filters.outlier.method="statistical" ^
5 --filters.outlier.mean_k=8 --filters.outlier.multiplier=3.0 ^
6 --filters.smrf.ignore="Classification[7:7]" ^
7 --filters.range.limits="Classification[2:2]" ^
8 --writers.las.compression=true ^
9 --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 SMRF processing with the ignore option. Finally, we add a range filter to extract only the ground returns (i.e., Classification value of 2).

The result is a more accurate representation of the ground returns.



Generating a DTM

This exercise uses PDAL to generate an elevation model surface using the output from the *Identifying ground* (page 400) exercise, PDAL's *writers.gdal* (page 121) 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 400) exercise. Please produce that file by following that exercise before starting this one.

Command

Invoke the following command, substituting accordingly, in your *Conda Shell*:

PDAL capability to generate rasterized output is provided by the [`writers.gdal`](#) (page 121) stage. There is no [*application*](#) (page 25) to drive this stage, and we must use a pipeline.

Pipeline breakdown

```
{  
  "pipeline": [  
    "./exercises/analysis/ground/denoised-ground-only.laz",  
    {  
      "filename": "./exercises/analysis/dtm/dtm.tif",  
      "gdaldriver": "GTiff",  
      "output_type": "all",  
      "resolution": "2.0",  
      "type": "writers.gdal"  
    }  
  ]  
}
```

Note: This pipeline is available in your workshop materials in the `./exercises/analysis/dtm/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 400) exercise.

2. `writers.gdal`

The *writers.gdal* (page 121) writer that bins the point cloud data into an elevation surface.

Execution

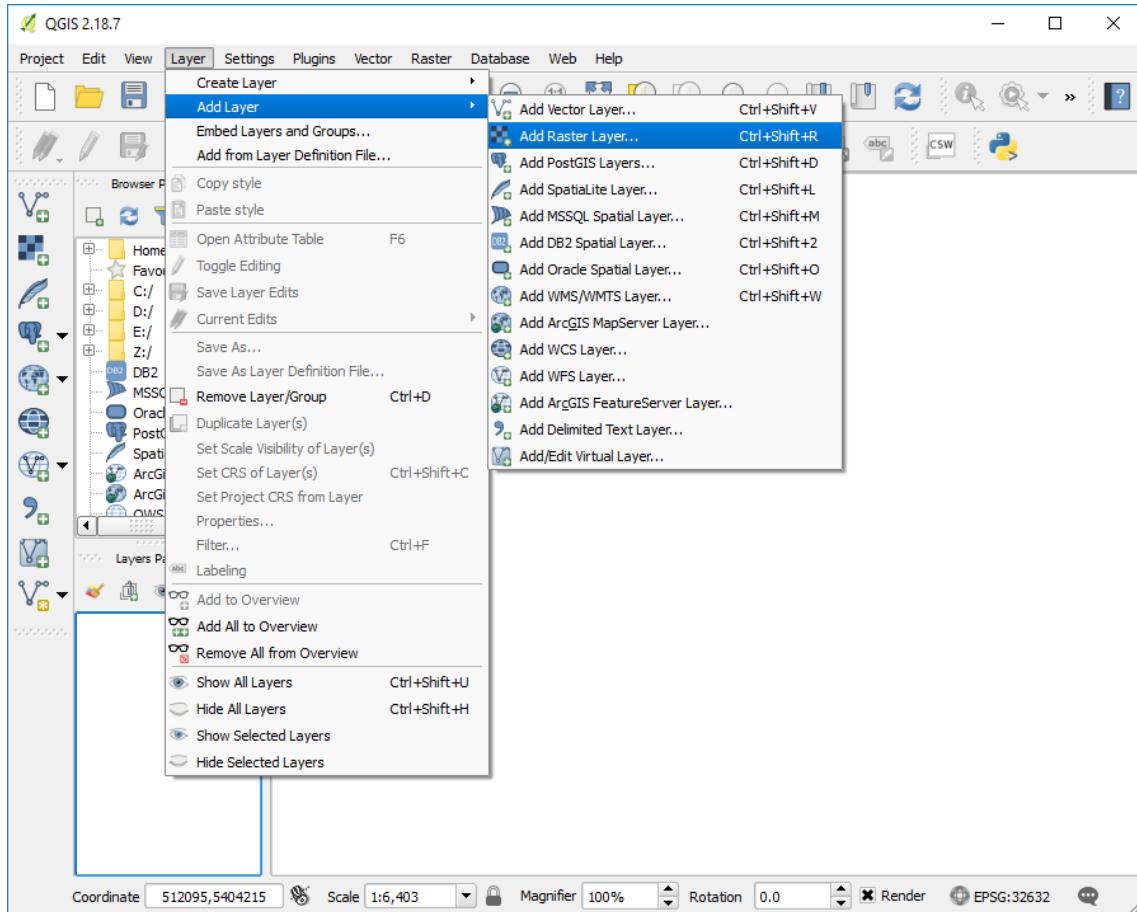
```
1 pdal pipeline ./exercises/analysis/dtm/gdal.json
```

```
(pdalworkshop) $ pdal pipeline ./exercises/analysis/dtm/gdal.json  
(pdalworkshop) $
```

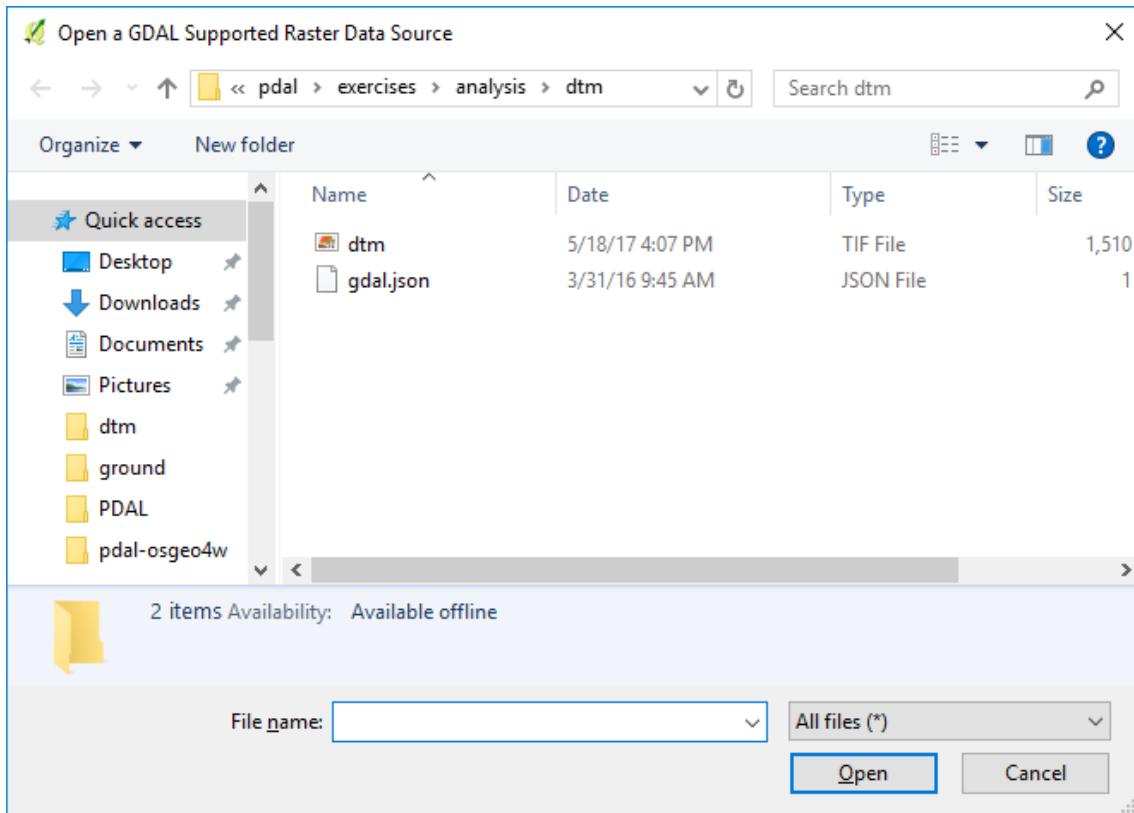
Visualization

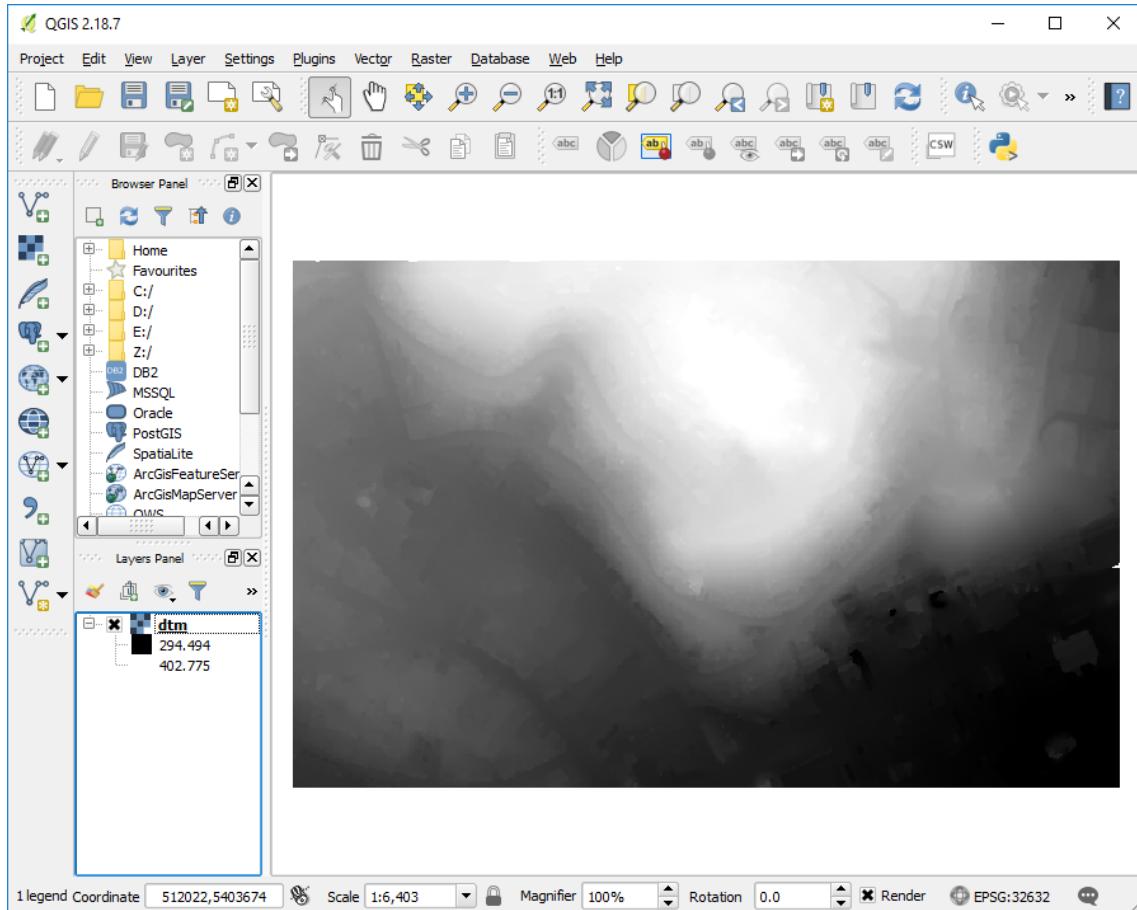
Something happened, and some files were written, but we cannot really see what was produced. Let us use qgis to visualize the output.

1. Open qgis and *Add Raster Layer*:

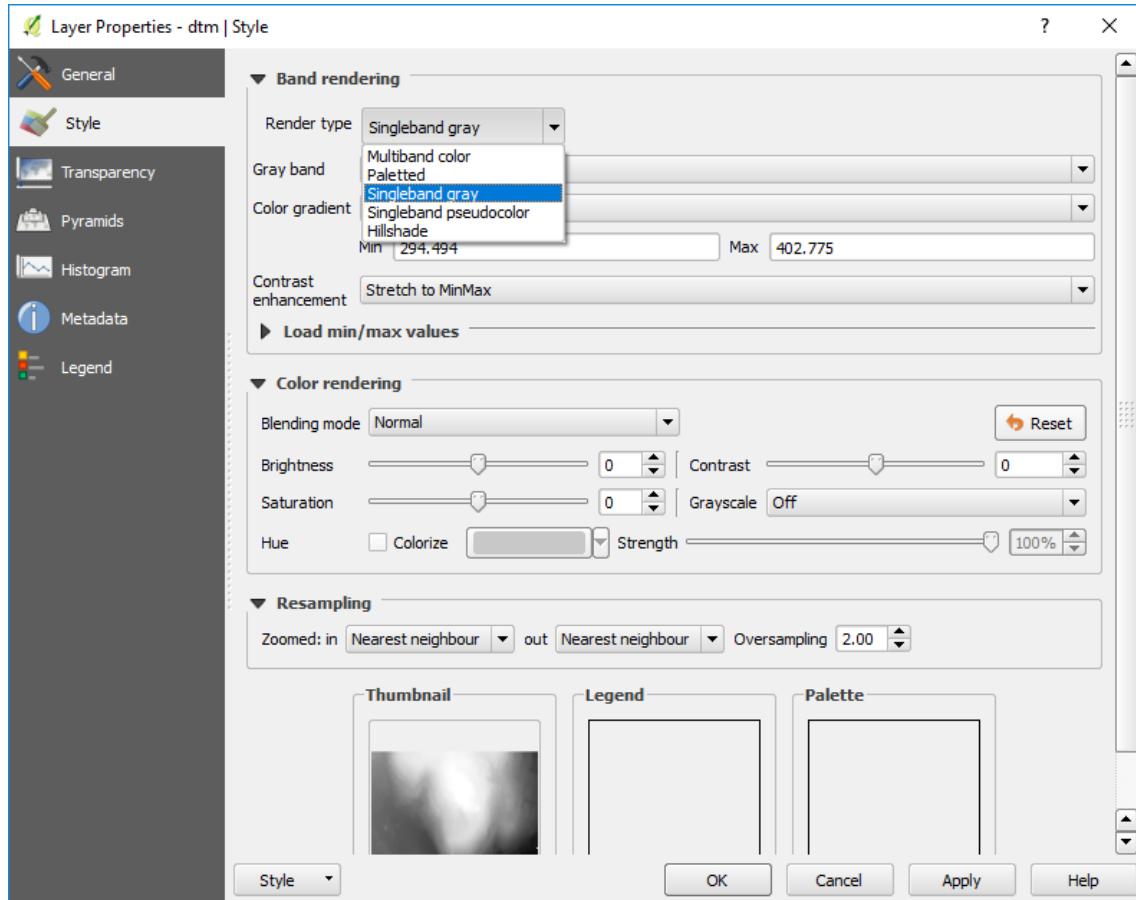


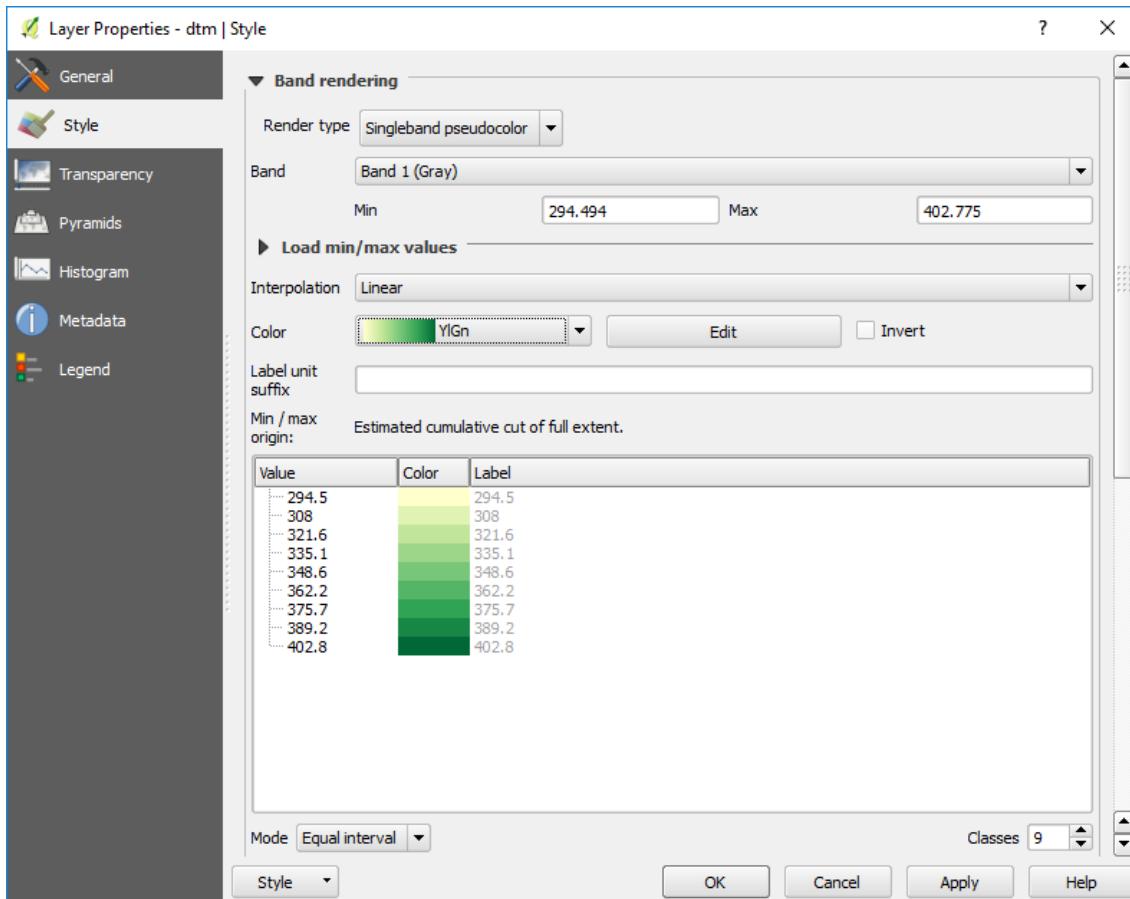
2. Add the *dtm.tif* file from your `./exercises/analysis/dtm` directory.



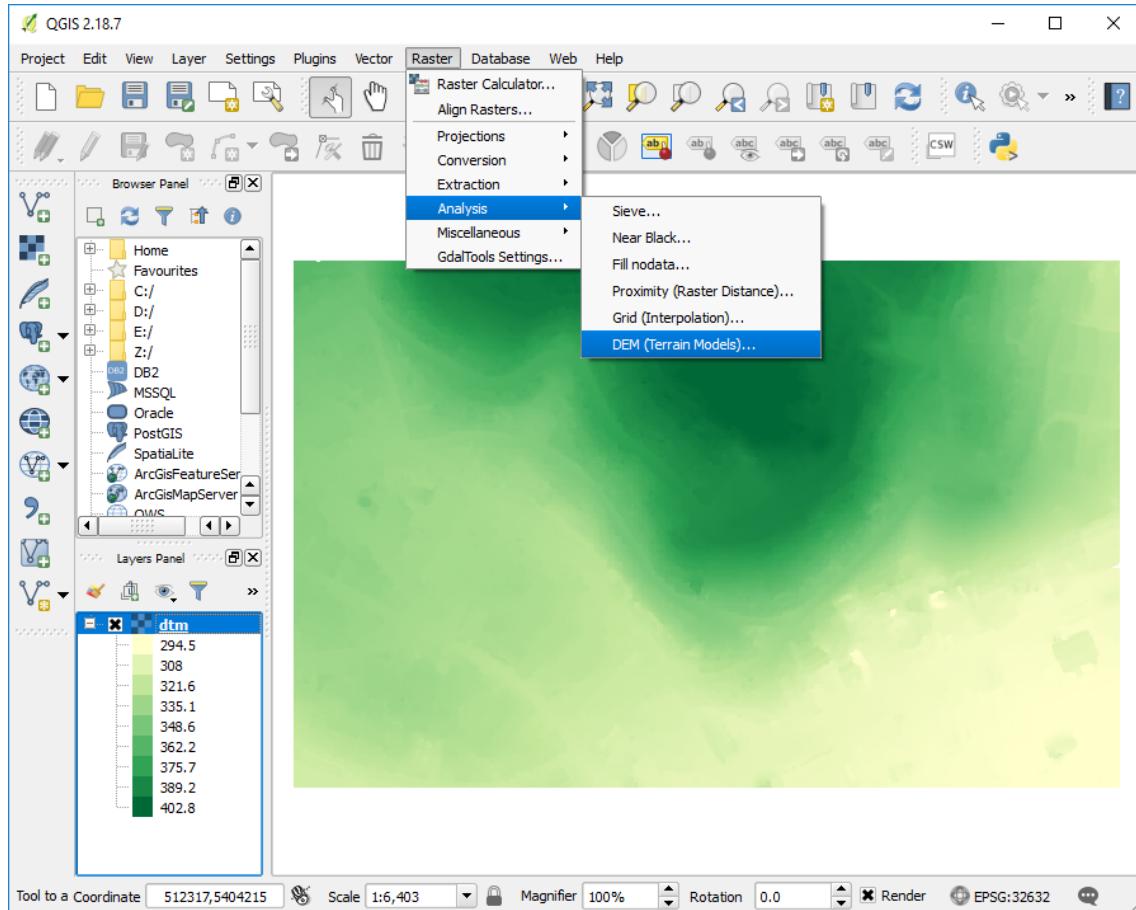


3. Classify the DTM by right-clicking on the *dtm.tif* and choosing *Properties*. Pick the pseudocolor rendering type, and then choose a color ramp and click *Classify*.

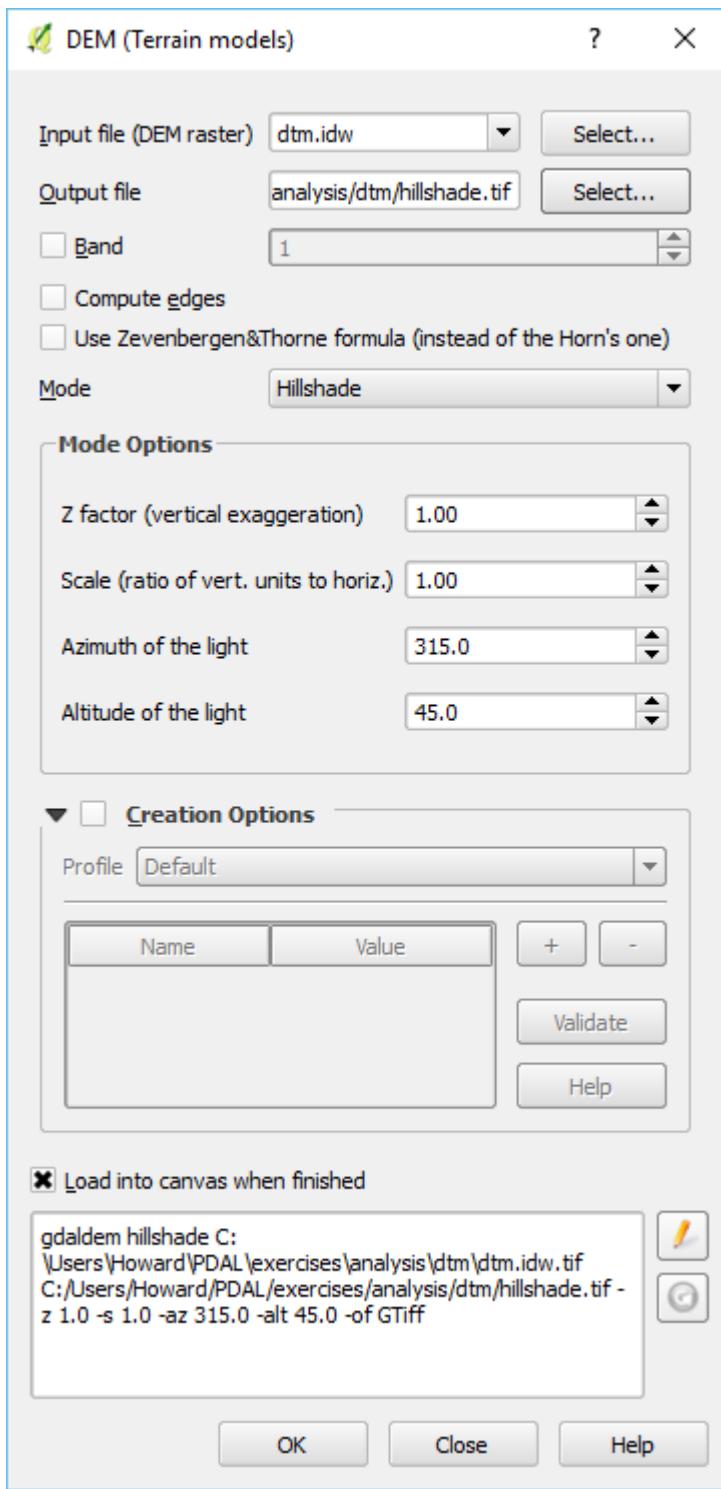




4. qgis provides access to [GDAL](http://gdal.org/) (<http://gdal.org/>) processing tools, and we are going to use that to create a hillshade of our surface. Choose *Raster->Analysis->Dem*:



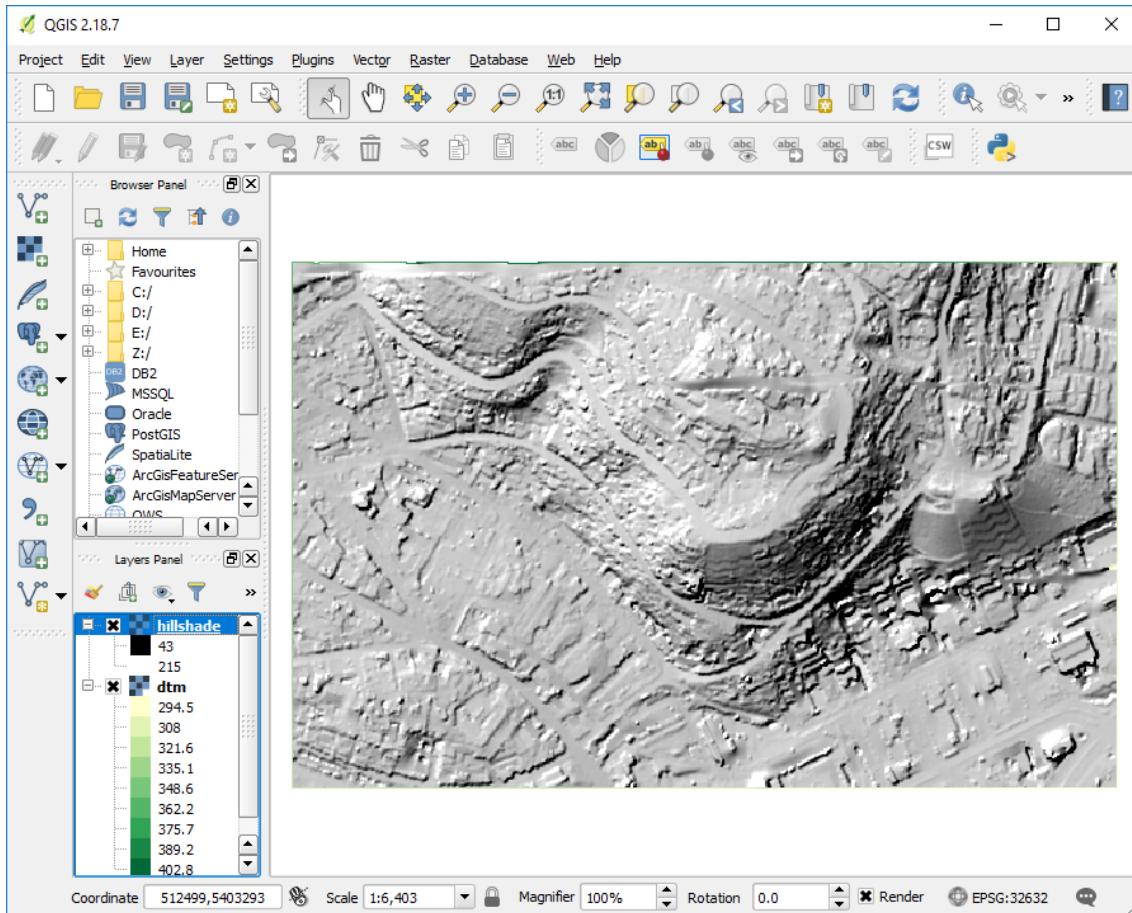
5. Click the window for the *Output file* and select a location to save the `hillshade.tif` file.



```
1 gdaldem hillshade ./exercises/analysis/dtm/dtm.tif \  
2 ./exercises/analysis/dtm/hillshade.tif \  
3 -z 1.0 -s 1.0 -az 315.0 -alt 45.0 \  
4 -of GTiff
```

```
1 gdaldem hillshade ./exercises/analysis/dtm/dtm.tif ^
2 ./exercises/analysis/dtm/hillshade.tif ^
3 -z 1.0 -s 1.0 -az 315.0 -alt 45.0 ^
4 -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 DEM tools, is a very powerful command line utility you can use for processing data.
2. `writers.gdal` (page 121) can be used for large data, but it does not interpolate a typical TIN (https://en.wikipedia.org/wiki/Triangulated_irregular_network) surface model.

Creating surface meshes

This exercise uses PDAL to create surface meshes. PDAL is able to use a number of meshing filters: <https://pdal.io/stages/filters.html#mesh>. Three of these are ‘in the box’, without needing plugins compiled. These are 2D Delaunay triangulation, Greedy projection meshing and Poisson surface meshing.

In this exercise we’ll create a Poisson surface mesh - a watertight isosurface - from our input point cloud.

Exercise

We will create mesh models of a building and its surrounds using an entwine data input source.

After running each command, the output *.ply* file can be viewed in Meshlab or CloudCompare.

See also:

PDAL implements Mischa Kazhdan’s Poisson surface reconstruction algorithm. For details see [\[Kazhdan2006\]](#)

Note: *writers.ply* will write out mesh vertices by default. In this exercise we set the attribute *faces="true"*. Try using the *ply* writer without it. Also, if you’re using a machine with a lot of processing power, try increasing the *depth* parameter for a more detailed mesh.

Command

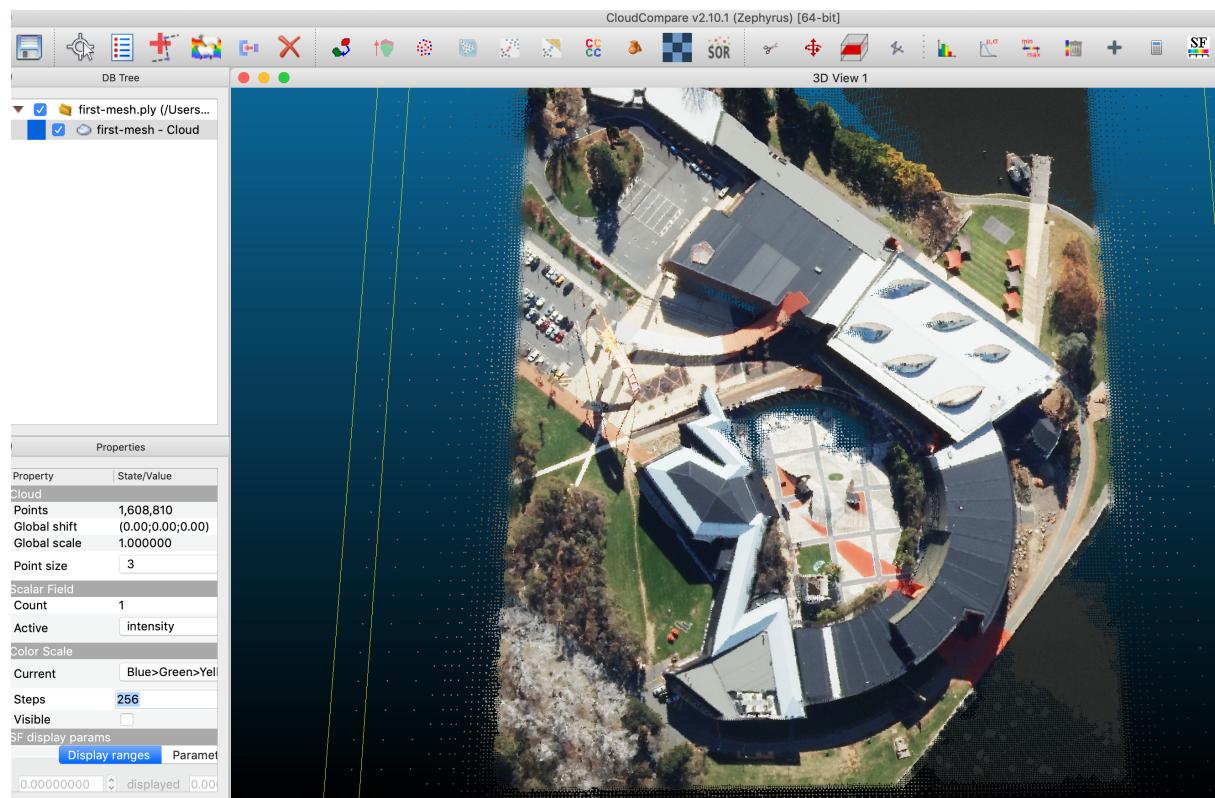
Invoke the following command, substituting accordingly, in your *Conda Shell*:

```
1 pdal translate -i ept://http://act-2015-rgb.s3.amazonaws.com \
2   -o ./exercises/analysis/meshing/first-mesh.ply \
3   poisson --filters.poisson.depth=16 \
4   --readers.ept.bounds="([692738, 692967], [6092255,6092562])" \
5   --verbose 4
```

```
1 pdal translate -i ept://http://act-2015-rgb.s3.amazonaws.com ^
2   -o ./exercises/analysis/meshing/first-mesh.ply ^
3   poisson --filters.poisson.depth=16 ^
4   --readers.ept.bounds="([692738, 692967], [6092255,6092562])" ^
5   --verbose 4
```

```
(pdalworkshop) $ pdal translate -i ept://http://act-2015-rgb.s3.amazonaws.com \
> -o ./exercises/analysis/meshing/first-mesh.ply \
> poisson --filters.poisson.depth=16 \
> --readers.ept.bounds="([692738, 692967], [6092255,6092562])" \
> --verbose 2
# Read input into tree:
#   Got kernel density:
#     Got normal field:
#       Finalized tree:
#   Set FEM constraints:
#Set point constraints:
Got average:
(pdalworkshop) $
```

You can view the mesh in Cloud Compare, you should see something similar to



Filtering

If we want to just mesh a building, or just terrain, or both we can apply a *range* filter based on point classification. These data have ground labeled as class 2, and buildings as 6.

In this exercise we will create a poisson mesh surface of a building and the ground surrounding it, using the same data subset as above and adding a [filters.range](#) (page 250) stage to limit the set of points used in mesh creation.

Command

Invoke the following command, substituting accordingly, in your *Conda Shell*:

```

1 pdal translate -i ept://http://act-2015-rgb.s3.amazonaws.com \
2   -o ./exercises/analysis/meshing/building-exercise.ply \
3     range poisson \
4     --filters.range.limits="Classification[2:2],Classification[6:6]" \
5     --filters.poisson.depth=16 \
6     --readers.ept.bounds="([692738, 692967], [6092255,6092562])" \
7     --verbose 4

```

```

1 pdal translate -i ept://http://act-2015-rgb.s3.amazonaws.com ^
2   -o ./exercises/analysis/meshing/building-exercise.ply ^
3     range poisson ^
4     --filters.range.limits="Classification[2:2],Classification[6:6]" ^
5     --filters.poisson.depth=16 ^
6     --readers.ept.bounds="([692738, 692967], [6092255,6092562])" ^
7     --verbose 4

```

```

(pdalworkshop) $ pdal translate -i ept://http://act-2015-rgb.s3.amazonaws.com \
>   -o ./exercises/analysis/meshing/building-exercise.ply \
>     range poisson \
>     --filters.range.limits="Classification[2:2],Classification[6:6]" \
>     --filters.poisson.depth=16 \
>     --readers.ept.bounds="([692738, 692967], [6092255,6092562])" \
>     --verbose 2
# Read input into tree:
#   Got kernel density:
#     Got normal field:
#       Finalized tree:
# Set FEM constraints:
#Set point constraints:
Got average:
(pdalworkshop) $

```

Rasterizing Attributes

This exercise uses PDAL to generate a raster surface using a fully classified point cloud with PDAL's *writers.gdal* (page 121).

Exercise

Note: The exercise fetches its data from a [Entwine](https://entwine.io) (<https://entwine.io>) service that organizes the point cloud collection for the entire country of Denmark. You can view the data online at <http://potree.entwine.io/data/denmark.html>

Command

PDAL capability to generate rasterized output is provided by the *writers.gdal* (page 121) stage. There is no *application* (page 25) to drive this stage, and we must use a pipeline.

Pipeline breakdown

```
{  
  "pipeline": [  
    {  
      "type": "readers.ept",  
      "filename": "ept://http://na-c.entwine.io/dk/ept.json",  
      "bounds": "([1401016, 1410670], [7476527, 7484590])",  
      "resolution": 5  
    },  
    {  
      "type": "writers.gdal",  
      "filename": "denmark-classification.tif",  
      "dimension": "Classification",  
      "data_type": "uint16_t",  
      "output_type": "mean",  
      "resolution": 5  
    }  
  ]  
}
```

Note: This pipeline is available in your workshop materials in the `./exercises/analysis/dtm/dtm.json` file. Make sure to edit the filenames to match your paths.

1. Reader

```
{  
    "type": "readers.ept",  
    "filename": "ept://http://na-c.entwine.io/dk/ept.json",  
    "bounds": "([1401016, 1410670], [7476527, 7484590])",  
    "resolution": 5  
},
```

The data is read from a EPT resource that contains the Denmark data. We're going to download a small patch of data by the Copenhagen airport area that is limited to a spatial resolution of 5m.

2. writers.gdal

The `writers.gdal` (page 121) 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": 5  
}
```

Execution

Issue the `pipeline` (page 47) operation to execute the interpolation:

```
pdal pipeline ./exercises/analysis/rasterize/classification.json -v 3
```

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

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```
{
    "type": "readers.ept",
    "filename": "ept://http://na-c.entwine.io/dk/ept.json",
    "bounds": "([1401016, 1410670], [7476527, 7484590])",
    "resolution": 5
},
{
    "type": "writers.gdal",
    "filename": "denmark-classification.tif",
    "dimension": "Classification",
    "data_type": "uint16_t",
    "output_type": "mean",
    "resolution": 5
}
]
```

```
(pdalworkshop) $ pdal pipeline ./exercises/analysis/rasterize/classification.json -v 3
(PDAL Debug) Debugging...
(Pdal pipeline readers.ept Debug) Endpoint: http://na-c.entwine.io/dk/
Got EPT info
PROJ["WGS 84 / Pseudo-Mercator", GEOCS["WGS 84", DATUM["WGS_1984", SPHEROID["WGS 84", 6378137, 298.25223563, AUTHORITY["EPSG", "7030"]]], AUTHORITY["EPSG", "6326"]], PRIMEM["Greenwich", 0, AUTHORITY["EPSG", "8901"]], UNIT["degree", 0.017453292519943, AUTHORITY["EPSG", "9122"]], AUTHORITY["EPSG", "4326"]], PROJECTION["Mercator_1SP"], PARAMETER["central_meridian", 0], PARAMETER["scale_factor", 1], PARAMETER["false_easting", 0], PARAMETER["false_northing", 0], UNIT["metre", 1, AUTHORITY["EPSG", "9001"]], AXIS["X", EAST], AXIS["Y", NORTH], EXTENSION["PROJ4", "+proj=merc +a=6378137 +b=6378137 +lat_ts=0.0 +lon_0=0.0 +x_0=0.0 +y_0=0 +k=1.0 +units=m +nadgrids=@null +wktext +no_defs"], AUTHORITY["EPSG", "3857"]]
Root resolution: 3108.53
Query resolution: 10
Actual resolution: 6.07135
Depth end: 10
Query bounds: ([1102422, 1107468], [7762273, 7777901], [-1.797693134862316e+308, 1.797693134862316e+308])
Threads: 4
(Pdal pipeline readers.ept Debug) Registering dim X: double
(Pdal pipeline readers.ept Debug) Registering dim Y: double
(Pdal pipeline readers.ept Debug) Registering dim Z: double
(Pdal pipeline readers.ept Debug) Registering dim Intensity: uint16_t
(Pdal pipeline readers.ept Debug) Registering dim ReturnNumber: uint8_t
(Pdal pipeline readers.ept Debug) Registering dim NumberOfReturns: uint8_t
(Pdal pipeline readers.ept Debug) Registering dim ScanDirectionFlag: uint8_t
(Pdal pipeline readers.ept Debug) Registering dim EdgeOfFlightLine: uint8_t
(Pdal pipeline readers.ept Debug) Registering dim Classification: uint8_t
(Pdal pipeline readers.ept Debug) Registering dim ScanAngleRank: float
(Pdal pipeline readers.ept Debug) Registering dim UserData: uint8_t
(Pdal pipeline readers.ept Debug) Registering dim PointSourceId: uint16_t
(Pdal pipeline readers.ept Debug) Registering dim GpsTime: double
(Pdal pipeline readers.ept Debug) Registering dim Red: uint16_t
(Pdal pipeline readers.ept Debug) Registering dim Green: uint16_t
(Pdal pipeline readers.ept Debug) Registering dim Blue: uint16_t
(Pdal pipeline Debug) Executing pipeline in standard mode.
(Pdal pipeline readers.ept Debug) Overlap nodes: 79
(Pdal pipeline readers.ept Debug) Overlap points: 7242657
(Pdal pipeline readers.ept Debug) Data 1/79: 0-0-0-0
(Pdal pipeline readers.ept Debug) Data 2/79: 1-0-1-1
(Pdal pipeline readers.ept Debug) Data 3/79: 2-1-2-2
(Pdal pipeline readers.ept Debug) Data 4/79: 3-2-5-4
(Pdal pipeline readers.ept Debug) Data 5/79: 4-4-11-8
(Pdal pipeline readers.ept Debug) Data 6/79: 5-8-22-16
(Pdal pipeline readers.ept Debug) Data 7/79: 5-8-23-16
(Pdal pipeline readers.ept Debug) Data 8/79: 6-16-45-32
(Pdal pipeline readers.ept Debug) Data 9/79: 6-16-46-32
```

Visualization



Basic interpolation of data with `writers.gdal` (page 121) will output raw classification values into the resulting raster file. We will need to add a color ramp to the data for a satisfactory preview.

Unfortunately, this does not give us a very satisfactory image to view. The reason is there is no color ramp associated with the file, and we're looking at pixel values with values from 0-31 according to the ASPRS LAS specification.

We want colors that correspond to the classification values a bit more directly. We can use a color ramp to assign explicit values. qgis 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 2 139 51 38 255 Ground
3 3 143 201 157 255 Low Veg
4 4 5 159 43 255 Med Veg
5 5 47 250 11 255 High Veg
6 6 209 151 25 255 Building
7 7 232 41 7 255 Low Point
8 8 197 0 204 255 reserved
```

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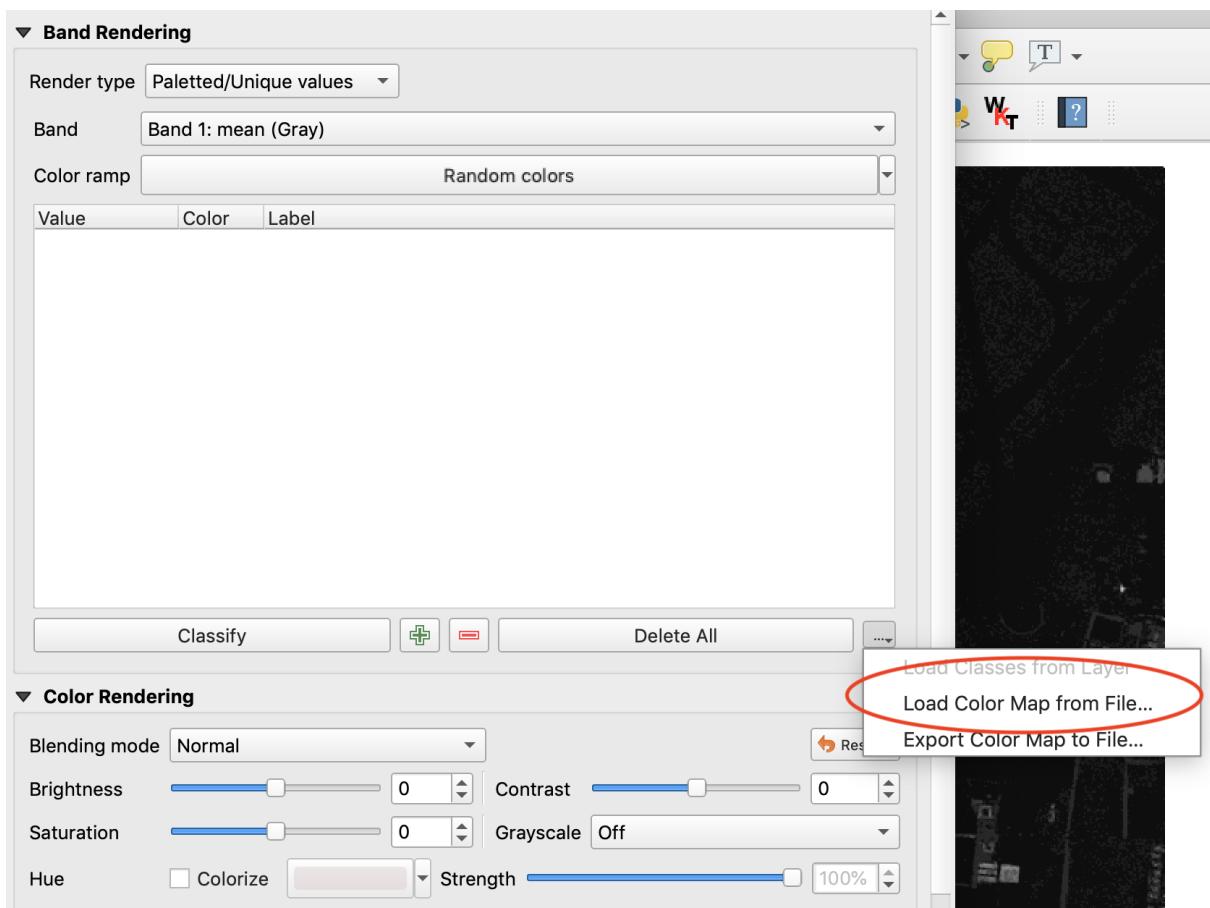
(continued from previous page)

```

9 26 44 240 255 Water
10 165 160 173 255 Rail
11 81 87 81 255 Road
12 203 210 73 255 Reserved
13 209 228 214 255 Wire - Guard (Shield)
14 160 168 231 255 Wire - Conductor (Phase)
15 220 213 164 255 Transmission Tower
16 214 211 143 255 Wire-Structure Connector (Insulator)
17 151 98 203 255 Bridge Deck
18 236 49 74 255 High Noise
19 185 103 45 255 Reserved
20 58 55 9 255 255 Reserved
21 76 46 58 255 255 Reserved
22 20 76 38 255 255 Reserved
23 78 92 32 255 255 Reserved
24 78 92 32 255 255 Reserved

```

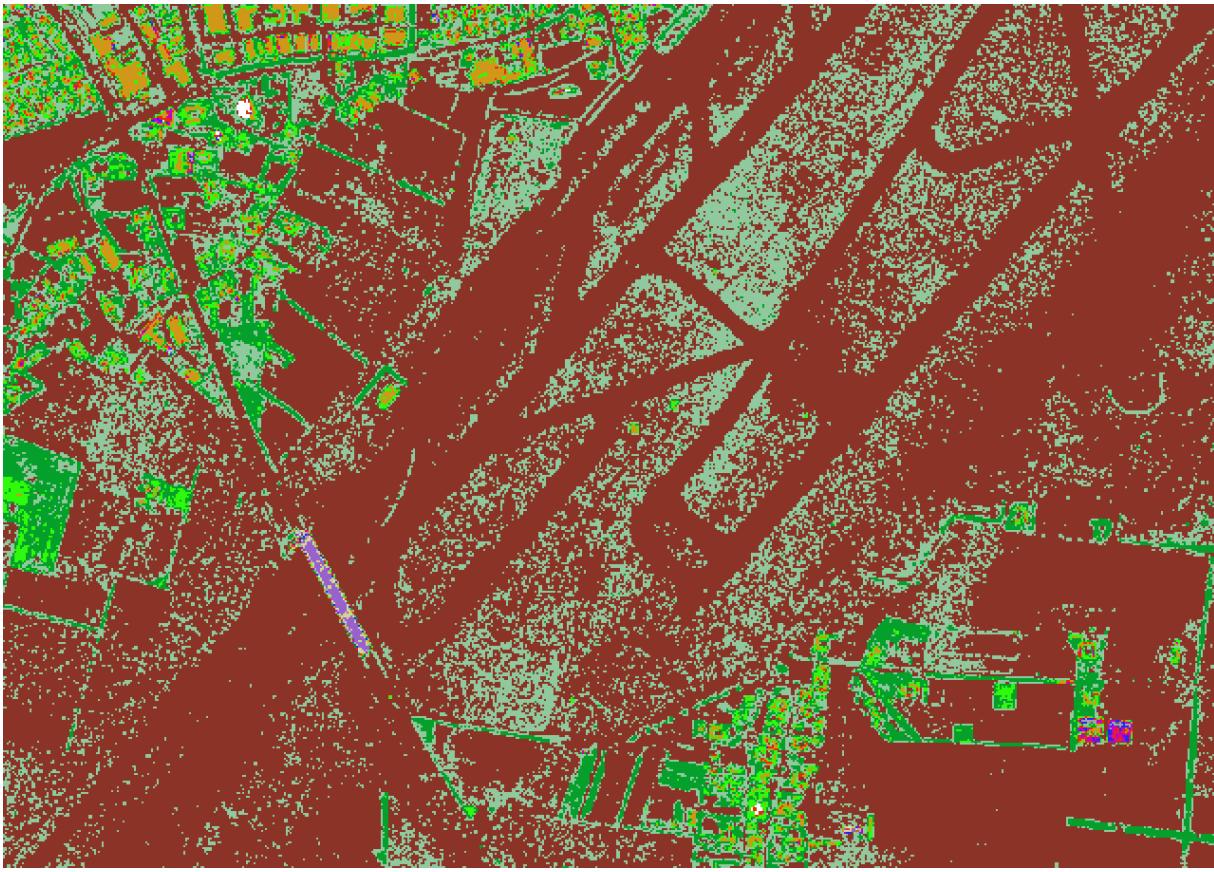
With this ramp, you can load the color values into QGIS as a color ramp if you change the layer to Palatted/Unique Values, and then load the color ramp file:



With the ramp, we can also use `gdaldem` (<http://www.gdal.org/gdaldem.html>) to apply it to a

new image:

```
1 gdaldem color-relief denmark-classification.tif ramp.txt classified-
  ↵-color.png -of PNG
```



Intensity

With PDAL's ability to override pipeline via commands, we can generate a relative intensity image:

```
1 pdal pipeline ./exercises/analysis/rasterize/classification.json \
2   --writers.gdal.dimension="Intensity" \
3   --writers.gdal.data_type="float" \
4   --writers.gdal.filename="intensity.tif" \
5   -v 3
6
7 gdal_translate intensity.tif intensity.png -of PNG
```

```
1 pdal pipeline ./exercises/analysis/rasterize/classification.json ^
2   --writers.gdal.dimension="Intensity" ^
```

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```
3 --writers.gdal.data_type="float" ^
4 --writers.gdal.filename="intensity.tif" ^
5 -v 3
6
7 gdal_translate intensity.tif intensity.png -of PNG
```

The same pipeline can be used to generate a preview image of the Intensity channel of the data by overriding pipeline arguments at the command line.



Notes

1. *writers.gdal* (page 121) 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 47) contains more information about overrides and organizing complex pipelines.

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 297) bindings and the [filters.python](#) (page 278) 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 297) 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 35).

Note: Python allows you to enhance and build functionality that you can use in the context of other [Pipeline](#) (page 47) operations.

PDAL Pipeline

We're going to create a PDAL [Pipeline](#) (page 47) to tell PDAL to run our Python script in a [filters.python](#) (page 278) stage.

```
1  {
2      "pipeline": [
3          {
4              "filename": "./exercises/python/athletic-fields.laz"
5          },
6          {
7              "type": "filters.python",
8              "function": "make_plot",
9              "module": "anything",
10             "pdalargs": "{\"filename\": \"./exercises/python/histogram."
11             "png\"}",
12             "script": "./exercises/python/histogram.py"
13         },
14     ]
```

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```
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/>). Store it as `histogram.py` next to the `histogram.json` Pipeline (page 47) 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
```

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```

20 # further processing.
21 def make_plot(ins, outs):
22
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                                     density=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

```

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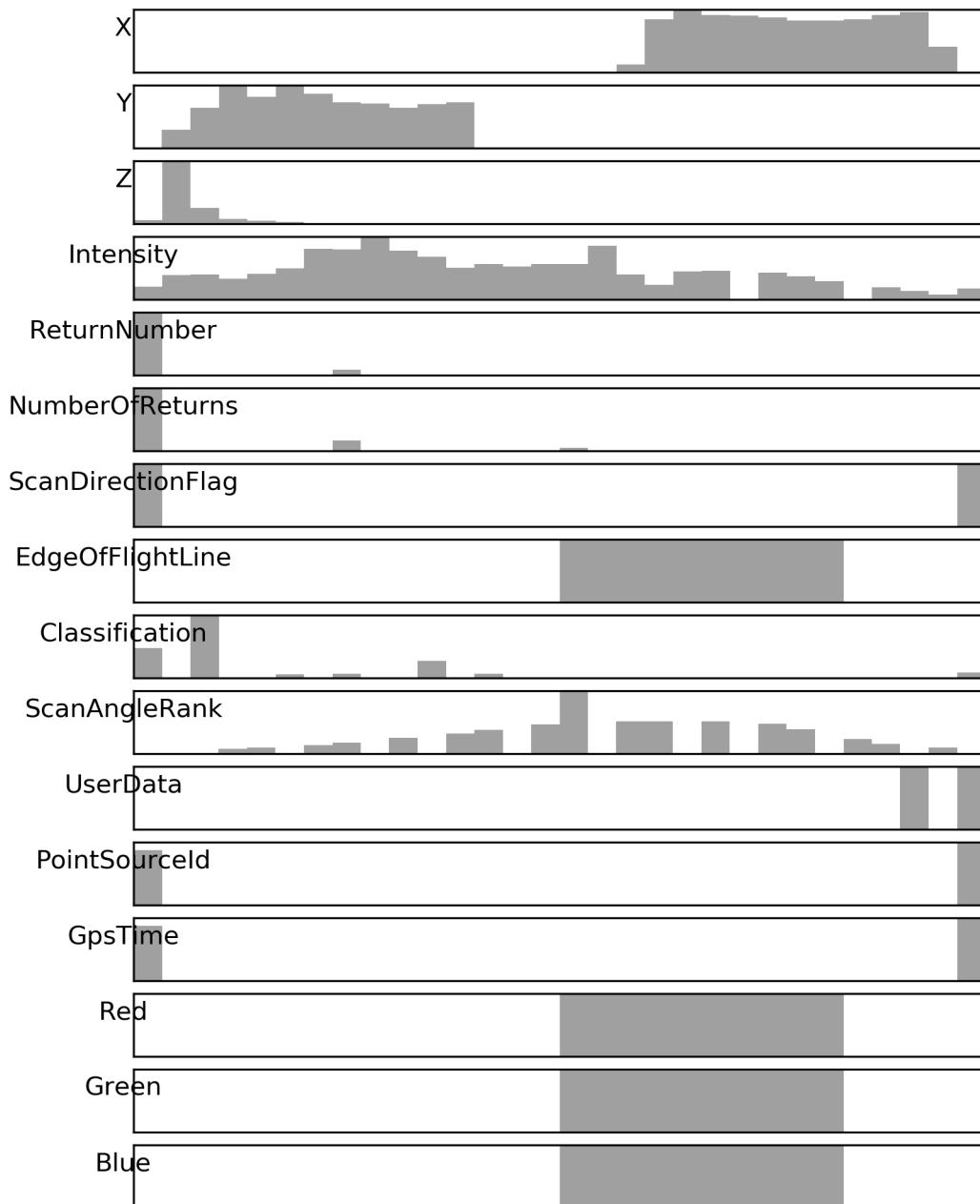
```
61 # a dictionary of arguments that can be explicitly passed into
62 # the module by the user. We passed in a filename arg in our `pdal_
63 #pipeline` call
64 if 'filename' in pdalargs:
65     filename = pdalargs['filename']
66 else:
67     filename = 'histogram.png'
68
69 # open up the filename and write out the
70 # bytes of the PNG stored in the BytesIO instance
71 o = open(filename, 'wb')
72 o.write(output.getvalue())
73 o.close()
74
75 # filters.programmable scripts need to
76 # return True to tell the filter it was successful.
77 return True
```

Run pdal pipeline

```
1 pdal pipeline ./exercises/python/histogram.json
```

```
(pdalworkshop) $ pdal pipeline ./exercises/python/histogram.json
anything:40: MatplotlibDeprecationWarning:
The 'normed' kwarg was deprecated in Matplotlib 2.1 and will be removed in 3.1. Use 'density' instead.
anything:47: UserWarning: Attempting to set identical left == right == 0 results in singular transformations; automatically expanding.
(pdalworkshop) $
```

Output



Notes

1. `writers.null` (page 134) 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 354), 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 250) PDAL filter to drop all points with very high intensity values.

Note: These data were provided by Dr. Craig Glennie and were collected by **NCALM** (<http://ncalm.cive.uh.edu/>), the National Center for Airborne Laser Mapping. The collect area is southwest of Austin, TX.

Command

Invoke the following command, substituting accordingly, into your ` Conda Shell`:

```
pdal translate \
./exercises/georeferencing/S1C1_csd_004.csd \
./exercises/georeferencing/S1C1_csd_004.laz \
reprojection range \
--filters.reprojection.out_srs="EPSG:32614" \
--filters.range.limits="Intensity[0:500]"
```

```
pdal translate ^
./exercises/georeferencing/S1C1_csd_004.csd ^
./exercises/georeferencing/S1C1_csd_004.laz ^
reprojection range ^
--filters.reprojection.out_srs="EPSG:32614" ^
--filters.range.limits="Intensity[0:500]"
```

```
(pdalworkshop) $ pdal translate \
> ./exercises/georeferencing/S1C1_csd_004.csd \
> ./exercises/georeferencing/S1C1_csd_004.laz \
> reprojection range \
> --filters.reprojection.out_srs="EPSG:32614" \
> --filters.range.limits="Intensity[0:500]"
(pdalworkshop) $
```

Visualization

View your georeferenced point cloud in <http://plas.io>.

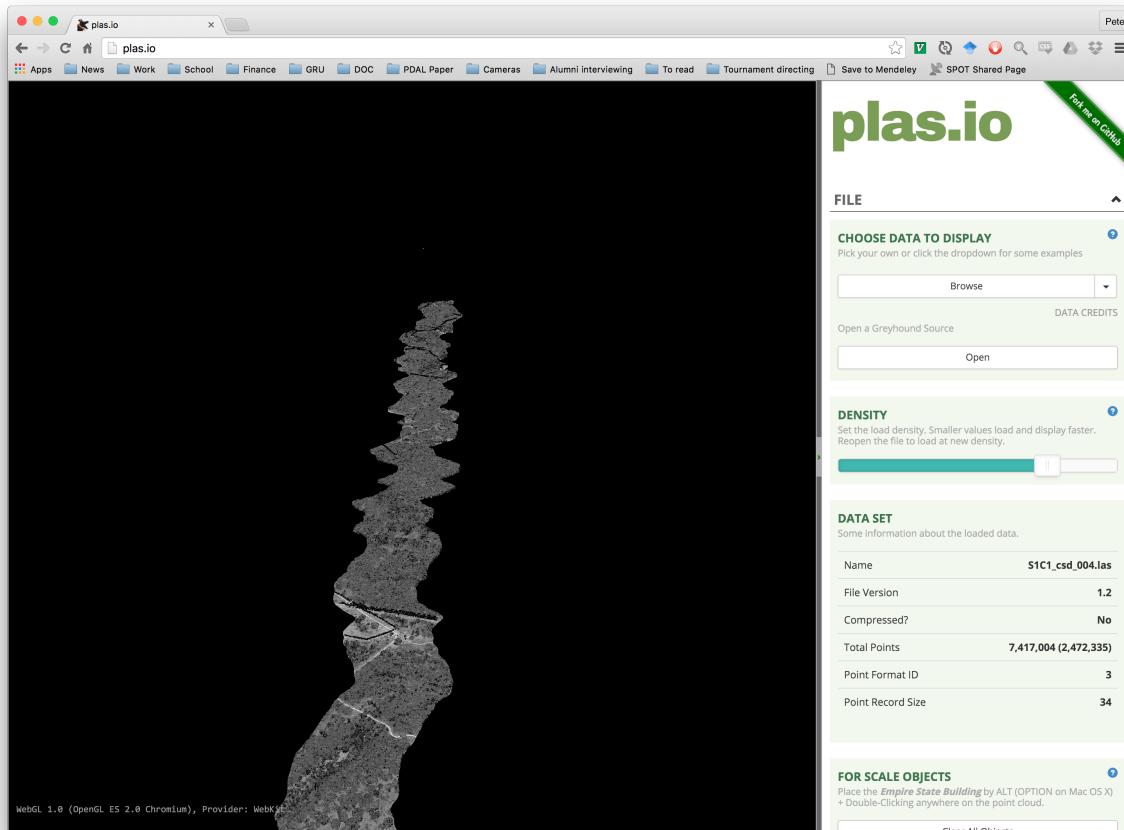


Fig. 7: Our airborne laser point cloud after georeferencing, reprojection, and intensity filtering.

Batch Processing

Batch Processing

PDAL doesn't handle matching multiple file inputs except for glob handling for merge operations, but does allow for command line substitution parameters to make batch processing simpler, substitutions work with both *Pipeline* (page 47) operations as well as with other applications such as *translate* (page 42).

Operating system variations

How substitutions are passed generally depends on the operating system and tools available. In the unix/linux environments, this is primarily using the *find* and *ls* programs to get lists of files (either with directories or just filenames) and the *xargs* or *parallel* program to pass those files to the pdal application (although *-exec* with *find* can also be used). These tools are available in the *docker* environment if you are running *PDAL* under docker. They are also available under Windows one installs *Cygwin* or *MinGW*. They are also available if Git for Windows is installed. They are also available as win32 command line programs installed from the GNU Findutils (<https://www.gnu.org/software/findutils/findutils.html>). They are available for MacOS and Linux.

Windows native tools

Substitutions can be handled directly in windows using *PowerShell* syntax.

While there are a number of ways to generate lists of files, the *Get-ChildItem* is used here, along with the *foreach* option to pass each separate filepath to the pdal application.

Example - Batch compression of LAS files to LAZ - PowerShell:

To compress a series of LAS files in one directory into compressed LAZ files in another directory, the *PowerShell* syntax would be:

```
Get-ChildItem .\DIR1\*.las | foreach {pdal translate -i .\DIR1\$($_.BaseName).las ^ -o .\DIR2\$($_.BaseName).laz}
```

Note the use of the *\$(\$_.BaseName)* syntax for the files passed. This option on the *\$(\$_)* shortcut for the full filename, removes the directory and the extension on the file and allows the user to set the path and extension manually.

Example - Parallel Batch compression of LAS files to LAZ - PowerShell:

This use of the *PowerShell* syntax doesn't allow a user to execute more than one process at a time. There is a free download of the *xargs* program that provides parallel execution available at <http://www.pirosa.co.uk/demo/wxargs/ppx2.exe>. For this tool, the file names are passed with using the *{}* syntax.

```
Get-ChildItem .\dir1\ | Select-Object -ExpandProperty BaseName ^ | .\ppx2.exe -P 3 pdal translate -i ".\dir1\{}.las" -o ".\dir2\{}.laz"
```

Example - Batch compression of LAS files to LAZ - Bash:

To compress a series of LAS files in one directory into compressed LAZ files in another directory, the *Bash* syntax would be:

```
ls ./dir1/*.las | parallel -I{} \
pdal translate -i ./dir1/{/.}.las -o ./dir2/{/.}.laz
```

In *Parallel*, then *{/}* syntax means strip the directory and the extension and just use the basename of the file. This allows you to easily change the output format and the location.

Example - Parallel Batch compression of LAS files to LAZ - Bash:

Parallel, as its name implies, allows parallel operations. Adding the *-j* syntax indicates the number simultaneous jobs to run

```
ls ./dir1/*.las | parallel -I{} -j 4 \
pdal translate -i ./dir1/{/.}.las -o ./dir2/{/.}.laz
```

Exercise - Pipeline Substitutions:

For the most flexibility, pipelines are used to apply a series of operations to a file (or group of files). In this exercise, we build on the [Generating a DTM](#) (page 406) pipeline example, but run this pipeline over 4 files and reproject, calculate a bare earth using the [filters.smrf](#) (page 155) filter, remove those points that aren't bare earth with [filters.range](#) (page 250) and then write the output using the [writers.gdal](#) (page 121).

The pipeline we are using is:

```
{
  "pipeline": [
    {
      "type": "readers.las"
    },
    {
      "type": "filters.reprojection"
    },
    {
      "type": "filters.smrf"
    },
    {
      "type": "filters.range",
    }
  ]
}
```

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```

    "limits": "Classification[2:2]"
},
{
  "gdaldriver": "GTiff",
  "output_type": "idw",
  "resolution": "2.0",
  "type": "writers.gdal"
}
]
}

```

You might have spotted that this pipeline doesn't have any input or output file references, or a value for the output spatial reference. We will be adding those at the command line, not within the actual pipeline and using the substitutions syntax to do this.

```

PS ./exercises/batch> Get-ChildItem ./exercises/batch/source/
→*.laz | ^
foreach {pdal pipeline ./exercises/batch/batch_srs_gdal.json ^
--readers.las.filename=./source/$( $_.BaseName).laz ^
--writers.gdal.filename=./dtm/$( $_.BaseName).tif ^
--filters.reprojection.in_srs=epsg:3794 ^
--filters.reprojection.in_srs=epsg:32733}

```

```

ls ./exercises/batch_processing/source/*.laz | \
parallel -I{} pdal pipeline ./exercises/batch_processing/batch_
→srs_gdal.json \
--readers.las.filename={} \
--writers.gdal.filename=./exercises/batch_processing/dtm{/.}.
→tif \
--filters.reprojection.in_srs=epsg:3794 \
--filters.reprojection.out_srs=epsg:32733

```

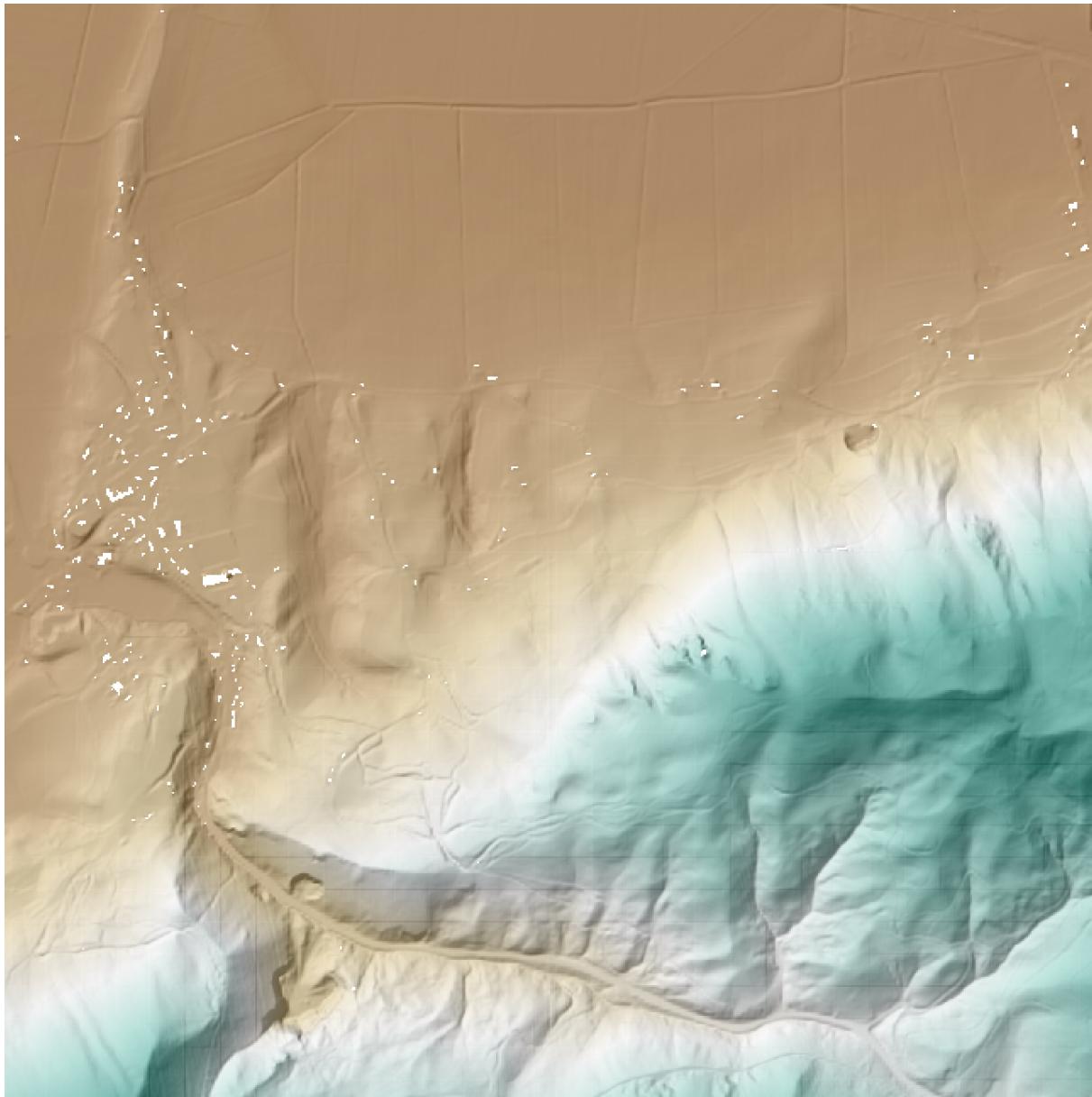
Once you have your dtms created with pdal, combine them to a single file with:

```

gdalbuildvrt ./exercises/batch_processing/dtm.vrt ./exercises/batch_
→processing/dtm*.tif

```

You can then visualize the vrt with *qgis*. Add the vrt twice, and set the properties of the lower layer to hillshade. Set the upper layer to Singleband PseudoColor and choose a pleasing color ramp. Then set the transparency of the upper layer to 50% and you'll get a nice display of the terrain.



13.1.5 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": [
```

(continues on next page)

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```
{  
    "type": "readers.ept",  
    "filename": "http://na-c.entwine.io/dublin/",  
    "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 an EPT resource using [readers.ept](#) (page 59) (See [Entwine](#) (page 369))
- Thin it by 1.0 meter spacing using [filters.sample](#) (page 234) (See [Thinning](#) (page 394))
- Filter out noise using [filters.outlier](#) (page 159) (See [Removing noise](#) (page 386))
- Classify ground points using [filters.smrf](#) (page 155) (See [Identifying ground](#) (page 400))
- Compute height above ground using [filters.hag_nn](#) (page 171)
- Generate a digital terrain model (DTM) using [writers.gdal](#) (page 121) (See [Generating a DTM](#) (page 406))
- Generate a average vegetative height model using [writers.gdal](#) (page 121)

Note: You should review specific [Exercises](#) (page 359) for specifics how to achieve each task.

13.1.6 Notes

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CHAPTER
FOURTEEN

DEVELOPMENT

14.1 Development

Developer documentation, such as how to update the docs, where the test frameworks are, who develops the software, and conventions to use when developing new code can be found in this section.

Note: Users looking for documentation on how to use PDAL's command line applications should look [here](#) (page 25) and users looking to use the PDAL API in their own applications should look [here](#) (page 523).

14.1.1 PDAL Architecture Overview

Author Andrew Bell

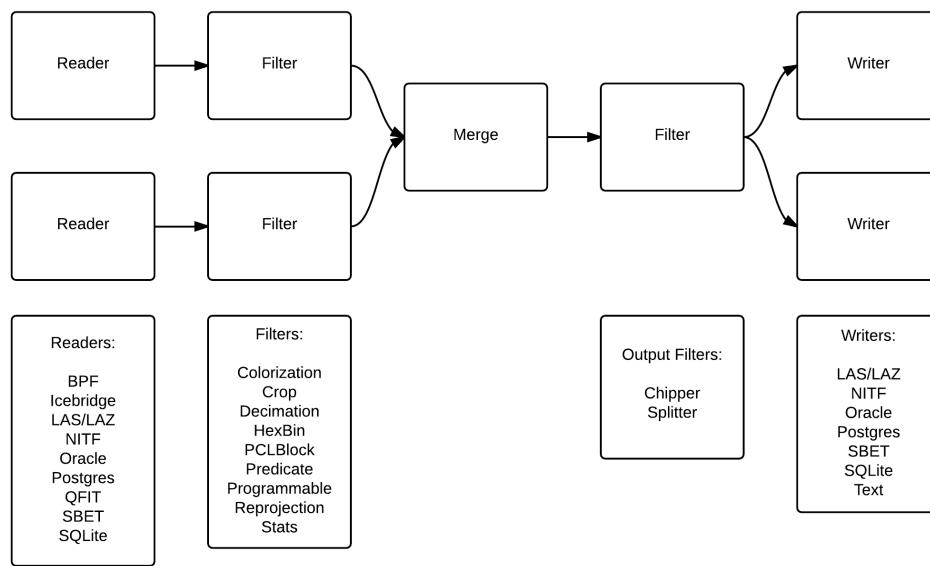
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Date 5/15/2016

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 judgment call, but detection of errors earlier in the process allows faster termination of a command. Files opened in this step should also be closed before returning.

3) void addDimensions(PointLayoutPtr layout)

This method allows stages to inform a point table's layout of the dimensions that it would like as part of the record of each point. Usually, only readers add dimensions to a point table, but there is no prohibition on filters or writers from adding dimensions if necessary. Dimensions should not be added to the layout outside of this method.

4) void prepared(PointTableRef)

Called after dimensions are added. It can be used to verify state and raise exceptions before stage execution.

Stage Execution

After all stages are prepared, processing continues with the execution of each stage by calling `execute()`. Each stage will be executed only after all stages preceding it in a pipeline have been executed. A stage is executed by invoking the following private virtual methods. It is important to note that `ready()` and `done()` are called only once for each stage while `run()` is called once for each point view to be processed by the stage.

1) void ready(PointTablePtr table)

This function allows preprocessing to be performed prior to actual processing of the points in a point view. For example, filters may initialize internal data structures or libraries, readers may connect to databases and writers may write a file header. If there is a choice between performing operations in the preparation stage (in the `initialize()` method) or the execution stage (in `ready()`), prefer to defer the operation until this point.

2) `PointViewSet run(PointViewPtr buf)`

This is the method in which processing of individual points occurs. One might read points into the view, transform point values in some way, or distribute the point references in the input view into numerous output views. This method is called once for each point view passed to the stage.

3) `void done(PointTablePtr table)`

This function allows a stage to clean up resources not released by a stage's destructor. It also allows other execution of termination functions, such as closing of databases, writing file footers, rewriting headers or closing or renaming files.

Streaming Stage Execution

PDAL normally processes all points through each stage before passing the points to the next stage. This means that all point data is held in memory during processing. There are some situations that may make this undesirable. As an alternative, PDAL allows execution of data with a point table that contains a fixed number of points (`StreamPointTable`). When a `StreamPointTable` is passed to the `execute()` function, the private `run()` function detailed above isn't called, and instead `processOne()` is called for each point. If a `StreamPointTable` is passed to `execute()` but a pipeline stage doesn't implement `processOne()`, an exception is thrown.

`bool processOne(PointRef& ref)`

This method allows processing of a single point. A reader will typically read a point from an input source. When a reader returns 'false' from this function, it indicates that there are no more points to be read. When a filter returns 'false' from this function, it indicates that the point just processed should be filtered out and not passed to subsequent stages for processing.

Implementing a Reader

A reader is a stage that takes input from a point cloud format supported by PDAL and loads points into a point table through a point view.

A reader needs to register or assign those dimensions that it will reference when adding point data to the point table. Dimensions that are predefined in PDAL can be registered by using the point table's `registerDim()` method. Dimensions that are not predefined can be added using `assignDim()`. If dimensions are determined as named entities from a point cloud source, it may not be known whether the dimensions are predefined or not. In this case the function `registerOrAssignDim()` can be used. When a dimension is assigned, rather than registered, the reader needs to inform PDAL of the type of the variable using the enumeration `Dimension::Type`.

In this example, the reader informs the point table's layout that it will reference the dimensions X, Y and Z.

```
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);
    }
}
```

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```

    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)

```

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```
{  
    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);  
    }  
}
```

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```

        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);
}
```

14.1.2 Compilation

This section describes how to build and install PDAL under Windows, Linux, and Mac.

See also:

[Download](#) (page 13) contains links to installable binaries for Windows, OSX, and RHEL Linux systems.

Contents:

Unix Compilation

PDAL comes with support for building with [CMake](https://cmake.org) (<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) (<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/) (<https://ninja-build.org/>) and [GNU Makefiles](https://www.gnu.org/software/make/manual/make.html) (<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 466) can be built from source or can be installed via a packaging system ([apt](https://help.ubuntu.com/lts/serverguide/apt.html) (<https://help.ubuntu.com/lts/serverguide/apt.html>) works well on Ubuntu and Debian-based Linux systems. [Conda](https://conda.io/en/latest/) (<https://conda.io/en/latest/>) works well on most systems. Some have had success with [brew](https://brew.sh/) (<https://brew.sh/>) on OSX systems.) Often, the only package that needs to be installed prior to building PDAL is GDAL. Installing a GDAL package will normally install other PDAL dependencies automatically.

```
$ apt install libgdal-dev
```

OR

```
$ conda install gdal
```

OR

```
$ brew install gdal
```

Using Ninja on Linux or OSX

Get the source code

PDAL can be cloned from [GitHub](#) (page 14) or you can download a [release bundle](#) (page 13)

Prepare a build directory

CMake allows you to generate different builders for a project. Here we're using Mac OSX, but the procedure and output are nearly identical on Linux distributions.

```
$ cd PDAL  
$ mkdir build  
$ cd build
```

Run CMake

Running CMake uses the specified generator to create an environment suitable for building PDAL with the requested tool. (Ninja in this case).

```
$ cmake -G Ninja ..  
-- Numpy output: /usr/lib/python2.7/dist-packages/numpy/core/include  
1.13.3  
  
-- Could NOT find LIBEXECINFO (missing: LIBEXECINFO_LIBRARY)  
-- Could NOT find LIBUNWIND (missing: LIBUNWIND_LIBRARY LIBUNWIND_  
INCLUDE_DIR)  
-- The following features have been enabled:  
  
* 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
```

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```
-- 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,
```

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```
"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 0.  
→23 sec  
    Start 2: pdal_filters_icp_test  
2/97 Test #2: pdal_filters_icp_test ..... Passed 0.  
→12 sec  
    Start 3: pdal_filters_python_test  
3/97 Test #3: pdal_filters_python_test ..... Passed 3.  
→52 sec  
    Start 4: pdal_io_numpy_test  
4/97 Test #4: pdal_io_numpy_test ..... Passed 0.  
→31 sec  
...  
93/96 Test #93: pdal_io_ilvis2_metadata_test ..... Passed 0.  
→03 sec  
    Start 94: pdal_io_ilvis2_reader_metadata_test  
94/96 Test #94: pdal_io_ilvis2_reader_metadata_test .... Passed 0.  
→05 sec  
    Start 95: xml_schema_test  
95/96 Test #95: xml_schema_test ..... Passed 0.  
→04 sec  
    Start 96: pdal_io_ilvis2_test  
96/96 Test #96: pdal_io_ilvis2_test ..... Passed 0.  
→04 sec  
  
100% tests passed, 0 tests failed out of 96  
  
Total Test time (real) = 39.54 sec
```

Failed tests may not indicate problems other than a lack of support for some feature on your

system. For example, tests for database drivers will fail if the database isn't installed or configured properly.

Install PDAL

PDAL can be installed to the default location (usually subdirectories of /usr/local) using Ninja.

```
$ ninja install
```

Building Under Windows

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Date 11/20/2020

Note: [Conda](#) (page 16) contains a pre-built up-to-date 64 bit Windows binary. It is fully-featured, and if you do not need anything custom, it is likely the fastest way to get going.

Introduction

Pre-built binary packages for Windows are available via [Conda](#) (page 16) (64-bit version), and all of the prerequisites required for compilation of a fully featured build are also available via that packaging system. This document assumes you will be using Conda Forge as your base, and anything more advanced is beyond the scope of the document.

Note: The GitHub Action build system uses the PDAL project's configuration on the Conda Forge system. It contains a rich resource of known working examples. See <https://github.com/PDAL/PDAL/blob/master/.github/workflows/win.yml> and <https://github.com/PDAL/PDAL/tree/master/scripts/ci/win> for inspiration.

Required Compiler

PDAL is known to compile on Visual Studio 2015 (<https://www.visualstudio.com/vs/older-downloads/>), and 2013 *might* work with some source tree adjustments. PDAL makes heavy use of C++11, and a compiler with good support for those features is required.

Prerequisite Libraries

PDAL uses the [GitHub Actions](https://github.com/PDAL/PDAL/actions) (<https://github.com/PDAL/PDAL/actions>) continuous integration platform for building and testing itself on Windows. The configuration that PDAL uses is valuable raw materials for configuring your own environment because the PDAL team must keep it up to date with both the [Conda](#) (page 16) environment and the Microsoft compiler situation.

You can see the current configuration at <https://github.com/PDAL/PDAL/blob/master/.github/workflows/win.yml>. The most interesting bits are the Setup step, the CMake step, and the Compile scripts. The configuration already has Miniconda installed, and the `setup.sh` script installs all of PDAL's prerequisites via the command line.

```
conda install geotiff laszip nitro curl ^  
gdal pcl cmake eigen ninja libgdal ^  
zstd numpy xz libxml2 laz-perf qhull ^  
sqlite hdf5 tiledb conda-build ninja -y
```

Note: The package list here might change over time. The canonical location to learn the prerequisite list for PDAL is the `scripts/ci/win` directory in PDAL's source tree.

Fetching the Source

Get the source code for PDAL. Presumably you have [GitHub for Windows](#) (<https://desktop.github.com/>) or something like it. Run a “git shell” and clone the repository into the directory of your choice.

```
c:\dev> git clone https://github.com/PDAL/PDAL.git
```

Switch to the `-maintenance` branch.

```
c:\dev> git checkout 1.9-maintenance
```

Note: PDAL's active development branch is `master`, and you are welcome to build it, but is not as stable as the major-versioned release branches are likely to be.

Configuration

PDAL uses [CMake](http://www.cmake.org) (<http://www.cmake.org>) for its build configuration. You will need to install CMake and have it available on your path to configure PDAL.

Invoke your `cmake` command to configure the PDAL.

```
cmake -G "NMake Makefiles" .
```

A fully-featured build will require more specification of libraries, enabled features, and their locations. For more information on this, users can refer to the `examples.sh` step in the Action.

Note: Placing your command in a `.bat` file will make for easy reuse.

Building

If you chose `NMake Makefiles` as your CMake generator, you can invoke the build by calling `nmake`:

```
nmake /f Makefile
```

If you chose “Visual Studio 14 Win64” as your CMake generator, open `PDAL.sln` and chose your configuration to build.

Running

After you've built the tree, you can run `pdal.exe` by issuing it

```
c:\dev\pdal\bin\pdal.exe
```

Note: You may need to have your Conda environment active to enable access to PDAL's dependencies.

Dependencies

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>) or [Conda](#) (<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 support. In conjunction with [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>) in its library build but there is no way for you to know this. In addition to embedding libgeotiff, it also strips away the library symbols that PDAL needs, meaning that PDAL can't simply link against [GDAL](#) (<http://www.gdal.org>). If you are building both of these libraries yourself, make sure you build GDAL using the "External libgeotiff" option, which will prevent the insanity that can ensue on some platforms. [Conda Forge](#) (<https://anaconda.org/conda-forge/pdal>) users, including those using that platform to link and build PDAL themselves, do not need to worry about this issue.

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 126) and *readers.las* (page 73) 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 and *writers.sqlite* (page 144):

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, *readers.sqlite* (page 104), or *readers.pgpointcloud* (page 90).:

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 and readers.oci 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) support for PDAL to write LAS-in-NITF files for *writers.nitf* (page 131). 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_command, *writers.pcd* (page 136), *readers.pcd* (page 89), and filterspclblock 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>) is an efficient multi-dimensional array management system which introduces a novel on-disk format that can effectively store dense and sparse array data with support for fast updates and reads. It features excellent compression, and an efficient parallel I/O system with high scalability. It is used by *writers.tiledb* (page 147) and *readers.tiledb* (page 110).:

Source: <https://github.com/TileDB-Inc/TileDB>
Conda: <https://anaconda.org/conda-forge/tiledb>

14.1.3 Errors and Error Handling

Exceptions

PDAL typically throws a `std::runtime_error` for error conditions that is catchable as `pdal::pdal_error`.

PDAL Position on (Non)conformance

PDAL proudly and unabashedly supports formal standards/specifications for file formats. We recognize, however, that in some cases files will not follow a given standard precisely, due to an unclear spec or simply out of carelessness.

When reading files that are not formatted correctly:

- PDAL may try to compensate for the error. This is typically done when as a practical matter the market needs support for well-known or pervasive, but nonetheless “broken”, upstream implementations.
- PDAL may explicitly reject such files. This is typically done where we do not wish to continue to promote or support mistakes that should be fixed upstream.

PDAL will strive to write correctly formatted files. In some cases, however, PDAL may choose to offer as an option the ability to break the standard if, as a practical matter, doing so would significantly aid the market. Such an option would never be the default behavior, however.

For files that are conformant but which lie, such as the extents in the header being wrong, we will generally offer both the ability to propagate the “wrong” information and the ability to helpfully correct it on the fly; the latter is generally our default position.

14.1.4 Metadata

In addition to point data, PDAL stores metadata during the processing of a pipeline. Metadata is stored internally as strings, though the API accepts a variety of types that are automatically converted as necessary. Each item of metadata consists of a name, a description (optional), a value and a type. In addition, each item of metadata can have a list of child metadata values.

Metadata is made available to users of PDAL through a JSON tree. Commands such as [pdal pipeline](#) (page 35) and [pdal translate](#) (page 42) 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  
            ]  
        }  
    }  
}
```

14.1.5 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 57) that conforms to PDAL's *pdal::Stage* (page 559), you can implement a simple read-filter-write pipeline using *Pipeline* (page 47) 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 <iostream>
#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");
```

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```

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);
```

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```
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);
}
```

Compiling and running the program

Note: Refer to *Compilation* (page 458) 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 2.0.0 REQUIRED CONFIG)
set(CMAKE_CXX_STANDARD 11)
set(CMAKE_CXX_STANDARD_REQUIRED ON)

add_executable(tutorial tutorial.cpp)

target_link_libraries(tutorial PRIVATE ${PDAL_LIBRARIES})
target_include_directories(tutorial PRIVATE
    ${PDAL_INCLUDE_DIRS})
```

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```
${PDAL_INCLUDE_DIRS}/pdal)
```

Note: Refer to [CMake](#) (page 502) 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
```

14.1.6 Writing a filter

PDAL can be extended through the development of filter functions.

See also:

For more on filters and their role in PDAL, and their lifecycle please refer to [PDAL Architecture Overview](#) (page 447).

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 209), are implemented as *static* filters and are statically linked into the PDAL library. Filters that require extra/optional dependencies, or are external to the core PDAL codebase altogether, such as [filters.python](#) (page 278), 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/pdal_internal.hpp>
6 #include <pdal/Filter.hpp>
7
8 namespace pdal
9 {
10
11 class PDAL_DLL MyFilter : public Filter
12 {
13 public:
14     MyFilter() : Filter()
15     {}
16     std::string getName() const;
17
18 private:
19     double m_value;
20     Dimension::Id m_myDimension;
21
22     virtual void addDimensions(PointLayoutPtr layout);
23     virtual void addArgs(ProgramArgs& args);
24     virtual PointViewSet run(PointViewPtr view);
25
26     MyFilter& operator=(const MyFilter&); // not implemented
27     MyFilter(const MyFilter&); // not implemented
28 };
29
30 } // namespace pdal

```

This header should be relatively straightforward, but we will point out one method that must be declared for the plugin interface to be satisfied.

```
std::string getName() const;
```

In many instances, you should be able to copy this header template verbatim, changing only the filter class name, includes, and member functions/variables as required by your implementation.

The source

Again, we start with a full listing of the filter source.

```
1 // MyFilter.cpp
2
3 #include "MyFilter.hpp"
4
5 #include <pdal/pdal_internal.hpp>
6
7 namespace pdal
8 {
9
10 static PluginInfo const s_info
11 {
12     "filters.name",
13     "My awesome filter",
14     "http://link/to/documentation"
15 };
16
17 CREATE_SHARED_STAGE(MyFilter, s_info)
18
19 std::string MyFilter::getName() const { return s_info.name; }
20
21 void MyFilter::addArgs(ProgramArgs& args)
22 {
23     args.add("param", "Some parameter", m_value, 1.0);
24 }
25
26 void MyFilter::addDimensions(PointLayoutPtr layout)
27 {
28     layout->registerDim(Dimension::Id::Intensity);
29     m_myDimension = layout->registerOrAssignDim("MyDimension",
30                                                 Dimension::Type::Unsigned8);
31 }
32
33 PointViewSet MyFilter::run(PointViewPtr input)
34 {
35     PointViewSet viewSet;
36     viewSet.insert(input);
37     return viewSet;
38 }
39
40 } // 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 macros to do just this.

We begin by creating a `PluginInfo` struct containing three identifying elements - the filter name, description, and a link to documentation.

```

1 static PluginInfo const s_info
2 {
3     "filters.name",
4     "My awesome filter",
5     "http://link/to/documentation"
6 };

```

PDAL requires that filter names always begin with `filters.`, and end with a string that uniquely identifies the filter. The description will be displayed to users of the PDAL CLI (`pdal --drivers`). When making a shared plugin, the name of the shared library must correspond with the name of the filter provided here. The name of the generated shared object must be

```
libpdal_plugin_filter_<filter name>.<shared library extension>
```

Next, we pass the following to the `CREATE_SHARED_STAGE` macro, passing in the name of the stage and the `PluginInfo` struct.

```
CREATE_SHARED_STAGE(MyFilter, s_info)
```

To create a static stage, we simply change `CREATE_SHARED_STAGE` to `CREATE_STATIC_STAGE`.

Finally, we implement a method to get the plugin name, which is primarily used by the PDAL CLI when using the `--drivers` or `--options` arguments.

```

1 std::string MyFilter::getName() const { return s_info.name; }
```

Now that the filter has implemented the proper plugin interface, we will begin to implement some methods that actually implement the filter. The `addArgs()` method is used to register and bind any provided options to the stage. Here, we get the value of `param`, if provided, else we populate `m_value` with the default value of `1.0`. Option names, descriptions, and default values specified in `addArgs()` will be displayed via the PDAL CLI with the `--options` argument.

```

1 void MyFilter::addArgs(ProgramArgs& args)
2 {
3     args.add("param", "Some parameter", m_value, 1.0);
4 }
```

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 void MyFilter::addDimensions(PointLayoutPtr layout)
2 {
3     layout->registerDim(Dimension::Id::Intensity);
4     m_myDimension = layout->registerOrAssignDim("MyDimension",
5                                                 Dimension::Type::Unsigned8);
6 }
```

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 1.9.0 REQUIRED CONFIG)
5
6 set(CMAKE_CXX_STANDARD 11)
7 set(CMAKE_CXX_STANDARD_REQUIRED ON)
8 add_library(pdal_plugin_filter_myfilter SHARED MyFilter.cpp)
9 target_link_libraries(pdal_plugin_filter_myfilter PRIVATE ${PDAL_
    ↴LIBRARIES})
10 target_include_directories(pdal_plugin_filter_myfilter PRIVATE ${PDAL_
    ↴INCLUDE_DIRS})
11 target_link_directories(pdal_plugin_filter_myfilter PRIVATE ${PDAL_
    ↴LIBRARY_DIRS})
```

Note: `CMakeLists.txt` contents may vary slightly depending on your project requirements, operating system, and compiler.

14.1.7 Writing a kernel

Author Bradley Chambers

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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 } // 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
```

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```

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     writer.prepare(table);
51     writer.execute(table);
52
53     return 0;
54 }
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`.

```

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);

```

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```
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 2.0.0 REQUIRED CONFIG)
5 set(CMAKE_CXX_STANDARD 11)
6 set(CMAKE_CXX_STANDARD_REQUIRED ON)

7
8 add_library(pdal_plugin_kernel_mykernel SHARED MyKernel.cpp)
9 target_link_libraries(pdal_plugin_kernel_mykernel PRIVATE ${PDAL_
    ↴LIBRARIES})
10 target_include_directories(pdal_plugin_kernel_mykernel PRIVATE
    ${PDAL_INCLUDE_DIRS})
11 target_link_directories(pdal_plugin_kernel_mykernel PRIVATE ${PDAL_
    ↴LIBRARY_DIRS})
```

14.1.8 Writing a reader

Authors Bradley Chambers, Scott Lewis

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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 count);
26         virtual void done(PointTableRef table);
27     };
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 count);
5 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     static PluginInfo const s_info
8     {
9         "readers.myreader",
10        "My Awesome Reader",
11        "http://link/to/documentation"
12    };
13
14    CREATE_SHARED_STAGE(MyReader, s_info)
15
16    std::string MyReader::getName() const { return s_info.name; }
17
18    void MyReader::addArgs(ProgramArgs& args)
```

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```

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", Dimension::Type::Unsigned64);
30 }
31
32 void MyReader::ready(PointTableRef)
33 {
34     m_index = 0;
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
fieldno)
41 {
42     T output;
43     bool bConverted = Utils::fromString(s[fieldno], output);
44     if (!bConverted)
45     {
46         std::stringstream oss;
47         oss << "Unable to convert " << name << ", " << s[fieldno] <<
48             ", to double";
49         throw pdal_error(oss.str());
50     }
51
52     return output;
53 }
54
55
56 point_count_t MyReader::read(PointViewPtr view, point_count_t count)
57 {
58     PointLayoutPtr layout = view->layout();
59     PointId nextId = view->size();
60     PointId idx = m_index;

```

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```

61 point_count_t numRead = 0;
62
63 m_stream.reset(new ILeStream(m_filename));
64
65 size_t HEADERSIZE(1);
66 size_t skip_lines((std::max)(HEADERSIZE, (size_t)m_index));
67 size_t line_no(1);
68 for (std::string line; std::getline(*m_stream->stream(), line); ↴
69   line_no++)
70 {
71     if (line_no <= skip_lines)
72     {
73       continue;
74     }
75
76     // MyReader format: X::Y::Z::Data
77     StringList s = Utils::split2(line, ':');
78
79     unsigned long u64(0);
80     if (s.size() != 4)
81     {
82       std::stringstream oss;
83       oss << "Unable to split proper number of fields. Expected 4, ↴
84       got "
85         << s.size();
86       throw pdal_error(oss.str());
87     }
88
89     std::string name("X");
90     view->setField(Dimension::Id::X, nextId, convert<double>(s, name, ↴
91       0));
92
93     name = "Y";
94     view->setField(Dimension::Id::Y, nextId, convert<double>(s, name, ↴
95       1));
96
97     name = "Z";
98     double z = convert<double>(s, name, 2) * m_scale_z;
      view->setField(Dimension::Id::Z, nextId, z);

```

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```

99         nextId,
100        convert<unsigned int>(s, name, 3));
101
102        nextId++;
103        if (m_cb)
104            m_cb(*view, nextId);
105        }
106        m_index = nextId;
107        numRead = nextId;
108
109        return numRead;
110    }
111
112 void MyReader::done(PointTableRef)
113 {
114     m_stream.reset();
115 }
116
117 } //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.

When making a shared plugin, the name of the shared library must correspond with the name of the reader provided here. The name of the generated shared object must be

```
libpdal_plugin_reader_<reader name>.<shared library extension>
```

```

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", Dimension::Type::Unsigned64);
7 }
```

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     m_index = 0;
4     SpatialReference ref("EPSG:4385");
5     setSpatialReference(ref);
```

This is a helper function, which will convert a string value into the type specified when it's called. In our example, it will be used to convert strings to doubles when reading from the input stream.

```

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 }
```

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```

13
14     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 {
2     PointLayoutPtr layout = view->layout();
3     PointId nextId = view->size();
4     PointId idx = m_index;
5     point_count_t numRead = 0;

```

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));

```

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 size_t line_no(1);
2 for (std::string line; std::getline(*m_stream->stream(), line); ↴
3     line_no++)
4 {
5     if (line_no <= skip_lines)
6     {
7         continue;

```

Here we take the line we read in the for block header, split it, and make sure that we have the proper number of fields.

```

1 // MyReader format: X::Y::Z::Data
2 StringList s = Utils::split2(line, ':');
3
4 unsigned long u64(0);
5 if (s.size() != 4)
6 {
7     std::stringstream oss;

```

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```

8     oss << "Unable to split proper number of fields. Expected 4, "
9     ↪got "
10    << s.size();
11    throw pdal_error(oss.str());

```

Here we take the values we read and put them into the PointView object. The X and Y fields are simply converted from the file and put into the respective fields. MyData is done likewise with the custom dimension we defined. The Z value is read, and multiplied by the scale_z option (defaulted to 1.0), before the converted value is put into the field.

When putting the value into the PointView object, we pass in the Dimension that we are assigning it to, the ID of the point (which is incremented in each iteration of the loop), and the dimension value.

```

1     std::string name("X");
2     view->setField(Dimension::Id::X, nextId, convert<double>(s, name,
3     ↪0));
4
5     name = "Y";
6     view->setField(Dimension::Id::Y, nextId, convert<double>(s, name,
7     ↪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,

```

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;

```

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();

```

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 2.0 REQUIRED CONFIG)
5 set(CMAKE_CXX_STANDARD 11)
6 set(CMAKE_CXX_STANDARD_REQUIRED ON)
7
8 add_library(pdal_plugin_reader_myreader SHARED MyReader.cpp)
9 target_link_libraries(pdal_plugin_reader_myreader PRIVATE ${PDAL_
    ↵LIBRARIES})
10 target_include_directories(pdal_plugin_reader_myreader PRIVATE
    ${PDAL_INCLUDE_DIRS})
11 target_link_directories(pdal_plugin_reader_myreader PRIVATE ${PDAL_
    ↵LIBRARY_DIRS})
12

```

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.

14.1.9 Writing a writer

Authors Bradley Chambers, Scott Lewis

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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;
```

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```

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
16 CREATE_SHARED_STAGE(MyWriter, s_info);
17
18 std::string MyWriter::getName() const { return s_info.name; }
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).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 }
```

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```

41 void MyWriter::initialize()
42 {
43     m_stream = FileStreamPtr(FileUtils::createFile(m_filename, true),
44                             FileStreamDeleter());
45     if (!m_stream)
46     {
47         std::stringstream out;
48         out << "writers.mywriter couldn't open '" << m_filename <<
49             "' for output.";
50         throw pdal_error(out.str());
51     }
52 }
53 }

55
56 void MyWriter::ready(PointTableRef table)
57 {
58     m_stream->precision(m_precision);
59     *m_stream << std::fixed;

60     Dimension::Id d = table.layout()->findDim(m_datafield);
61     if (d == Dimension::Id::Unknown)
62     {
63         std::ostringstream oss;
64         oss << "Dimension not found with name '" << m_datafield << "'";
65         throw pdal_error(oss.str());
66     }
67 }

68     m_dataDim = d;
69
70     *m_stream << "#X:Y:Z:MyData" << m_newline;
71 }

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;

```

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```

83
84     if (!m_datafield.empty()) {
85         myData = (int)(view->getFieldAs<double>(m_dataDim, idx) + 0.
86         ↵5);
87     }
88
89     *m_stream << x << ":" << y << ":" << z << ":" <<
90     myData << m_newline;
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.

When making a shared plugin, the name of the shared library must correspond with the name of the writer provided here. The name of the generated shared object must be

:: libpdal_plugin_writer_<writer name>.shared library extension>

```

1 struct FileStreamDeleter
2 {
3     template <typename T>
4     void operator()(T* ptr)
```

(continues on next page)

(continued from previous page)

```

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).setPositional();
5   args.add("newline", "Line terminator", m_newline, "\n");
6   args.add("datafield", "Data field", m_datafield, "UserData");
7   args.add("precision", "Precision", m_precision, 3);
8 }

```

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);

```

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```

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) + 0.
12      ↵5);
13    }
14
15    *m_stream << x << ":" << y << ":" << z << ":"
16    << myData << m_newline;
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 2.0.0 REQUIRED CONFIG)
5 set(CMAKE_CXX_STANDARD 11)
6 set(CMAKE_CXX_STANDARD_REQUIRED ON)
7
8 add_library(pdal_plugin_writer_mywriter SHARED MyWriter.cpp)
9 target_link_libraries(pdal_plugin_writer_mywriter PRIVATE ${PDAL_
    ↴LIBRARIES})
10
11 target_link_directories(pdal_plugin_writer_mywriter PRIVATE ${PDAL_
    ↴LIBRARY_DIRS})
12 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.

14.1.10 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 471).

Note: We assume you have either *built or installed* (page 458) 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
```

14.2 Project

Project resources, such as how to update the docs, where the test frameworks are, who develops the software, and conventions to use when developing new code can be found in this section.

14.2.1 Coding Conventions

To the extent possible and reasonable, we value consistency of source code formatting, class and variable naming, and so forth. Please follow existing code, rather than introducing your own (of course, better) formatting or change existing code unless you're changing behavior.

This note lists some such conventions that we would like to follow, where it makes sense to do so.

Source Formatting

We use astyle (<http://astyle.sourceforge.net>) as a tool to reformat C++ source code files in a consistent fashion. The file astylerc, at the top of the github repo, contains the default settings we use.

Our conventions are:

- Lines should be kept to 80 characters where reasonable.

- LF endings (unix style), not CRLF (windows style)
- spaces, not tabs
- indent to four (4) spaces (“Four shalt be the number thou shalt count, and the number of the counting shall be four. Three shalt thou not count, neither count thou five...”)
- braces shall be on their own lines, like this:

```
if (p)
{
    foo();
}
```

- copyright header, license, and author(s) on every file
- two spaces between major units, e.g. function bodies

Naming Conventions

- classes should be names using UpperCamelCase
- functions should be in lowerCamelCase
- member variables should be prefixed with “m_”, followed by the name in lowerCamelCase – for example, “m_numberOfPoints”
- there should be one class per file, and the name of the file should match the class name – that is, class PointData should live in files PointData.hpp and PointData.cpp.

Other Conventions

- Surround all code with “namespace pdal { ... }”; where justifiable, you may introduce a nested namespace.
- All exceptions that are not caught internally should be of type pdal_error. Exceptions used as local error handling should always be caught.
- Don’t put member function bodies in the class declaration in the header file, unless clearly justified for performance reasons. Use the “inline” keyword in these cases(?)
- Use const.
- Don’t put “using” declarations in headers.
- Document all public (and protected) member functions using doxygen markup.

#include Conventions

- For public headers from the ./include/pdal directory, use angle brackets: #include <pdal/Stage.h>
- For private headers (from somewhere in ./src), use quotes: #include “Support.hpp”
- Don’t #include a file where a simple forward declaration will do. (Note: this only applies to pdal files; don’t forward declare from system or 3rd party headers.)
- Don’t include a file unless it actually is required to compile the source unit.
- Don’t use manual include guards. All reasonable compilers support the once pragma:

```
#pragma once
```

14.2.2 Contributors

Numerous organizations, companies, and individuals have contributed time, money, and code to build PDAL up into a highly capable software package. Without these contributions, PDAL would not progress as quickly, and its quality wouldn’t be as high. The development team is proud of the software, and it collectively represents years of experiences doing point cloud data management. We hope you’ll find it useful too.

This page is to recognize these contributors and their contributions. Thanks.

Engineering Contributors



(<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>) founded the project, and he provides project leadership and software development. **Andrew Bell** (<https://github.com/abellgithub>) has contributed design, refactoring, and new feature development of PDAL over the past couple of years.

Michael Gerlek (<http://github.com/mpgerlek>) helped bootstrap PDAL by providing its first design, basic primitive objects, and first stage implementations.



Grover Consulting Services

(<https://grovercsllc.com/>) Bradley Chambers (<https://github.com/chambbj>) from Grover Consulting Services (<https://grovercsllc.com/>) has contributed numerous features and capabilities to the PDAL project, including *Poisson sampling* (page 234) and Progressive Morphological Filters. He is also a prolific *Tutorials* (page 307) 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>) sponsors development of PDAL for its use in point cloud data management systems. CRREL (<http://www.erdc.usace.army.mil/Locations/CRREL.aspx>)'s GRiD (<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.

14.2.3 Docs

Requirements

To build the PDAL documentation yourself, you need to install the following items:

- [Sphinx](http://sphinx-doc.org/) (<http://sphinx-doc.org/>)
- [Breathe](https://github.com/michaeljones/breathe) (<https://github.com/michaeljones/breathe>)
- [Doxygen](http://www.stack.nl/~dimitri/doxygen/) (<http://www.stack.nl/~dimitri/doxygen/>)
- [Latex](https://en.wikipedia.org/wiki/LaTeX) (<https://en.wikipedia.org/wiki/LaTeX>)
- [dvipng](https://en.wikipedia.org/wiki/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) (<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) (<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 523) 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 Github Actions. It will be committed by the PDAL-docs [GitHub](https://github.com/PDAL/PDAL) ([http://github.com/PDAL/PDAL](https://github.com/PDAL/PDAL)) user and pushed to the <https://github.com/PDAL/pdal.github.io> repository. The website is then served via GitHub Pages (<https://pages.github.com/>).

14.2.4 Building Docker Containers for PDAL

PDAL's *repository* (page 14) is linked to [DockerHub](https://hub.docker.com/r/pdal/pdal/) (<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/ubuntu-dependencies:latest` – PDAL's dependencies
- `pdal/pdal:latest` – PDAL master
- `pdal/pdal:1.5` – PDAL maintenance branch

Note: Containers are built upon the *Dependencies* (page 510) container, but the *Dependencies* (page 510) container is not pinned to specific Bionic or PDAL release times. It corresponds to where ever the `dependencies` tag of the PDAL source tree at <https://github.com/PDAL/PDAL> resides

Dependencies

The PDAL dependencies Docker container is used by both the latest and release branch Docker containers. The dependencies container is also used during *Continuous Integration* (page 522) testing by Travis. It is built using the Dockerfile at <https://github.com/PDAL/PDAL/blob/master/scripts/docker/ubuntu/dependencies/Dockerfile>

The `pdal/dependencies:latest` image is regenerated by force-pushing a tag of the SHA you wish to use to have [DockerHub](https://hub.docker.com/r/pdal/pdal/) (<https://hub.docker.com/r/pdal/pdal/>) build.

```
git tag -f dependencies
git push origin refs/tags/dependencies -f
```

Note: The dependencies container is currently built upon [Ubuntu Bionic](http://releases.ubuntu.com/18.04/) (<http://releases.ubuntu.com/18.04/>). When the next Ubuntu LTS is released, the PDAL project will likely move to it.

Maintenance

A PDAL container corresponding to the last major release is automatically created and maintained with every commit to the active release branch. For example, the `1.4-maintenance` branch will have a corresponding `pdal/pdal:1.4` container made with every commit on [DockerHub](https://hub.docker.com/r/pdal/pdal/) (<https://hub.docker.com/r/pdal/pdal/>). Users are encouraged to use these containers for testing, bug confirmation, and deployment

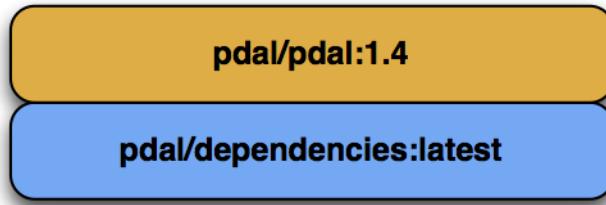


Fig. 1: Docker containers on maintenance branch correspond to major PDAL releases.

Latest (or master)

A PDAL container corresponding to a developer-selected release point is made available at `pdal/pdal:latest` and corresponds to the manual push of a `docker-master` tag by PDAL developers. This container is typically used for testing and verification of fixes, and it is recommended that users looking to depend on PDAL's Docker containers always use known release versions off of the last stable release branch.

Warning: You should be using the *Maintenance* (page 510) Docker container for any production-oriented operations. Only use the latest one to test or prototype a latest, unreleased feature.

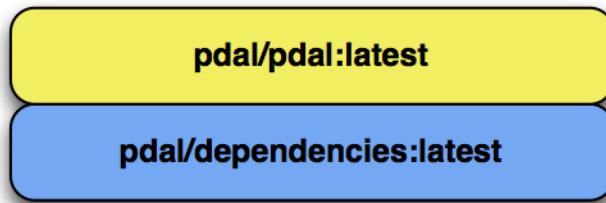


Fig. 2: The `pdal/pdal:latest` branch is current relative to the `docker-master` branch in GitHub.

```
$ git tag -f docker-master  
$ git push origin refs/tags/docker-master -f
```

14.2.5 Alpine

This page is intended to provide information about Alpine that may be useful for PDAL developers, especially when it comes to adding new PDAL dependencies.

Packages

When adding a dependency to PDAL, you will need to update our Travis configuration for continuous integration and testing, and Dockerfiles for automated builds. Begin by checking for your package in <https://pkgs.alpinelinux.org/packages>. Packages containing binaries can typically be found by searching for the library/package name alone. Development files are typically grouped in a separate subpackage with `-dev` appended to the package name. Libraries are sometimes grouped in yet another subpackage with `-libs` appended. It may take a little inspection of the package contents to determine exactly what you are getting with a particular package.

If a package does not yet exist, you'll need to consult https://wiki.alpinelinux.org/wiki/Creating_an_Alpine_package or phone a friend. Alpine developers can frequently be found on the IRC channel `#alpine-devel`.

Travis

We currently run our Travis CI builds by first pulling `alpine:3.6` and then running a script within the Alpine container. Any new dependencies that are required for PDAL to be built and tested will need to be added to

<https://github.com/PDAL/PDAL/blob/master/scripts/ci/script.sh>.

Docker

Our Docker automated builds are built from the Dockerfiles located in <https://github.com/PDAL/PDAL/tree/master/scripts/docker>. There are folders for each supported release as well as master, and there are variants for Alpine and Ubuntu based images. In the Alpine Dockerfiles, any development dependencies should be added in the `apk add` step that uses the `--virtual` switch, as these will be deleted after compilation. Any runtime dependencies should be added to the regular `apk add` step.

14.2.6 Testing

Unit Tests

A unit test framework is provided, with the goal that all (nontrivial) classes will have unit tests. At the very least, each new class should have a corresponding unit test file stubbed in, even if there aren't any tests yet.

- Our unit tests also include testing of the command line *Applications* (page 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    0.02s
  Start 2: pdal_config_test
2/61 Test #2: pdal_config_test ..... Passed    0.02s
  Start 3: pdal_file_utils_test
3/61 Test #3: pdal_file_utils_test ..... Passed    0.02s
  Start 4: pdal_georeference_test
4/61 Test #4: pdal_georeference_test ..... Passed    0.02s
```

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	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

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	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_terrassolid_test			
30/61	Test #30: pdal_io_terrassolid_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

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	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			

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	Start 47: xml_schema_test			
47/61	Test #47: <i>xml_schema_test</i>	Passed	0.02	↳ sec
	Start 48: pdal_filters_attribute_test			
48/61	Test #48: <i>pdal_filters_attribute_test</i>	Passed	0.09	↳ sec
	Start 49: pdal_plugins_cpd_kernel_test			
49/61	Test #49: <i>pdal_plugins_cpd_kernel_test</i>	***Exception: Other		↳ 0.08 sec
	Start 50: hexbintest			
50/61	Test #50: <i>hexbintest</i>	Passed	0.03	↳ sec
	Start 51: icetest			
51/61	Test #51: <i>icetest</i>	Passed	0.04	↳ sec
	Start 52: mrsidtest			
52/61	Test #52: <i>mrsidtest</i>	Passed	0.06	↳ sec
	Start 53: pdal_io_nitf_writer_test			
53/61	Test #53: <i>pdal_io_nitf_writer_test</i>	Passed	0.08	↳ sec
	Start 54: pdal_io_nitf_reader_test			
54/61	Test #54: <i>pdal_io_nitf_reader_test</i>	Passed	0.04	↳ sec
	Start 55: ocitest			
55/61	Test #55: <i>ocitest</i>	***Failed	0.06	↳ sec
	Start 56: pcetest			
56/61	Test #56: <i>pcetest</i>	Passed	0.28	↳ sec
	Start 57: pgpointcloudtest			
57/61	Test #57: <i>pgpointcloudtest</i>	Passed	1.66	↳ sec
	Start 58: plangtest			
58/61	Test #58: <i>plangtest</i>	Passed	0.14	↳ sec
	Start 59: python_predicate_test			
59/61	Test #59: <i>python_predicate_test</i>	Passed	0.16	↳ sec
	Start 60: python_programmable_test			
60/61	Test #60: <i>python_programmable_test</i>	Passed	0.15	↳ sec

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```

Start 61: sqlitetest
61/61 Test #61: sqlitetest ..... Passed 0.55s
→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

```

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```

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

```

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```
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)
```

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```
[ 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 PostgreSQL PointCloud plugin was enabled on the CMake command line (with `-DBUILD_PLUGIN_PGPLINTCLOUD=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).

14.2.7 Continuous Integration

PDAL *regression tests* (page 513) are run on a per-commit basis using GitHub Actions (<https://github.com/features/actions>)

Status

Configuration

Continuous integration configuration is modified by manipulating configuration files in two locations:

- `./github/workflows`
- `./scripts/ci`

Linux, OSX, and Windows builds are all configured separately with scripts in the `./scripts/ci` directory.

Dependencies

All of the tests use Conda Forge for dependencies.

The Linux builder has a “fixed” configuration that pins GDAL to a specific version to prevent the rest of the dependency tree from floating according to Conda Forge’s package dependency rules.

Docs

Docs are always built and doc artifacts are attached to the build:

- HTML
- PDF
- Misspelled words

Push to pdal.io

Docs are pushed to pdal.io under the following conditions:

- Doc building succeeds
- The push branch denoted in `./github/workflows/docs.yaml` matches the current `*-maintenance` branch.

14.3 API

PDAL is a C++ library, and its primary API is in that language. There is also a *Python* (page 297) 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 447).

14.3.1 C++ API

`pdal::BOX2D`

class `pdal::BOX2D`

BOX2D (page 523) represents a two-dimensional box with double-precision bounds.

Subclassed by `pdal::BOX3D` (page 526)

Public Functions

inline `BOX2D()`

Construct an “empty” bounds box.

inline `BOX2D(double minx, double miny, double maxx, double maxy)`

Construct and initialize a bounds box.

Parameters

- `minx` – Minimum X value.
- `miny` – Minimum Y value.
- `maxx` – Maximum X value.
- `maxy` – Maximum Y value.

bool `empty() const`

Determine whether a bounds box has not had any bounds set.

Returns Whether the bounds box is empty.

bool `valid() const`

Determine whether a bounds box has had any bounds set.

Returns Whether the bounds box is valid.

void clear()

Clear the bounds box to an empty state.

BOX2D (page 523) &**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 523) &**grow**(double dist)

Expand the bounds of the box in all directions by a specified amount.

Parameters **dist** – Distance by which to expand the box.

inline bool contains(double x, double y) const

Determine if a bounds box contains a point.

Parameters

- **x** – X dimension value.
- **y** – Y dimension value.

Returns Whether both dimensions are equal to or less than the maximum box values and equal to or more than the minimum box values.

inline bool equal(const *BOX2D* (page 523) &other) const

Determine if the bounds of this box are the same as that of another box.

Empty bounds boxes are always equal.

Parameters **other** – Bounds box to check for equality.

Returns true if the provided box has equal limits to this box, false otherwise.

inline bool operator==(*BOX2D* (page 523) const &other) const

Determine if the bounds of this box are the same as that of another box.

Empty bounds boxes are always equal.

Parameters **other** – Bounds box to check for equality.

Returns true if the provided box has equal limits to this box, false otherwise.

inline bool operator!=(*BOX2D* (page 523) const &other) const

Determine if the bounds of this box are different from that of another box.

Empty bounds boxes are never unequal.

Parameters **other** – Bounds box to check for inequality.

Returns `true` if the provided box has limits different from this box,
`false` otherwise.

inline `BOX2D` (page 523) `&grow`(const `BOX2D` (page 523) `&other`)
Expand this box to contain another box.

Parameters `other` – Box that this box should contain.

inline void `clip`(const `BOX2D` (page 523) `&other`)
Clip this bounds box by another so it will be contained by the other box.

Parameters `other` – Clipping box for this box.

inline bool `contains`(const `BOX2D` (page 523) `&other`) const
Determine if another bounds box is contained in this bounds box.
Equal limits are considered to be contained.

Parameters `other` – Bounds box to check for containment.

Returns `true` if the provided box is contained in this box, `false`
otherwise.

inline bool `overlaps`(const `BOX2D` (page 523) `&other`) const
Determine if another box overlaps this box.

Parameters `other` – Box to test for overlap.

Returns Whether the provided box overlaps this box.

inline std::string `toBox`(uint32_t precision = 8) const
Convert this box to a string suitable for use in SQLite.

Parameters `precision` – Precision for output [default: 8]

Returns String format of this box.

inline std::string `toWKT`(uint32_t precision = 8) const
Convert this box to a well-known text string.

Parameters `precision` – Precision for output [default: 8]

Returns String format of this box.

inline std::string `toGeoJSON`(uint32_t precision = 8) const
Convert this box to a GeoJSON text string.

Parameters `precision` – Precision for output [default: 8]

Returns String format of this box.

void `parse`(const std::string &s, std::string::size_type &pos)
Parse a string as a `BOX2D` (page 523).

Parameters

- **s** – String representation of the box.
- **pos** – Position in the string at which to start parsing. On return set to parsing end position.

Public Members

double **minx**
Minimum X value.

double **maxx**
Maximum X value.

double **miny**
Minimum Y value.

double **maxy**
Maximum Y value.

Public Static Functions

static const *BOX2D* (page 523) &**getDefaultSpatialExtent()**
Return a statically-allocated Bounds extent that represents infinity.

Returns A bounds box with infinite bounds,

struct **error** : public std::runtime_error

Public Functions

inline **error**(const std::string &err)

class pdal::**BOX3D** : private pdal::*BOX2D* (page 523)
BOX3D (page 526) represents a three-dimensional box with double-precision bounds.

Public Functions

inline **BOX3D()**

Clear the bounds box to an empty state.

inline **BOX3D**(const *BOX3D* (page 527) &box)

BOX3D (page 526) &**operator=**(const *BOX3D* (page 526) &box) = default

inline explicit **BOX3D**(const *BOX2D* (page 523) &box)

inline **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).

Returns Whether the bounds box is empty.

bool **valid()** const

Determine whether a bounds box has had any bounds set.

Returns \true if the bounds box is not empty

BOX3D (page 526) &**grow**(double x, double y, double z)

Expand the bounds of the box if a value is less than the current minimum or greater than the current maximum.

If the bounds box is currently empty, both minimum and maximum box bounds will be set to the provided value.

Parameters

- **x** – X dimension value.

- **y** – Y dimension value.
- **z** – Z dimension value.

void clear()

Clear the bounds box to an empty state.

inline bool contains(double x, double y, double z) const

Determine if a bounds box contains a point.

Parameters

- **x** – X dimension value.
- **y** – Y dimension value.
- **z** – Z dimension value.

Returns Whether both dimensions are equal to or less than the maximum box values and equal to or more than the minimum box values.

inline bool contains(const *BOX3D* (page 526) &other) const

Determine if another bounds box is contained in this bounds box.

Equal limits are considered to be contained.

Parameters other – Bounds box to check for containment.

Returns `true` if the provided box is contained in this box, `false` otherwise.

inline bool equal(const *BOX3D* (page 526) &other) const

Determine if the bounds of this box are the same as that of another box.

Empty bounds boxes are always equal.

Parameters other – Bounds box to check for equality.

Returns `true` if the provided box has equal limits to this box, `false` otherwise.

inline bool operator==(*BOX3D* (page 526) const &rhs) const

Determine if the bounds of this box are the same as that of another box.

Empty bounds boxes are always equal.

Parameters other – Bounds box to check for equality.

Returns `true` if the provided box has equal limits to this box, `false` otherwise.

inline bool operator!=(*BOX3D* (page 526) const &rhs) const

Determine if the bounds of this box are different from that of another box.

Empty bounds boxes are never unequal.

Parameters **other** – Bounds box to check for inequality.

Returns **true** if the provided box has limits different from this box, **false** otherwise.

inline *BOX3D* (page 526) &**grow**(const *BOX3D* (page 526) &other)

Expand this box to contain another box.

Parameters **other** – Box that this box should contain.

inline *BOX3D* (page 526) &**grow**(double dist)

Expand this box by a specified amount.

Parameters **dist** – Distance by which box should be expanded.

inline void **clip**(const *BOX3D* (page 526) &other)

Clip this bounds box by another so it will be contained by the other box.

Parameters **other** – Clipping box for this box.

inline bool **overlaps**(const *BOX3D* (page 526) &other) const

Determine if another box overlaps this box.

Parameters **other** – Box to test for overlap.

Returns Whether the provided box overlaps this box.

inline *BOX2D* (page 523) **to2d**() const

Convert this box to 2-dimensional bounding box.

Returns Bounding box with Z dimension stripped.

inline std::string **toBox**(uint32_t precision = 8) const

Convert this box to a string suitable for use in SQLite.

Parameters **precision** – Precision for output [default: 8]

Returns String format of this box.

inline std::string **toWKT**(uint32_t precision = 8) const

Convert this box to a well-known text string.

Parameters **precision** – Precision for output [default: 8]

Returns String format of this box.

void **parse**(const std::string &s, std::string::size_type &pos)

Parse a string as a *BOX3D* (page 526).

Parameters

- **s** – String representation of the box.
- **pos** – Position in the string at which to start parsing. On return set to parsing end position.

Public Members

double **minz**
Minimum Z value.

double **maxz**
Maximum Z value.

double **minx**
Minimum X value.

double **maxx**
Maximum X value.

double **miny**
Minimum Y value.

double **maxy**
Maximum Y value.

Public Static Functions

static const *BOX3D* (page 526) &**getDefaultSpatialExtent()**
Return a statically-allocated Bounds extent that represents infinity.

Returns A bounds box with infinite bounds,

struct **error** : public std::runtime_error

Public Functions

inline **error**(const std::string &err)

pdal::Charbuf

class pdal::Charbuf : public std::streambuf
Allow a data buffer to be used at a std::streambuf.

Public Functions

inline PDAL_DLL Charbuf()

Construct an empty *Charbuf* (page 531).

inline PDAL_DLL Charbuf(std::vector<char> &v, pos_type bufOffset = 0)

Construct a *Charbuf* (page 531) that wraps a byte vector.

Parameters

- **v** – Byte vector to back streambuf.
- **bufOffset** – Offset in vector (ignore bytes before offset).

inline PDAL_DLL Charbuf(char *buf, size_t count, pos_type bufOffset = 0)

Construct a *Charbuf* (page 531) that wraps a byte buffer.

Parameters

- **buf** – Buffer to back streambuf.
- **count** – Size of buffer.
- **bufOffset** – Offset in vector (ignore bytes before offset).

**PDAL_DLL void initialize (char *buf, size_t count,
pos_type bufOffset=0)**

Set a buffer to back a *Charbuf* (page 531).

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:

enumerator `None`

enumerator `Signed`

enumerator `Unsigned`

enumerator `Floating`

enum `Type`

Values:

enumerator `None`

enumerator `Unsigned8`

enumerator `Signed8`

enumerator `Unsigned16`

enumerator `Signed16`

enumerator `Unsigned32`

enumerator `Signed32`

enumerator `Unsigned64`

enumerator `Signed64`

enumerator `Float`

enumerator `Double`

Functions

inline *BaseType* (page 532) **fromName**(std::string name)

inline std::string **toName**(*BaseType* (page 532) b)

inline std::size_t **size**(*Type* (page 532) t)

inline *BaseType* (page 532) **base**(*Type* (page 532) t)

inline std::string **interpretationName**(*Type* (page 532) dimtype)
Get a string representation of a datatype.

Parameters **dimtype** – [in] *Dimension* (page 532) type.

Returns String representation of dimension type.

inline *Type* (page 532) **type**(std::string s)

Get the type corresponding to a type name.

Parameters **s** – Name of type.

Returns Corresponding type enumeration value.

inline *Type* (page 532) **type**(const std::string &baseType, size_t size)

inline std::size_t **extractName**(const std::string &s, std::string::size_type p)
Extract a dimension name of a string.

Dimension (page 532) names start with an alpha and continue with numbers or underscores.

Parameters

- **s** – String from which to extract dimension name.
- **p** – Position at which to start extracting.

Returns Number of characters in the extracted name.

inline std::string **fixName**(std::string name)

inline bool **nameValid**(std::string name)

inline std::istream &**operator>>**(std::istream &in, *Dimension* (page 532)::*Type* (page 532) &type)

```
inline std::ostream &operator<<(std::ostream &out, const Dimension (page 532)::Type  
                                (page 532) &type)
```

Variables

```
static const int COUNT = 1024  
static const int PROPRIETARY = 512  
class Detail  
    #include <DimDetail.hpp>
```

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

```
inline Extractor(const char *buf, std::size_t size)
```

Construct an extractor to operate on a buffer.

Parameters

- **buf** – Buffer to extract from.
- **size** – Buffer size.

```
inline operator bool()
```

Determine if the buffer is good.

Returns Whether the buffer is good.

```
inline void seek(std::size_t pos)
```

Seek to a position in the buffer.

Parameters **pos** – Position to seek in buffer.

```
inline void skip(std::size_t cnt)
```

Advance buffer position.

Parameters **cnt** – Number of bytes to skip in buffer.

```
inline size_t position() const
```

Return the get position of buffer.

Returns Get position.

inline bool **good()** const

Determine whether the extractor is good (the get pointer is in the buffer).

Returns Whether the get pointer is valid.

inline void **get**(std::string &s, size_t size)

Extract a string of a particular size from the buffer.

Trim trailing null bytes.

Parameters

- **s** – String to extract to.

- **size** – Number of bytes to extract from buffer into string.

inline void **get**(std::vector<char> &buf)

Extract data to char vector.

Vector must be sized to indicate number of bytes to extract.

Parameters **buf** – Vector to which bytes should be extracted.

inline void **get**(std::vector<unsigned char> &buf)

Extract data to unsigned char vector.

Vector must be sized to indicate number of bytes to extract.

Parameters **buf** – Vector to which bytes should be extracted.

inline void **get**(char *buf, size_t size)

Extract data into a provided buffer.

Parameters

- **buf** – Pointer to buffer to which bytes should be extracted.

- **size** – Number of bytes to extract.

inline void **get**(unsigned char *buf, size_t size)

Extract data into a provided unsigned buffer.

Parameters

- **buf** – Pointer to buffer to which bytes should be extracted.

- **size** – Number of bytes to extract.

virtual *Extractor* (page 534) &**operator>>**(uint8_t &v) = 0

virtual *Extractor* (page 534) &**operator>>**(int8_t &v) = 0

virtual *Extractor* (page 534) &**operator>>**(uint16_t &v) = 0

virtual *Extractor* (page 534) &**operator>>**(int16_t &v) = 0

virtual *Extractor* (page 534) &**operator>>**(uint32_t &v) = 0

virtual *Extractor* (page 534) &**operator>>**(int32_t &v) = 0

virtual *Extractor* (page 534) &**operator>>**(uint64_t &v) = 0

virtual *Extractor* (page 534) &**operator>>**(int64_t &v) = 0

virtual *Extractor* (page 534) &**operator>>**(float &v) = 0

virtual *Extractor* (page 534) &**operator>>**(double &v) = 0

pdal::FileUtils

namespace pdal::FileUtils

Functions

std::istream ***openFile**(std::string const &filename, bool asBinary = true)

Open an existing file for reading.

Parameters

- **filename** – Filename.
- **asBinary** – Read as binary file (don't convert /r/n to /n)

Returns Pointer to opened stream.

std::ostream ***createFile**(std::string const &filename, bool asBinary = true)

Create/truncate a file and open for writing.

Parameters

- **filename** – Filename.
- **asBinary** – Write as binary file (don't convert /n to /r/n)

Returns Point to opened stream.

`std::ostream *openExisting(std::string const &filename, bool asBinary = true)`

Open an existing file for write.

Parameters

- **filename** – Filename.
- **asBinary** – Write as binary file (don't convert /n to /r/n)

Returns Point to opened stream.

`bool directoryExists(const std::string &dirname)`

Determine if a directory exists.

Parameters **dirname** – Name of directory.

Returns Whether a directory exists.

`bool createDirectory(const std::string &dirname)`

Create a directory.

Parameters **dirname** – Directory name.

Returns Whether the directory was created.

`bool createDirectories(const std::string &path)`

Create all directories in the provided path.

Parameters **dirname** – Path name.

Returns \false on failure

`void deleteDirectory(const std::string &dirname)`

Delete a directory and its contents.

Parameters **dirname** – Directory name.

`std::vector<std::string> directoryList(const std::string &dirname)`

List the contents of a directory.

Parameters **dirname** – Name of directory to list.

Returns List of entries in the directory.

`void closeFile(std::ostream *ofs)`

Close a file created with `createFile`.

Parameters **ofs** – Pointer to stream to close.

`void closeFile(std::istream *ifs)`

Close a file created with `openFile`.

Parameters **ifs** – Pointer to stream to close.

bool deleteFile(const std::string &filename)

Delete a file.

Parameters filename – Name of file to delete.

Returns true if successful, false otherwise

void renameFile(const std::string &dest, const std::string &src)

Rename a file.

Parameters

- **dest** – Desired filename.

- **src** – Source filename.

bool fileExists(const std::string &filename)

Determine if a file exists.

Parameters Filename. –

Returns Whether the file exists.

uintmax_t fileSize(const std::string &filename)

Get the size of a file.

Parameters filename – Filename.

Returns 0 on error or invalid file type.

Returns Size of file.

std::string readFileToString(const std::string &filename)

Read a file into a string.

Parameters filename – Filename.

Returns File contents as a string

std::string getcwd()

Get the current working directory with trailing separator.

Returns The current working directory.

std::string toCanonicalPath(std::string filename)

Return the path with all “.”, “..” and symbolic links removed.

The file must exist.

Parameters filename – Name of file to convert to canonical path.

Returns Canonical version of provided filename, or empty string.

std::string toAbsolutePath(const std::string &filename)

If the filename is an absolute path, just return it otherwise, make it absolute (relative to current working dir) and return it.

Parameters `filename` – Name of file to convert to absolute path.

Returns Absolute version of provided filename.

`std::string toAbsolutePath(const std::string &filename, const std::string base)`

If the filename is an absolute path, just return it otherwise, make it absolute (relative to base dir) and return that.

Parameters

- `filename` – Name of file to convert to absolute path.
- `base` – Base name to use.

Returns Absolute version of provided filename relative to base.

`std::string getFilename(const std::string &path)`

Return the file component of the given path, e.g.

“d:/foo/bar/a.c” -> “a.c”

Parameters `path` – Path from which to extract file component.

Returns File part of path.

`std::string getDirectory(const std::string &path)`

Return the directory component of the given path, e.g.

“d:/foo/bar/a.c” -> “d:/foo/bar/”

Parameters `path` – Path from which to extract directory component.

Returns Directory part of path.

`std::string stem(const std::string &path)`

Return the filename stripped of the extension.

. and .. are returned unchanged.

Parameters `path` – File path from which to extract file stem.

Returns Stem of filename.

`bool isDirectory(const std::string &path)`

Determine if path is a directory.

Parameters `path` – Directory to check.

Returns Whether the path represents a directory.

`bool isAbsolutePath(const std::string &path)`

Determine if the path is an absolute path.

Parameters `path` – Path to test.

Returns Whether the path is absolute.

```
void fileTimes(const std::string &filename, struct tm *createTime, struct tm  
    *modTime)
```

Get the file creation and modification times.

Parameters

- **filename** – Filename.
- **createTime** – Pointer to creation time structure.
- **modTime** – Pointer to modification time structure.

```
std::string extension(const std::string &path)
```

Return the extension of the filename, including the separator (.).

Parameters **path** – File path from which to extract extension.

Returns Extension of filename.

```
std::vector<std::string> glob(std::string filespec)
```

Expand a filespec to a list of files.

Parameters **filespec** – File specification to expand.

Returns List of files that correspond to provided file specification.

MapContext (page 540) **mapFile**(const std::string &filename, bool readOnly = true,
 uintmax_t pos = 0, uintmax_t size = 0)

Map a file to memory.

Parameters

- **filename** – Filename to map.
- **readOnly** – Must be true at this time.
- **pos** – Starting position of file to map.
- **size** – Number of bytes in file to map.

Returns *MapContext* (page 540). `addr()` gets the mapped address. `what()` gets any error message. `addr()` returns `nullptr` on error.

MapContext (page 540) **unmapFile**(*MapContext* (page 540) ctx)

Unmap a previously mapped file.

Parameters **ctx** – Previously returned *MapContext* (page 540)

Returns *MapContext* (page 540) indicating current state of the file mapping.

```
struct MapContext  
#include <FileUtils.hpp>
```

pdal::Filter

```
class pdal::Filter : public virtual pdal::Stage (page 559)
    Subclassed by pdal::ApproximateCoplanarFilter, pdal::AssignFilter, pdal::CSFilter,
    pdal::ChipperFilter, pdal::ClusterFilter, pdal::ColorinterpFilter, pdal::ColorizationFilter,
    pdal::CovarianceFeaturesFilter, pdal::CpdFilter, pdal::CropFilter, pdal::DBSCANFilter,
    pdal::DEMFilter, pdal::DecimationFilter, pdal::DelaunayFilter, pdal::DividerFilter,
    pdal::ELMFilter, pdal::EigenvaluesFilter, pdal::EstimateRankFilter,
    pdal::FaceRasterFilter, pdal::FarthestPointSamplingFilter, pdal::FerryFilter,
    pdal::GpsTimeConvert, pdal::GreedyProjection, pdal::GroupByFilter,
    pdal::HagDelaunayFilter, pdal::HagDemFilter, pdal::HagNnFilter, pdal::HeadFilter,
    pdal::HexBin, pdal::IQRFilter, pdal::InfoFilter, pdal::IterativeClosestPoint,
    pdal::LOFFilter, pdal::LiTreeFilter, pdal::LloydKMeansFilter, pdal::LocateFilter,
    pdal::MADFilter, pdal::MatlabFilter, pdal::MergeFilter, pdal::MiniballFilter,
    pdal::MongoExpressionFilter, pdal::MortonOrderFilter, pdal::NNDistanceFilter,
    pdal::NeighborClassifierFilter, pdal::NormalFilter, pdal::OptimalNeighborhood,
    pdal::OutlierFilter, pdal::OverlayFilter, pdal::PMFFilter, pdal::PlaneFitFilter,
    pdal::PoissonFilter, pdal::ProjPipelineFilter, pdal::RadialDensityFilter,
    pdal::RandomizeFilter, pdal::RangeFilter, pdal::ReciprocityFilter,
    pdal::RelaxationDartThrowing, pdal::ReprojectionFilter, pdal::ReturnsFilter,
    pdal::SMRFilter, pdal::SampleFilter, pdal::SeparateScanLineFilter, pdal::ShellFilter,
    pdal::SkewnessBalancingFilter, pdal::SortFilter, pdal::SplitterFilter, pdal::StatsFilter,
    pdal::StreamCallbackFilter, pdal::TailFilter, pdal::TeaserFilter,
    pdal::TransformationFilter, pdal::VoxelCenterNearestNeighborFilter,
    pdal::VoxelCentroidNearestNeighborFilter, pdal::VoxelDownsizeFilter,
    pdal::ZsmoothFilter
```

Public Functions

Filter()

~Filter()

Filter (page 541) **&operator=**(const *Filter* (page 541)&) = delete

Filter(const *Filter* (page 541)&) = delete

struct **Args**

Public Members

expr::ConditionalExpression **m_where**
Arg ***m_whereArg**
Filter (page 541)::WhereMergeMode **m_whereMerge**
Arg ***m_whereMergeArg**

pdal::IStream

class **pdal::IStream**
Stream wrapper for input of binary data.
Subclassed by pdal::IBeStream, pdal::ILeStream, pdal::ISwitchableStream

Public Functions

inline PDAL_DLL **IStream()**
Default constructor.

inline PDAL_DLL **IStream(const std::string &filename)**
Construct an *IStream* (page 542) from a filename.

Parameters **filename** – File from which to read.

inline PDAL_DLL **IStream(std::istream *stream)**
Construct an *IStream* (page 542) from an input stream pointer.

Parameters **stream** – Stream from which to read.

inline PDAL_DLL **~IStream()**

inline PDAL_DLL int open (const std::string &filename)
Open a file to extract.

Parameters **filename** – Filename.

Returns -1 if a stream is already assigned, 0 otherwise.

inline PDAL_DLL void close ()
Close the underlying stream.

inline PDAL_DLL operator bool()
Return the state of the stream.

Returns The state of the underlying stream.

inline PDAL_DLL void seek (std::streampos pos)

Seek to a position in the underlying stream.

Parameters **pos** – Position to seek to,

**inline PDAL_DLL void seek (std::streampos off,
std::ios_base::seekdir way)**

Seek to an offset from a specified position.

Parameters

- **off** – Offset.

- **way** – Absolute position for offset (beg, end or cur)

inline PDAL_DLL void skip (std::streamoff offset)

Skip relative to the current position.

Parameters **offset** – Offset from the current position.

inline PDAL_DLL std::streampos position () const

Determine the position of the get pointer.

Returns Current get position.

inline PDAL_DLL bool good () const

Determine if the underlying stream is good.

Returns Whether the underlying stream is good.

inline PDAL_DLL std::istream * stream ()

Fetch a pointer to the underlying stream.

Returns Pointer to the underlying stream.

inline PDAL_DLL void pushStream (std::istream *strm)

Temporarily push a stream to read from.

Parameters **strm** – New stream to read from.

inline PDAL_DLL std::istream * popStream ()

Pop the current stream and return it.

The last stream on the stack cannot be popped.

Returns Pointer to the popped stream.

inline PDAL_DLL void get (std::string &s, size_t size)

Fetch data from the stream into a string.

NOTE - Stops when a null byte is encountered. Use a buffer/vector reader to read data with embedded nulls.

Parameters

- **s** – String to fill.
- **size** – Maximum number of bytes to extract.

inline PDAL_DLL void get (std::vector< char > &buf)

Fetch data from the stream into a vector of char.

Parameters **buf** – Buffer to fill.

inline PDAL_DLL void get (std::vector< unsigned char > &buf)

Fetch data from the stream into a vector of unsigned char.

Parameters **buf** – Buffer to fill.

inline PDAL_DLL void get (char *buf, size_t size)

Fetch data from the stream into the specified buffer of char.

Parameters

- **buf** – Buffer to fill.
- **size** – Number of bytes to extract.

inline PDAL_DLL void get (unsigned char *buf, size_t size)

Fetch data from the stream into the specified buffer of unsigned char.

Parameters

- **buf** – Buffer to fill.
- **size** – Number of bytes to extract.

pdal::Log

class pdal::Log

pdal::Log (page 544) is a logging object that is provided by *pdal::Stage* (page 559) to facilitate logging operations.

Log stream operations

inline std::ostream ***getLogStream()**

Returns the stream object that is currently being used to for log operations regardless of logging level of the instance.

std::ostream &**get**(LogLevel level = LogLevel::Info)

Returns the log stream given the logging level.

Parameters **level** – logging level to request If the logging level asked for with *pdal::Log::get* (page 545) is less than the logging level of the *pdal::Log* (page 544) instance

void **floatPrecision**(int level)

Sets the floating point precision.

void **clearFloat()**

Clears the floating point precision settings of the streams.

Destructor

~Log()

The destructor will clean up its own internal log stream, but it will not touch one that is given via the constructor.

Logging level

inline LogLevel **getLevel()**

Returns the logging level of the *pdal::Log* (page 544) instance

inline void **setLevel**(LogLevel v)

Sets the logging level of the *pdal::Log* (page 544) instance.

Parameters **v** – logging level to use for *get()* (page 545) comparison operations

inline void **setLeader**(const std::string &leader)

Set the leader string (deprecated).

Parameters **leader** – [in] Leader string.

inline void **pushLeader**(const std::string &leader)

Push the leader string onto the stack.

Parameters **leader** – Leader string

```
inline std::string leader() const  
    Get the leader string.
```

Returns The current leader string.

```
inline void popLeader()  
    Pop the current leader string.
```

```
std::string getLevelString(LogLevel v) const
```

Returns A string representing the LogLevel

Public Static Functions

```
static LogPtr makeLog(std::string const &leaderString, std::string const &outputName,  
                      bool timing = false)
```

```
static LogPtr makeLog(std::string const &leaderString, std::ostream *v, bool timing =  
                      false)
```

pdal::Metadata

```
class pdal::Metadata
```

Public Functions

```
inline Metadata()
```

```
inline Metadata(const std::string &name)
```

```
inline MetadataNode (page 547) getNode() const
```

Public Static Functions

```
static std::string PDAL_DLL inferType (const std::string &val)  
class pdal::MetadataNode
```

Public Functions

inline **MetadataNode()**

inline **MetadataNode**(const std::string &name)

inline *MetadataNode* (page 547) **add**(const std::string &name)

inline *MetadataNode* (page 547) **addList**(const std::string &name)

inline *MetadataNode* (page 547) **clone**(const std::string &name) const

inline *MetadataNode* (page 547) **add**(*MetadataNode* (page 547) node)

inline *MetadataNode* (page 547) **addList**(*MetadataNode* (page 547) node)

inline *MetadataNode* (page 547) **addEncoded**(const std::string &name, const unsigned char *buf, size_t size, const std::string &descrip = std::string())

inline *MetadataNode* (page 547) **addListEncoded**(const std::string &name, const unsigned char *buf, size_t size, const std::string &descrip = std::string())

inline *MetadataNode* (page 547) **addWithType**(const std::string &name, const std::string &value, const std::string &type, const std::string &descrip)

```
inline MetadataNode (page 547) add(const std::string &name, const double &value,  
                                const std::string &descrip = std::string(), size_t  
                                precision = 10)
```

```
template<typename T>  
inline MetadataNode (page 547) add(const std::string &name, const T (page 548)  
                                &value, const std::string &descrip = std::string())
```

```
template<typename T>  
inline MetadataNode (page 547) addList(const std::string &name, const T (page 548)  
                                &value, const std::string &descrip =  
                                std::string())
```

```
inline MetadataNode (page 547) addOrUpdate(const std::string &lname, const double  
                                &value, const std::string &descrip =  
                                std::string(), size_t precision = 10)
```

```
template<typename T>  
inline MetadataNode (page 547) addOrUpdate(const std::string &lname, const T  
                                (page 548) &value)
```

```
template<typename T>  
inline MetadataNode (page 547) addOrUpdate(const std::string &lname, const T  
                                (page 548) &value, const std::string  
                                &descrip)
```

```
inline MetadataNode (page 547) addOrUpdate(MetadataNode (page 547) n)
```

```
inline std::string type() const
```

```
inline MetadataType kind() const
```

```
inline std::string name() const
```

```
template<typename T>  
inline T (page 548) value() const
```

```
inline std::string value() const
```

```
inline std::string jsonValue() const  
  
inline std::string description() const  
  
inline MetadataNodeList children() const  
  
inline MetadataNodeList children(const std::string &name) const  
  
inline bool hasChildren() const  
  
inline std::vector<std::string> childNames() const  
  
inline operator bool() const  
  
inline bool operator!()  
  
inline bool valid() const  
  
inline bool empty() const  
  
template<typename PREDICATE>  
inline MetadataNode (page 547) find(PREDICATE (page 549) p) const  
  
template<typename PREDICATE>  
inline MetadataNodeList findChildren(PREDICATE (page 549) p)  
  
template<typename PREDICATE>  
inline MetadataNode (page 547) findChild(PREDICATE (page 549) p) const  
  
inline MetadataNode (page 547) findChild(const char *s) const  
  
inline MetadataNode (page 547) findChild(std::string s) const
```

pdal::Options

class pdal::Options

Public Functions

inline Options()

inline explicit Options(const Option &opt)

void add(const Option &option)

void add(const *Options* (page 550) &options)

void addConditional(const Option &option)

void addConditional(const *Options* (page 550) &option)

void remove(const Option &option)

inline void replace(const Option &option)

inline void toMetadata(*MetadataNode* (page 547) &parent) const

template<typename T>

inline void add(const std::string &name, *T* (page 550) value)

inline void add(const std::string &name, const std::string &value)

inline void add(const std::string &name, const bool &value)

template<typename T>

inline void replace(const std::string &name, *T* (page 550) value)

inline void replace(const std::string &name, const std::string &value)

```
inline void replace(const std::string &name, const bool &value)  
  
inline StringList getValues(const std::string &name) const  
  
inline StringList getKeys() const  
  
std::vector<Option> getOptions(std::string const &name = "") const
```

StringList `toCommandLine`() const
Convert options to a string list appropriate for parsing with *ProgramArgs* (page 555).

Returns List of options as argument strings.

Public Static Functions

```
static Options (page 550) fromFile(const std::string &filename, bool  
throwOnOpenError = true)
```

pdal::PointTable

Warning: doxygenclass: Cannot find class “pdal::PointTable” in doxygen xml output for project “api” from directory: doxygen/xml

pdal::PointView

```
class pdal::PointView : public pdal::PointContainer
```

Public Functions

PointView(const *PointView* (page 551)&) = delete

PointView (page 551) &**operator=**(const *PointView* (page 551)&) = delete

PointView(PointTableRef pointTable)

```
PointView(PointTableRef pointTable, const SpatialReference &srs)

virtual ~PointView()

PointViewIter begin()

PointViewIter end()

inline int id() const

inline point_count_t size() const

inline bool empty() const

inline void appendPoint(const PointView (page 551) &buffer, PointId id)

inline void append(const PointView (page 551) &buf)

inline PointViewPtr makeNew() const
    Return a new point view with the same point table as this point buffer.

inline PointRef point(PointId id)

template<class T>
inline T (page 552) getFieldAs(Dimension (page 532)::Id dim, PointId pointIndex)
    const

inline void getField(char *pos, Dimension (page 532)::Id d, Dimension
    (page 532)::Type (page 532) type, PointId id) const

template<typename T>
void setField(Dimension (page 532)::Id dim, PointId idx, T (page 552) val)

inline void setField(Dimension (page 532)::Id dim, Dimension (page 532)::Type
    (page 532) type, PointId idx, const void *val)

template<typename T>
```

```
inline virtual bool compare(Dimension (page 532)::Id dim, PointId id1, PointId id2)  
    const
```

```
inline virtual bool compare(Dimension (page 532)::Id dim, PointId id1, PointId id2)  
    const
```

```
void calculateBounds(BOX2D (page 523) &box) const
```

Returns a cumulated bounds of all points in the *PointView* (page 551).

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 526) &box) const
```

```
void dump(std::ostream &ostr) const
```

```
inline bool hasDim(Dimension (page 532)::Id id) const
```

```
inline std::string dimName(Dimension (page 532)::Id id) const
```

```
inline Dimension (page 532)::IdList dims() const
```

```
inline std::size_t pointSize() const
```

```
inline std::size_t dimSize(Dimension (page 532)::Id id) const
```

```
inline Dimension (page 532)::Type (page 532) dimType(Dimension (page 532)::Id id)  
    const
```

```
inline DimTypeList dimTypes() const
```

```
inline virtual PointLayoutPtr layout() const
```

inline PointTableRef **table()** const

inline SpatialReference **spatialReference()** const

inline void **getPackedPoint**(const DimTypeList &dims, PointId idx, char *buf) const
Fill a buffer with point data specified by the dimension list.

Parameters

- **dims** – [in] List of dimensions/types to retrieve.
- **idx** – [in] Index of point to get.
- **buf** – [in] Pointer to buffer to fill.

inline void **setPackedPoint**(const DimTypeList &dims, PointId idx, const char *buf)
Load the point buffer from memory whose arrangement is specified by the dimension list.

Parameters

- **dims** – [in] Dimension/types of data in packed order
- **idx** – [in] Index of point to write.
- **buf** – [in] Packed data buffer.

inline char ***getPoint**(PointId id)

Provides access to the memory storing the point data.

Though this function is public, other access methods are safer and preferred.

inline char ***getOrAddPoint**(PointId id)

Provides access to the memory storing the point data.

Though this function is public, other access methods are safer and preferred.

inline void **clearTemps()**

MetadataNode (page 547) **toMetadata()** const

void **invalidateProducts()**

TriangularMesh ***createMesh**(const std::string &name)

Creates a mesh with the specified name.

Parameters **name** – Name of the mesh.

Returns Pointer to the new mesh. Null is returned if the mesh already exists.

```
TriangularMesh *mesh(const std::string &name = "")
```

Get a pointer to a mesh.

Parameters **name** – Name of the mesh.

Returns New mesh. Null is returned if the mesh already exists.

```
Rasterd *createRaster(const std::string &name, const RasterLimits &limits, double  
noData = 0)
```

Creates a raster with the specified name.

Parameters

- **name** – Name of the raster.
- **limits** – Limits of the raster to create.

Returns Pointer to the new raster. Null is returned if the raster already exists.

```
Rasterd *raster(const std::string &name = "")
```

Get a pointer to a raster.

Parameters **name** – Name of the raster.

Returns Pointer to the New raster. Null

```
KD3Index &build3dIndex()
```

```
KD2Index &build2dIndex()
```

Friends

```
friend class plang::Invocation
```

pdal::ProgramArgs

```
class pdal::ProgramArgs
```

Parses command lines, provides validation and stores found values in bound variables.

Add arguments with *add* (page 556). When all arguments have been added, use *parse* (page 558) to validate command line and assign values to variables bound with *add* (page 556).

Public Functions

```
inline Arg &add(const std::string &name, const std::string description, std::string &var,  
                 std::string def)
```

Add a string argument to the list of arguments.

Parameters

- **name** – Name of argument. Argument names are specified as “longname[,shortname]”, where shortname is an optional one-character abbreviation.
- **description** – Description of the argument.
- **var** – Reference to variable to bind to argument.
- **def** – Default value of argument.

Returns Reference to the new argument.

```
inline Arg &add(const std::string &name, const std::string &description,  
                 std::vector<std::string> &var)
```

Add a list-based (vector) string argument.

Parameters

- **name** – Name of argument. Argument names are specified as “longname[,shortname]”, where shortname is an optional one-character abbreviation.
- **description** – Description of the argument.
- **var** – Reference to variable to bind to argument.

Returns Reference to the new argument.

```
inline bool set(const std::string &name) const
```

Return whether the argument (as specified by it's longname) had its value set during parsing.

```
template<typename T>
```

```
inline Arg &add(const std::string &name, const std::string &description, std::vector<T  
                (page 556)> &var)
```

Add a list-based (vector) argument.

Parameters

- **name** – Name of argument. Argument names are specified as “longname[,shortname]”, where shortname is an optional one-character abbreviation.
- **description** – Description of the argument.

- **var** – Reference to variable to bind to argument.

Returns Reference to the new argument.

```
template<typename T>
inline Arg &add(const std::string &name, const std::string &description, std::vector<T> &var, std::vector<T> def)
    Add a list-based (vector) argument with a default.
```

Parameters

- **name** – Name of argument. Argument names are specified as “longname[,shortname]”, where shortname is an optional one-character abbreviation.
- **description** – Description of the argument.
- **var** – Reference to variable to bind to argument.

Returns Reference to the new argument.

```
template<typename T>
inline Arg &add(const std::string &name, const std::string description, T def)
    Add an argument to the list of arguments with a default.
```

Parameters

- **name** – Name of argument. Argument names are specified as “longname[,shortname]”, where shortname is an optional one-character abbreviation.
- **description** – Description of the argument.
- **var** – Reference to variable to bind to argument.
- **def** – Default value of argument.

Returns Reference to the new argument.

```
template<typename T>
inline Arg &add(const std::string &name, const std::string description, T def)
    Add an argument to the list of arguments.
```

Parameters

- **name** – Name of argument. Argument names are specified as “longname[,shortname]”, where shortname is an optional one-character abbreviation.
- **description** – Description of the argument.
- **var** – Reference to variable to bind to argument.

Returns Reference to the new argument.

inline void **parseSimple**(std::vector<std::string> &s)
Parse a command line as specified by its argument vector.

No validation occurs and only argument value exceptions are raised, but assignments are made to bound variables where possible.

Parameters **s** – List of strings that constitute the argument list.

inline void **parse**(const std::vector<std::string> &s)
Parse a command line as specified by its argument list.

Parsing validates the argument vector and assigns values to variables bound to added arguments.

Parameters **s** – List of strings that constitute the argument list.

inline void **addSynonym**(const std::string &name, const std::string &synonym)
Add a synonym for an argument.

Parameters

- **name** – Longname of existing argument.
- **synonym** – Synonym for argument.

inline void **reset**()

Reset the state of all arguments and bound variables as if no parsing had occurred.

inline std::string **commandLine**() const

Return a string suitable for use in a “usage” line for display to users as help.

inline void **dump**(std::ostream &out, size_t indent, size_t totalWidth) const
Write a formatted description of arguments to an output stream.

Write a list of the names and descriptions of arguments suitable for display as help information.

Parameters

- **out** – Stream to which output should be written.
- **indent** – Number of characters to indent all text.
- **totalWidth** – Total width to assume for formatting output.
Typically this is the width of a terminal window.

inline void **dump2**(std::ostream &out, size_t nameIndent, size_t descripIndent, size_t totalWidth) const

Write a verbose description of arguments to an output stream.

Each argument is on its own line. The argument’s description follows on subsequent lines.

Parameters

- **out** – Stream to which output should be written.
- **nameIndent** – Number of characters to indent argument lines.
- **descripIndent** – Number of characters to indent description lines.
- **totalWidth** – Total line width.

inline void **dump3**(std::ostream &out) const

Write a JSON array of arguments to an output stream.

Parameters **out** – Stream to which output should be written.

pdal::Reader

pdal::Reader (page 559) are classes that provided interfaces to various the various point cloud formats and hands them off to a PDAL pipeline in a common format that is described via the *pdal::Schema*.

class **Reader** : public virtual pdal::*Stage* (page 559)

Subclassed by pdal::BpfReader, pdal::BufferReader, pdal::DbReader, pdal::DracoReader, pdal::E57Reader, pdal::EptReader, pdal::EsriReader, pdal::FauxReader, pdal::GDALReader, pdal::HdfReader, pdal::IcebridgeReader, pdal::Ilvis2Reader, pdal::LasReader, pdal::MatlabReader, pdal::MbReader, pdal::MemoryViewReader, pdal::MrsidReader, pdal::OSGReader, pdal::ObjReader, pdal::OptechReader, pdal::PcdReader, pdal::PlyReader, pdal::PtsReader, pdal::QfitReader, pdal::RdbReader, pdal::RxpReader, pdal::SbetReader, pdal::TIndexReader, pdal::TerrasolidReader, pdal::TextReader, pdal::TileDBReader

pdal::Stage

pdal::Stage (page 559) is the base class of *pdal::Filter* (page 541), *pdal::Reader* (page 559), 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 560) into a pipeline. The pipeline is run with by calling in sequence *prepare()* (page 560) and *execute()* (page 560) 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 541), *pdal::Reader* (page 559), pdal::Streamable, *pdal::Writer* (page 584)

Public Types

enum **WhereMergeMode**

Values:

enumerator **Auto**

enumerator **True**

enumerator **False**

Public Functions

Stage()

virtual **~Stage()**

inline void **setInput**(*Stage* (page 559) &input)

Add a stage to the input list of this stage.

Parameters **input** – *Stage* (page 559) to use as input.

inline void **setProgressFd**(int fd)

Set a file descriptor to which progress information should be written.

Parameters **fd** – Progress file descriptor.

QuickInfo preview()

Retrieve some basic point information without reading all data when possible.

Usually implemented only by Readers.

void prepare(PointTableRef table)

Prepare a stage for execution.

This function needs to be called on the terminal stage of a pipeline (linked set of stages) before *execute* (page 560) can be called. Prepare recurses through all input stages.

Parameters **table** – PointTable 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 560) function.

inline virtual void **execute**(StreamPointTable &table)

inline virtual bool **pipelineStreamable**() const

Determine if a pipeline with this stage as a sink is streamable.

Returns Whether the pipeline is streamable.

inline virtual const [Stage](#) (page 559) ***findNonstreamable**() const

Return a pointer to a pipeline's first non-streamable stage, if one exists.

Returns nullptr if the stage is streamable, a pointer to this stage otherwise.

void **setSpatialReference**(SpatialReference const &srs)

Set the spatial reference of a stage.

Set the spatial reference that will override that being carried by the [PointView](#) (page 551) 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 559) 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 551) being processed. This is usually used when reprojecting data to a new spatial reference. The stage spatial reference will be carried by PointViews processes by this stage to subsequent stages.

Returns The stage's spatial reference.

inline void **setOptions**([Options](#) (page 550) options)

Set a stage's options.

Set the options on a stage, clearing all previously set options.

Parameters **options** – [Options](#) (page 550) to set.

void **addConditionalOptions**(const [Options](#) (page 550) &opts)

Add options if an option with the same name doesn't already exist on the stage.

Parameters **opts** – [Options](#) (page 550) to add.

void **addAllArgs**([ProgramArgs](#) (page 555) &args)

Add a stage's options to a [ProgramArgs](#) (page 555) set.

Parameters `args` – *ProgramArgs* (page 555) to add to.

inline void **addOptions**(const *Options* (page 550) &opts)

Add options to the existing option set.

Parameters `opts` – *Options* (page 550) to add.

inline void **removeOptions**(const *Options* (page 550) &opts)

Remove options from a stage's option set.

Parameters `opts` – *Options* (page 550) to remove.

inline void **setLog**(const LogPtr &log)

Set the stage's log.

Parameters `log` – *Log* (page 544) pointer.

inline virtual LogPtr **log**() const

Return the stage's log pointer.

Returns *Log* (page 544) pointer.

void **startLogging**() const

Push the stage's leader into the log.

void **stopLogging**() const

Pop the stage's leader from the log.

inline bool **isDebug**() const

Determine whether the stage is in debug mode or not.

Returns The stage's debug state.

virtual std::string **getName**() const = 0

Return the name of a stage.

Returns The stage's name.

inline void **setTag**(const std::string &tag)

Set a specific tag name.

inline virtual std::string **tag**() const

Return the tag name of a stage.

Returns The tag name.

inline std::vector<*Stage* (page 559)*> **&getInputs**()

Return a list of the stage's inputs.

Returns A vector pointers to input stages.

inline *MetadataNode* (page 547) **getMetadata**() const

Get the stage's metadata node.

Returns *Stage* (page 559)'s metadata.

```
void serialize(MetadataNode (page 547) root, PipelineWriter::TagMap &tags) const  
    Serialize a stage by inserting appropriate data into the provided MetadataNode  
    (page 547).
```

Used to dump a pipeline specification in a portable format.

Parameters

- **root** – Node to which a stages metadata should be added.
- **tags** – Pipeline writer's current list of stage tags.

Public Static Functions

```
static bool parseName(std::string o, std::string::size_type &pos)
```

Parse a stage name from a string.

Return the name and update the position in the input string to the end of the stage name.

Parameters

- ***o*** – Input string to parse.
- ***pos*** – Parsing start/end position.

Returns Whether the parsed name is a valid stage name.

```
static bool parseTagName(std::string o, std::string::size_type &pos)
```

Parse a tag name from a string.

Return the name and update the position in the input string to the end of the tag name.

Parameters

- ***o*** – Input string to parse.
- ***pos*** – Parsing start/end position.
- ***tag*** – Parsed tag name.

Returns Whether the parsed name is a valid tag name.

pdal::StageFactory

class pdal::StageFactory

This class provides a mechanism for creating [Stage](#) (page 559) 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 564) if desired.

Note: [Stage](#) (page 559) creation is thread-safe.

Public Functions

StageFactory(bool ignored = true)

Create a stage factory.

Parameters **ignored** – Ignored argument.

[Stage](#) (page 559) ***createStage**(const std::string &type)

Create a stage and return a pointer to the created stage.

The factory takes ownership of any successfully created stage.

Parameters **stage_name** – Type of stage to be created.

Returns Pointer to created stage.

void destroyStage([Stage](#) (page 559) *stage)

Destroy a stage created by this factory.

This doesn't need to be called unless you specifically want to destroy a stage as all stages are destroyed when the factory is destroyed.

Parameters **stage** – Pointer to stage to destroy.

Public Static Functions

static std::string inferReaderDriver(const std::string &filename)

Infer the reader to use based on a filename.

Find the default reader for a file.

Parameters

- **filename** – Filename that should be analyzed to determine a driver.

- **filename** – Filename for which to infer a reader.

Returns Driver name or empty string if no reader can be inferred from the filename.

Returns Name of the reader driver associated with the file.

```
static std::string inferWriterDriver(const std::string &filename)
```

Infer the writer to use based on filename extension.

Find the default writer for a file.

Parameters **filename** – Filename for which to infer a writer.

Returns Driver name or empty string if no writer can be inferred from the filename.

Returns Name of the writer driver associated with the file.

pdal::Utils

:cpp:namespace:`pdal::Utils` is a set of utility functions.

```
namespace pdal::Utils
```

TypeDefs

```
using BacktraceEntries = std::deque<BacktraceEntry (page 582)>
```

Functions

```
std::string toJSON(const MetadataNode (page 547) &m)
```

```
void toJSON(const MetadataNode (page 547) &m, std::ostream &o)
```

```
uintmax_t fileSize(const std::string &path)
```

```
std::ostream *createFile(const std::string &path, bool asBinary)
```

Create a file (may be on a supported remote filesystem).

Parameters

- **path** – Path to file to create.
- **asBinary** – Whether the file should be written in binary mode.

Returns Pointer to the created stream, or NULL.

`bool isRemote(const std::string &path)`
Open a file (potentially on a remote filesystem).

Parameters

- **path** – Path (potentially remote) of file to open.
- **asBinary** – Whether the file should be opened binary.

Returns Pointer to stream opened for input.

`std::string fetchRemote(const std::string &path)`

`std::istream *openFile(const std::string &path, bool asBinary)`

`void closeFile(std::ostream *out)`

Close an output stream.

Parameters **out** – Stream to close.

`void closeFile(std::istream *in)`

Close an input stream.

Parameters **out** – Stream to close.

`bool fileExists(const std::string &path)`

Check to see if a file exists.

Parameters **path** – Path to file.

Returns Whether the file exists or not.

`double computeHausdorff(PointViewPtr srcView, PointViewPtr candView)`

`std::pair<double, double> computeHausdorffPair(PointViewPtr viewA, PointViewPtr viewB)`

`std::string dllDir()`

`double computeChamfer(PointViewPtr srcView, PointViewPtr candView)`

`inline void printError(const std::string &s)`

`inline double toDouble(const Everything &e, Dimension (page 532)::Type (page 532) type)`

```
template<typename INPUT>
inline Everything extractDim(INPUT (page 566) &ext, Dimension (page 532)::Type
                           (page 532) type)

template<typename OUTPUT>
inline void insertDim(OUTPUT (page 567) &ins, Dimension (page 532)::Type
                      (page 532) type, const Everything &e)

inline MetadataNode (page 547) toMetadata(const BOX2D (page 523) &bounds)

inline MetadataNode (page 547) toMetadata(const BOX3D (page 526) &bounds)

inline int openProgress(const std::string &filename)

inline void closeProgress(int fd)

inline void writeProgress(int fd, const std::string &type, const std::string &text)

std::vector< std::string > PDAL_DLL maybeGlob (const std::string &path)
template<>
inline StatusWithReason (page 583) fromString(const std::string &s, Eigen::MatrixXd
                                              &matrix)

template<>
inline StatusWithReason (page 583) fromString(const std::string &s, SrsBounds
                                              &srsBounds)

template<typename CONTAINER, typename VALUE>
bool contains(const CONTAINER (page 567) &cont, const VALUE (page 567) &val)
    Determine if a container contains a value.
```

Parameters

- **cont** – Container.
- **val** – Value.

Returns `true` if the value is in the container, `false` otherwise.

```
template<typename KEY, typename VALUE>
```

```
bool contains(const std::map<KEY (page 567), VALUE (page 567)> &c, const KEY (page 567) &v)
```

Determine if a map contains a key.

Parameters

- **c** – Map.
- **v** – Key value.

Returns true if the value is in the container, false otherwise.

```
template<typename CNTAINER, typename VALUE>
```

```
void remove(CNTAINER (page 568) &cont, const VALUE (page 568) &val)
```

Remove all instances of a value from a container.

Parameters

- **cont** – Container.
- **v** – Value to remove.

```
template<typename CNTAINER, typename PREDICATE>
```

```
void remove_if(CNTAINER (page 568) &cont, PREDICATE (page 568) 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 > backtrace ()
```

Generate a backtrace as a list of strings.

Returns List of functions at the point of the call.

```
template<>
```

```
inline StatusWithReason (page 583) fromString(const std::string &s, BOX2D (page 523) &bounds)
```

```
template<>
```

```
inline StatusWithReason (page 583) fromString(const std::string &s, BOX3D (page 526) &bounds)
```

```
template<>
```

```
inline StatusWithReason (page 583) fromString(const std::string &s, Bounds &bounds)
```

BacktraceEntries (page 565) **backtraceImpl()**

```
template<class T> PDAL_DLL const T & 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.

Parameters

- **t** – the input value.
- **min** – the lower bound.
- **max** – the upper bound.

Returns the value to clamped to the given bounds.

```
PDAL_DLL void random_seed (unsigned int seed)
```

Set a seed for random number generation.

Parameters **seed** – Seed value.

```
PDAL_DLL double random (double minimum, double maximum)
```

Generate a random value in the range [minimum, maximum].

Parameters

- **minimum** – Lower value of range for random number generation.
- **maximum** – Upper value of range for random number generation.

```
inline PDAL_DLL bool compare_approx (double v1, double v2,  
double tolerance)
```

Determine if two values are within a particular range of each other.

Parameters

- **v1** – First value to compare.
- **v2** – Second value to compare.
- **tolerance** – Maximum difference between v1 and v2

```
inline double sround(double r)
```

Round double value to nearest integral value.

Parameters **r** – Value to round

Returns Rounded value

```
inline std::string tolower(const std::string &s)  
    Convert a string to lowercase.
```

Returns Converted string.

```
inline std::string toupper(const std::string &s)  
    Convert a string to uppercase.
```

Returns Converted string.

```
inline bool iequals(const std::string &s, const std::string &s2)  
    Compare strings in a case-insensitive manner.
```

Parameters

- **s** – First string to compare.
- **s2** – Second string to compare.

Returns Whether the strings are equal.

```
inline bool startsWith(const std::string &s, const std::string &prefix)  
    Determine if a string starts with a particular prefix.
```

Parameters

- **s** – String to check for prefix.
- **prefix** – Prefix to search for.

Returns Whether the string begins with the prefix.

```
inline bool endsWith(const std::string &s, const std::string &postfix)  
    Determine if a string ends with a particular postfix.
```

Parameters

- **s** – String to check for postfix.
- **postfix** – Postfix to search for.

Returns Whether the string ends with the postfix.

```
inline int cksum(char *buf, size_t size)  
    Generate a checksum that is the integer sum of the values of the bytes in a buffer.
```

Parameters

- **buf** – Pointer to buffer.
- **size** – Size of buffer.

Returns Generated checksum.

```
PDAL_DLL int getenv (std::string const &name, std::string &val)  
    Fetch the value of an environment variable.
```

Parameters

- **name** – Name of environment variable.
- **name** – Value of the environment variable if it exists, empty otherwise.

Returns 0 on success, -1 on failure

**PDAL_DLL int setenv (const std::string &env,
const std::string &val)**

Set the value of an environment variable.

Parameters

- **env** – Name of environment variable.
- **val** – Value of environment variable.

Returns 0 on success, -1 on failure

PDAL_DLL int unsetenv (const std::string &env)

Clear the value of an environment variable.

Parameters **env** – Name of the environment variable to clear.

Returns 0 on success, -1 on failure

PDAL_DLL void eatwhitespace (std::istream &s)

Skip stream input until a non-space character is found.

Parameters **s** – Stream to process.

PDAL_DLL void trimLeading (std::string &s)

Remove whitespace from the beginning of a string.

Parameters **s** – String to be trimmed.

PDAL_DLL void trimTrailing (std::string &s)

Remove whitespace from the end of a string.

Parameters **s** – String to be trimmed.

inline void **trim**(std::string &s)

Remove whitespace from the beginning and end of a string.

Parameters **s** – String to be trimmed.

PDAL_DLL bool eatcharacter (std::istream &s, char x)

If specified character is at the current stream position, advance the stream position by 1.

Parameters

- **s** – Stream to insect.
- **x** – Character to check for.

Returns true if the character is at the current stream position, false otherwise.

PDAL_DLL std::string base64_encode (const unsigned char *buf, size_t size)

Convert a buffer to a string using base64 encoding.

Parameters

- **buf** – Pointer to buffer to encode.
- **size** – Size of buffer.

Returns Encoded buffer.

inline std::string base64_encode(std::vector<uint8_t> const &bytes)

Convert a buffer to a string using base64 encoding.

Parameters **bytes** – Pointer to buffer to encode.

Returns Encoded buffer.

PDAL_DLL std::vector< uint8_t > base64_decode (std::string const &input)

Decode a base64-encoded string into a buffer.

Parameters **input** – String to decode.

Returns Buffer containing decoded string.

PDAL_DLL FILE * portable_popen (const std::string &command, const std::string &mode)

Start a process to run a command and open a pipe to which input can be written and from which output can be read.

Parameters **command** – Command to run in subprocess. \mode Either ‘r’, ‘w’ or ‘r+’ to specify if the pipe should be opened as read-only, write-only or read-write.

Returns Pointer to FILE for input/output from the subprocess.

PDAL_DLL int portable_pclose (FILE *fp)

Close file opened with *portable_popen* (page 572).

Parameters **fp** – Pointer to file to close.

Returns 0 on success, -1 on failure.

```
PDAL_DLL 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,

```
PDAL_DLL std::string replaceAll (std::string input,  
const std::string &replaceWhat, const std::string &replaceWithWhat)
```

Replace all instances of one string found in the input with another value.

Parameters

- **input** – Input string to modify.
- **replaceWhat** – Token to locate in input string.
- **replaceWithWhat** – Replacement for found tokens.

Returns Modified version of input string.

```
PDAL_DLL std::vector< std::string > wordWrap (std::string const &inputString,  
size_t lineLength, size_t firstLength=0)
```

Break a string into a list of strings to not exceed a specified length.

Whitespace is condensed to a single space and each string is free of whitespace at the beginning and end when possible. Optionally, a line length for the first line can be different from subsequent lines.

Parameters

- **inputString** – String to split into substrings.
- **lineLength** – Maximum length of substrings.
- **firstLength** – When non-zero, the maximum length of the first substring. When zero, the first firstLength is assigned the value provided in lineLength.

Returns List of substrings generated from the input string.

```
PDAL_DLL std::vector< std::string > wordWrap2 (std::string const &inputString,  
size_t lineLength, size_t firstLength=0)
```

Break a string into a list of strings to not exceed a specified length.

The concatenation of the returned substrings will yield the original string. The algorithm attempts to break the original string such that each substring begins with a word.

Parameters

- **inputString** – String to split into substrings.
- **lineLength** – Maximum length of substrings.
- **firstLength** – When non-zero, the maximum length of the first substring. When zero, the first firstLength is assigned the value provided in lineLength.

Returns List of substrings generated from the input string.

PDAL_DLL std::string escapeJSON (const std::string &s)

Add escape characters or otherwise transform an input string so as to be a valid JSON string.

Parameters **s** – Input string.

Returns Valid JSON version of input string.

PDAL_DLL std::string demangle (const std::string &s)

Demangle a C++ symbol into readable form.

Demangle strings using the compiler-provided demangle function.

Parameters

- **s** – String to demangle.
- **s** – [in] String to be demangled.

Returns Demangled symbol.

Returns Demangled string

PDAL_DLL int screenWidth ()

Return the screen width of an associated tty.

Returns The tty screen width or 80 if on Windows or it can't be determined.

PDAL_DLL std::string escapeNonprinting (const std::string &s)

Escape non-printing characters by using standard notation (i.e.

) or hex notation (\x10) as necessary.

Parameters **s** – String to modify.

Returns Copy of input string with non-printing characters converted to printable notation.

PDAL_DLL double normalizeLongitude (double longitude)

Normalize longitude so that it's between (-180, 180].

Parameters **longitude** – Longitude to normalize.

Returns Normalized longitude.

PDAL_DLL 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.

Parameters

- **buf** – Point to buffer to dump.
- **count** – Size of buffer.

Returns Buffer converted to hex string.

template<typename PREDICATE> PDAL_DLL std::string::size_type extract (const std::string::size_type p, PREDICATE pred)

Count the number of characters in a string that meet a predicate.

Parameters

- **s** – String in which to start counting characters.
- **p** – Position in input string at which to start counting.
- **pred** – Unary predicate that tests a character.

Returns Then number of characters matching the predicate.

inline PDAL_DLL std::string::size_type extractSpaces (const std::string &s, std::string::size_type p)

Count the number of characters spaces in a string at a position.

Parameters

- **s** – String in which to start counting characters.
- **p** – Position in input string at which to start counting.

Returns Then number of space-y characters matching the predicate.

```
template<typename PREDICATE> PDAL_DLL std::vector< std::string > split (const std::string &s, PREDICATE p)
```

Split a string into substrings based on a predicate.

Characters matching the predicate are discarded.

Parameters

- **s** – String to split.
- **p** – Unary predicate that returns true to indicate that a character is a split location.

Returns Substrings.

```
template<typename PREDICATE> PDAL_DLL std::vector< std::string > split2 (const std::string &s, PREDICATE p)
```

Split a string into substrings.

Characters matching the predicate are discarded, as are empty strings otherwise produced by [split\(\)](#) (page 576).

Parameters

- **s** – String to split.
- **p** – Predicate returns true if a char in a string is a split location.

Returns Vector of substrings.

```
inline PDAL_DLL std::vector< std::string > split (const std::string &s, char tChar)
```

Split a string into substrings based a splitting character.

The splitting characters are discarded.

Parameters

- **s** – String to split.
- **tChar** – Character indicating split positions.

Returns Substrings.

```
inline PDAL_DLL std::vector< std::string > split2 (const std::string &s, char tChar)
```

Split a string into substrings based a splitting character.

The splitting characters are discarded as are empty strings otherwise produced by [split\(\)](#) (page 576).

Parameters

- **s** – String to split.
- **p** – Character indicating split positions.

Returns Substrings.

PDAL_DLL std::vector< std::string > simpleWordexp (const std::string &s)

Perform shell-style word expansion (break a string into arguments).

This only does simple handling of quoted values and backslashes and doesn't support fancier shell behavior. Use the real wordexp() if you need all that. The behavior of escaped values in a string was surprising to me, so try the shell first if you think you've found a problem.

Parameters **s** – Input string to parse.

Returns List of arguments.

template<typename T>

std::string **typeidName()**

Return a string representation of a type specified by the template argument.

Returns String representation of the type.

inline *RedirectStream* (page 584) **redirect**(std::ostream &out, std::ostream &dst)

Redirect a stream to some other stream, by default a null stream.

Parameters

- **out** – Stream to redirect.
- **dst** – Destination stream.

Returns Context for stream restoration (see *restore()* (page 577)).

inline *RedirectStream* (page 584) **redirect**(std::ostream &out)

Redirect a stream to a null stream.

Parameters **out** – Stream to redirect.

Returns Context for stream restoration (see *restore()* (page 577)).

inline *RedirectStream* (page 584) **redirect**(std::ostream &out, const std::string &file)

Redirect a stream to some file.

Parameters

- **out** – Stream to redirect.
- **file** – Name of file where stream should be redirected.

Returns Context for stream restoration (see *restore()* (page 577)).

inline void **restore**(std::ostream &out, *RedirectStream* (page 584) &redir)

Restore a stream redirected with *redirect()* (page 577).

Parameters

- **out** – Stream to be restored.
- **redir** – *RedirectStream* (page 584) returned from corresponding *redirect()* (page 577) 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.

Parameters **in** – Value to range test.

Returns Whether value can be safely converted to template type.

```
template<typename T_IN, typename T_OUT>
```

```
bool inRange(T_IN (page 578) in)
```

Determine whether a value may be safely converted to the given output type without over/underflow.

If the output type is integral and different from the input type, the value will be rounded before being tested.

Parameters **in** – Value to range test.

Returns Whether value can be safely converted to template type.

```
template<typename T_IN, typename T_OUT>
```

```
bool numericCast(T_IN (page 578) in, T_OUT (page 578) &out)
```

Convert a numeric value from one type to another.

Floating point values are rounded to the nearest integer before a conversion is attempted.

Parameters

- **in** – Value to convert.
- **out** – Converted value.

Returns **true** if the conversion was successful, **false** if the datatypes/input value don't allow conversion.

```
template<>
```

```
inline bool numericCast(double in, float &out)
```

Convert a numeric value from double to float.

Specialization to handle NaN.

Parameters

- **in** – Value to convert.

- **out** – Converted value.

Returns `true` if the conversion was successful, `false` if the datatypes/input value don't allow conversion.

`template<typename T>`

`std::string toString(const T (page 579) &from)`

Convert a value to its string representation by writing to a stringstream.

Parameters `from` – Value to convert.

Returns String representation.

`inline std::string toString(bool from)`

Convert a bool to a string.

`inline std::string toString(double from, size_t precision = 10)`

Convert a double to string with a precision of 10 decimal places.

Parameters `from` – Value to convert.

Returns String representation of numeric value.

`inline std::string toString(float from)`

Convert a float to string with a precision of 10 decimal places.

Parameters `from` – Value to convert.

Returns String representation of numeric value.

`inline std::string toString(long long from)`

Convert a long long int to string.

Parameters `from` – Value to convert.

Returns String representation of numeric value.

`inline std::string toString(unsigned long from)`

Convert an unsigned long long int to string.

Parameters `from` – Value to convert.

Returns String representation of numeric value.

`inline std::string toString(long from)`

Convert a long int to string.

Parameters `from` – Value to convert.

Returns String representation of numeric value.

`inline std::string toString(unsigned int from)`

Convert an unsigned int to string.

Parameters `from` – Value to convert.

Returns String representation of numeric value.

inline std::string **toString**(int from)

Convert an int to string.

Parameters **from** – Value to convert.

Returns String representation of numeric value.

inline std::string **toString**(unsigned short from)

Convert an unsigned short to string.

Parameters **from** – Value to convert.

Returns String representation of numeric value.

inline std::string **toString**(short from)

Convert a short int to string.

Parameters **from** – Value to convert.

Returns String representation of numeric value.

inline std::string **toString**(char from)

Convert a char (treated as numeric) to string.

Parameters **from** – Value to convert.

Returns String representation of numeric value.

inline std::string **toString**(unsigned char from)

Convert an unsigned char (treated as numeric) to string.

Parameters **from** – Value to convert.

Returns String representation of numeric value.

inline std::string **toString**(signed char from)

Convert a signed char (treated as numeric) to string.

Parameters **from** – Value to convert.

Returns String representation of numeric value.

template<typename T>

StatusWithReason (page 583) **fromString**(const std::string &from, *T* (page 580) *&to)

template<typename T>

StatusWithReason (page 583) **fromString**(const std::string &from, *T* (page 580) &to)

Convert a string to a value by reading from a string stream.

Parameters

- **from** – String to convert.

- **to** – Converted value.

Returns `true` if the conversion was successful, `false` otherwise.

template<>

inline *StatusWithReason* (page 583) **fromString**(const std::string &from, std::string &to)

template<>

inline *StatusWithReason* (page 583) **fromString**(const std::string &s, char &to)

Convert a numeric string to a char numeric value.

\parm{s} String to convert.

Parameters **to** – Converted numeric value.

Returns `true` if the conversion was successful, `false` otherwise.

template<>

inline *StatusWithReason* (page 583) **fromString**(const std::string &s, unsigned char &to)

Convert a numeric string to an unsigned char numeric value.

\parm{s} String to convert.

Parameters **to** – Converted numeric value.

Returns `true` if the conversion was successful, `false` otherwise.

template<>

inline *StatusWithReason* (page 583) **fromString**(const std::string &s, signed char &to)

Convert a numeric string to a signed char numeric value.

\parm{s} String to convert.

Parameters **to** – Converted numeric value.

Returns `true` if the conversion was successful, `false` otherwise.

template<>

inline *StatusWithReason* (page 583) **fromString**(const std::string &s, double &d)

Specialization conversion from string to double to handle Nan.

Parameters

- **s** – String to be converted.
- **d** – Converted value.

Returns `true` if the conversion was successful, `false` otherwise.

template<typename E>

```
std::underlying_type<E (page 581)>::type toNative(E (page 581) e)
    Return the argument cast to its underlying type.
```

Typically used on an enum.

Parameters **e** – Variable for which to find the underlying type.

Returns Converted variable.

```
template<>
inline StatusWithReason (page 583) fromString(const std::string &from,
                                             pdal::i3s::Obb &obb)
```

```
template<>
inline StatusWithReason (page 583) fromString(const std::string &from,
                                             pdal::expr::AssignStatement &stmt)
```

```
template<>
inline StatusWithReason (page 583) fromString(const std::string &from,
                                             pdal::expr::ConditionalExpression
                                             &expr)
```

Variables

```
const char dynamicLibExtension[] = ".so"
const char dirSeparator = '/'
const char pathListSeparator = ':'

struct BacktraceEntry
    #include <BacktraceImpl.hpp>
```

Public Functions

```
inline BacktraceEntry()
```

Public Members

```
std::string libname  
void *addr  
std::string symname  
int offset  
class Random  
#include <Random.hpp>
```

Public Functions

```
PDAL_DLL Random()  
  
PDAL_DLL Random(int32_t seed)  
  
PDAL_DLL Random(const std::vector<int32_t> seed)  
  
PDAL_DLL Random(const std::string &seed)  
  
PDAL_DLL std::mt19937 & generator ()
```

Public Static Functions

```
static PDAL_DLL unsigned int quick ()  
class StatusWithReason  
#include <Utils.hpp>
```

Public Functions

```
inline StatusWithReason()  
  
inline StatusWithReason(bool ok)  
  
StatusWithReason(int code)
```

```
inline StatusWithReason(int code, const std::string &what)

inline int code() const

inline operator bool() const

inline std::string what() const

struct RedirectStream
#include <Utils.hpp>
```

Public Functions

```
inline RedirectStream()
```

Public Members

```
std::ofstream *m_out
std::streambuf *m_buf
std::unique_ptr<NullOStream> m_null
```

pdal::Writer

class **Writer** : public virtual pdal::*Stage* (page 559)

A *Writer* (page 584) is a terminal stage for a PDAL pipeline.

It usually writes output to a file, but this isn't a requirement. The class provides support for some operations common for producing point output.

Subclassed by pdal::DbWriter, pdal::DracoWriter, pdal::E57Writer,
pdal::EptAddonWriter, pdal::FbxWriter, pdal::FlexWriter, pdal::GltfWriter,
pdal::MatlabWriter, pdal::NullWriter, pdal::PcdWriter, pdal::PlyWriter,
pdal::RasterWriter, pdal::SbetWriter, pdal::TextWriter, pdal::TileDBWriter

14.3.2 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;
LASSRSRH 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;
```

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```
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);
```

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```
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.

14.4 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_TILEDB=ON`, for example, in `CMakeCache.txt`).

If you’ve successfully built the plugin, a shared object called

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

should have been created that’s installed in a location where pdal can find it. pdal will search the following paths for plugins: `., ./lib, ../lib, ./bin, ../bin`.

You can also override the default search path by setting the environment variable `PDAL_DRIVER_PATH` to a list of directories that pdal should search for plugins.

- Why do I get the error “`Unable to convert scaled value ...`”

This error usually occurs when writing LAS files, but can occur with other formats.

Simply, the output format you’ve chosen doesn’t support values as large (or small) as those that you’re trying to write. For example, if the output format specifies 32-bit signed

integers, attempting to write a value larger than 2,147,483,647 will cause this error, as 2,147,483,647 is the largest 32-bit signed integer.

The LAS format always stores X, Y and Z values as 32-bit integers. You can specify a scale factor to be applied to those values in order to change their magnitude, but their precision is limited to 32 bits. If the value you're attempting to write, when divided by the scale factor you've specified, is larger than 2,147,483,647, you will get this error. For example, if you attempt to write the value 6 with a scale factor of .00000001, you'll get this error, as $6 / .00000001$ is 6,000,000,000, which is larger than the maximum integer value.

- Why am I using 100GB of memory when trying to process a 10GB LAZ file?

If you're performing an operation that is using *standard mode* (page 49), 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 121)) 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 49) 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 also supports reading and writing PCL PCD files using *readers.pcd* (page 89) and *writers.pcd* (page 136).

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/) (<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 73) is emitting error messages about GeoTIFF, this means the keys that were written into your file were incorrect or at least not readable by `libgeotiff` (<https://trac.osgeo.org/geotif>). Rewrite the file using PDAL to fix the issue:

```
pdal translate badfile.las goodfile.las --writers.las.forward=all
```

14.5 License

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14.5.1 Overall PDAL license (BSD)

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14.6 References

14.6.1 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 = {https://doi.org/10.5281/zenodo.2556738}  
}
```

14.6.2 Reference

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BIBLIOGRAPHY

- [LLW+19] missing journal in Xuechen2019
- [MS10] Andriy Myronenko and Xubo Song. Point set registration: coherent point drift. *IEEE transactions on pattern analysis and machine intelligence*, 32(12):2262–75, dec 2010.
- [YG88] Alan L. Yuille and Norberto M. Grzywacz. The Motion Coherence Theory. *Second International Conference on Computer Vision*, 1988.
- [Gle07] Craig L. Glennie. Rigorous 3D error analysis of kinematic scanning LIDAR systems. *Journal of Applied Geodesy*, jan 2007.
- [Bartels2010] Bartels, Marc, and Hong Wei. “Threshold-free object and ground point separation in LIDAR data.” *Pattern recognition letters* 31.10 (2010): 1089-1099.
- [Breunig2000] Breunig, M.M., Kriegel, H.-P., Ng, R.T., Sander, J., 2000. LOF: Identifying Density-Based Local Outliers. *Proc. 2000 Acm Sigmod Int. Conf. Manag. Data* 1–12.
- [Chen2012] Chen, Ziyue et al. “Upward-Fusion Urban DTM Generating Method Using Airborne Lidar Data.” *ISPRS Journal of Photogrammetry and Remote Sensing* 72 (2012): 121–130.
- [Cook1986] Cook, Robert L. “Stochastic sampling in computer graphics.” *ACM Transactions on Graphics (TOG)* 5.1 (1986): 51-72.
- [Demantke2011] Demantké J., Mallet C., David N., Vallet, B. “Dimensionality Based Scale Selection in 3d LIDAR Point Clouds.” *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XXXVIII-5/W12, 97-102, 2011
- [Dippe1985] Dippé, Mark AZ, and Erling Henry Wold. “Antialiasing through stochastic sampling.” *ACM Siggraph Computer Graphics* 19.3 (1985): 69-78.
- [Ester1996] Ester, Martin, et al. “A density-based algorithm for discovering clusters in large spatial databases with noise.” *Kdd. Vol. 96. No. 34.* 1996.
- [Fischer2010] Fischer, Kaspar, Bernd Gärtner, and Martin Kutz. “Fast Smallest-Enclosing-Ball Computation in High Dimensions.” 26473 (2010): 630–641. Web.

- [Guinard2017] Guinard S., Landrieu L. “Weakly Supervised Segmented-Aided Classification of Urban Scenes From 3D LIDAR Point Clouds.” *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-1/W1, 151-157, 2017
- [Kazhdan2006] Kazhdan, Michael, Matthew Bolitho, and Hugues Hoppe. “Poisson surface reconstruction.” *Proceedings of the fourth Eurographics symposium on Geometry processing*. Vol. 7. 2006.
- [Li2012] Li, Wenkai, et al. “A new method for segmenting individual trees from the lidar point cloud.” *Photogrammetric Engineering & Remote Sensing* 78.1 (2012): 75-84.
- [Limberger2015] Limberger, Frederico A., and Manuel M. Oliveira. “Real-Time Detection of Planar Regions in Unorganized Point Clouds.” *Pattern Recognition* 48.6 (2015): 2043–2053. Web.
- [Lloyd1982] Lloyd, Stuart. “Least squares quantization in PCM.” *IEEE transactions on information theory* 28.2 (1982): 129-137.
- [McCool1992] McCool, Michael, and Eugene Fiume. “Hierarchical Poisson disk sampling distributions.” *Proceedings of the conference on Graphics interface*. Vol. 92. 1992.
- [Mesh2009] ALoopingIcon. “Meshing Point Clouds.” *MESHLAB STUFF*. n.p., 7 Sept. 2009. Web. 13 Nov. 2015.
- [Pingel2013] Pingel, Thomas J., Keith C. Clarke, and William A. McBride. “An Improved Simple Morphological Filter for the Terrain Classification of Airborne LIDAR Data.” *ISPRS Journal of Photogrammetry and Remote Sensing* 77 (2013): 21–30.
- [Rusu2008] Rusu, Radu Bogdan, et al. “Towards 3D point cloud based object maps for household environments.” *Robotics and Autonomous Systems* 56.11 (2008): 927-941.
- [Weyrich2004] Weyrich, T et al. “Post-Processing of Scanned 3D Surface Data.” *Proceedings of Eurographics Symposium on Point-Based Graphics 2004* (2004): 85–94. Print.
- [Yang2020] Yang, Heng, Jingnan Shi, and Luca Carlone, “TEASER: Fast and Certifiable Point Cloud Registraton,” arXiv preprint, arXiv:2001.07715, 2020.
- [Zhang2003] Zhang, Keqi, et al. “A progressive morphological filter for removing nonground measurements from airborne LIDAR data.” *Geoscience and Remote Sensing, IEEE Transactions on* 41.4 (2003): 872-882.
- [Zhang2016] Zhang, Wuming, et al. “An easy-to-use airborne LiDAR data filtering method based on cloth simulation.” *Remote Sensing* 8.6 (2016): 501.

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