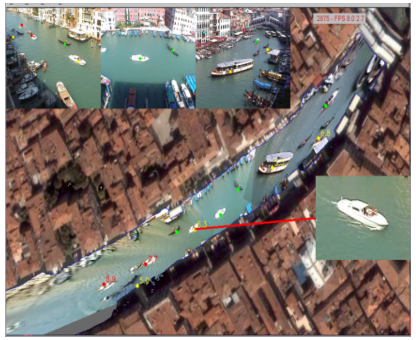
UNIVERSITÀ di VERONA

Dipartimento di INFORMATICA

Laurea magistrale in ingegneria e scienze informatiche

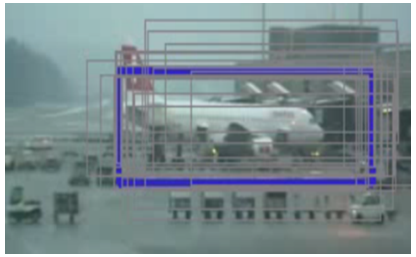
Acquisizione e gestione dati 3D

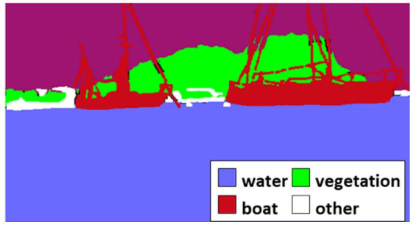
Corso di Robotica
Parte di Laboratorio



Docente:

Domenico Daniele Bloisi





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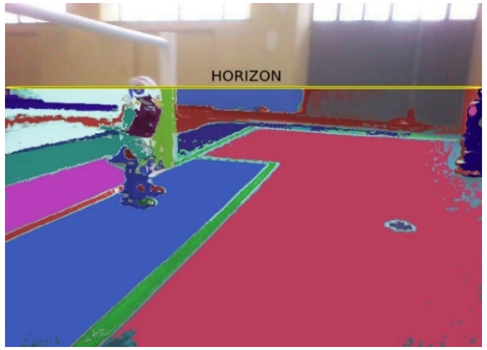
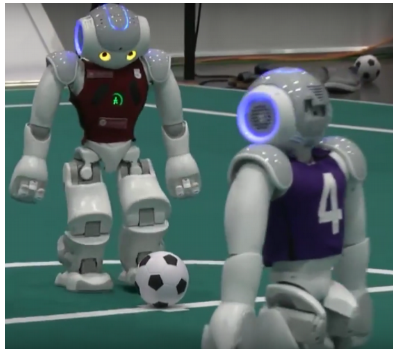




References and Credits

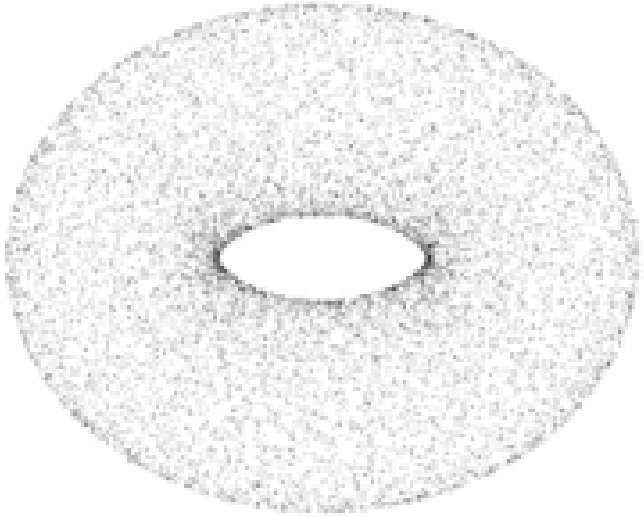
Questo materiale deriva da:

Alberto Pretto – Sapienza Università di Roma
Introduction to PCL: The Point Cloud Library
Basic topics

http://www.dis.uniroma1.it/~pretto/download/pcl_intro.pdf

Point cloud: a definition

- A point cloud is a data structure used to represent a collection of multi-dimensional points
- It is commonly used to represent three-dimensional data



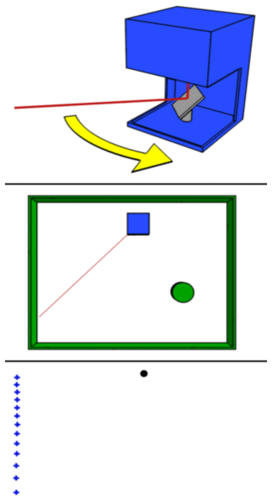
https://en.wikipedia.org/wiki/Point_cloud

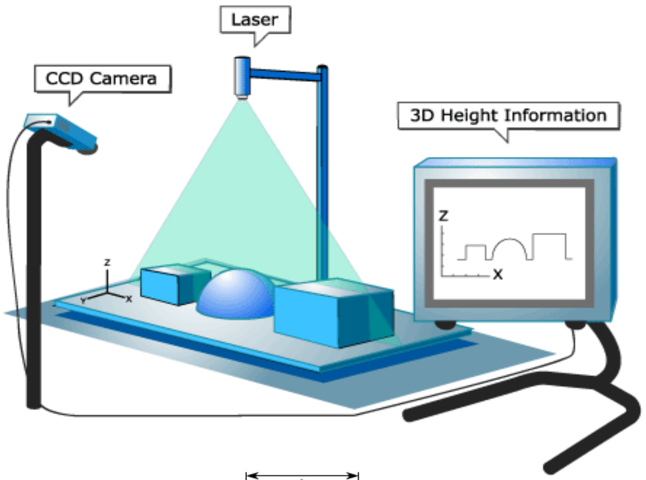
Point cloud: a definition

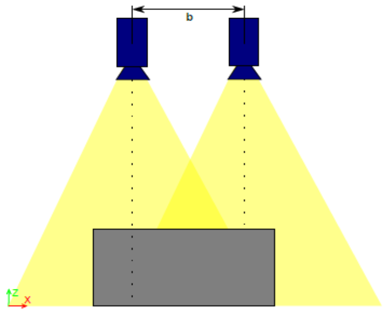
- The points in the point cloud usually represent the X, Y, and Z geometric coordinates of a sampled surface
- Each point can hold additional information: RGB colors, intensity values, etc...

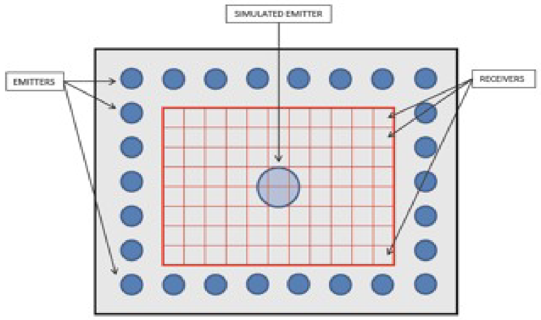
Where do they come from?

- 2/3D Laser scans
- Laser triangulation
- Stereo cameras
- RGB-D cameras
- Structured light cameras
- Time of flight cameras



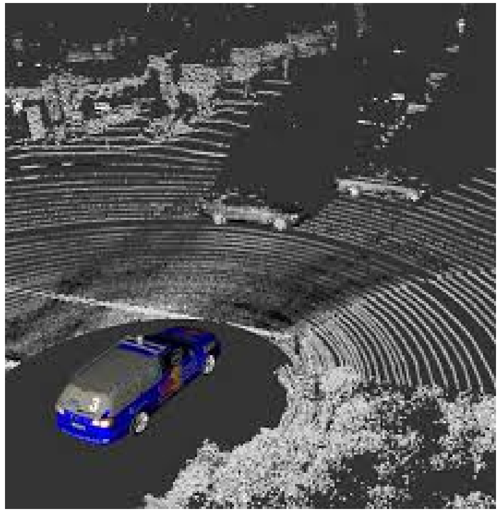


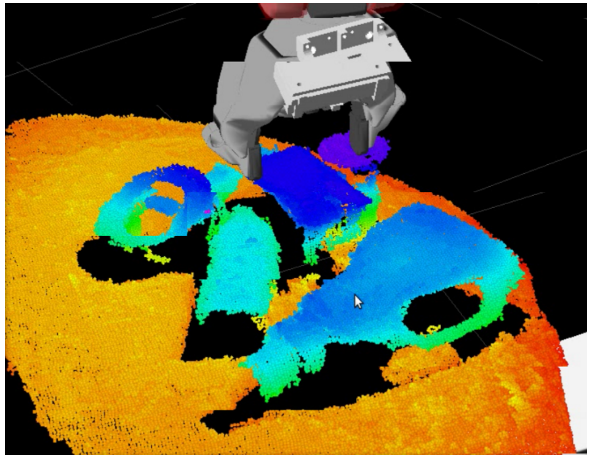


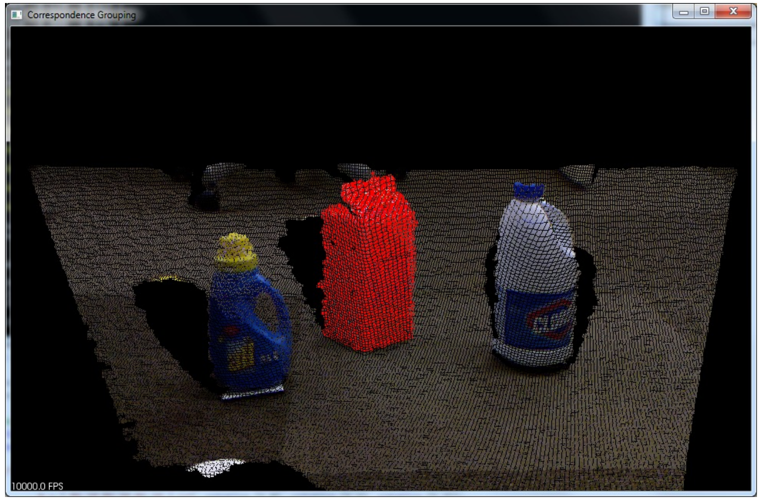


Point clouds in robotics

- Navigation / Obstacle avoidance
- Object recognition and registration
- Grasping and manipulation







Point Cloud Library

→ pointclouds.org

- The Point Cloud Library (PCL) is a standalone, large scale, open source (C++) library for 2D/3D image and point cloud processing

- PCL is released under the terms of the BSD license and thus free for commercial and research use

Point Cloud Library

- PCL provides the 3D processing pipeline for ROS, so you can also get the perception pcl stack and still use PCL standalone

- Among others, PCL depends on Boost, Eigen, OpenMP,...

PCL Basic Structures: PointCloud

A PointCloud is a templated C++ class that contains the following data fields:

- **width (int)** - specifies the width of the point cloud dataset in the number of points.
  → the total number of points in the cloud (equal with the number of elements in points) for unorganized datasets
  → the width (total number of points in a row) of an organized point cloud dataset
- **height (int)** - Specifies the height of the point cloud dataset in the number of points
  → set to 1 for unorganized point clouds
  → the height (total number of rows) of an organized point cloud dataset
- **points (std::vector <PointT>)** - Contains the data array where all the points of type PointT are stored.

PointCloud vs PointCloud2

We distinguish between two data formats for the point clouds:

- **PointCloud<PointType>** with a specific data type (for actual usage in the code)
- **PointCloud2** as a general representation containing a header defining the point cloud structure (e.g., for loading, saving or sending as a ROS message)

Conversion between the two frameworks is easy:
- pcl::fromROSMsg and pcl::toROSMsg

Important: clouds are often handled using smart pointers, e.g.:
- **PointCloud<PointType>::Ptr cloud_ptr;**

Point Types

PointXYZ - float x, y, z
PointXYZI - float x, y, z, intensity
PointXYZRGB - float x, y, z, rgb
PointXYZRGBA - float x, y, z, uint32 t rgba
Normal - float normal[3], curvature
PointNormal - float x, y, z, normal[3], curvature

→ See pcl/include/pcl/point_types.h for more examples

CMakeLists.txt

```
project( pcl_test )
cmake_minimum_required (VERSION 2.8)
cmake_policy(SET CMP0015 NEW)

find_package(PCL 1.7 REQUIRED )
add_definitions(${PCL_DEFINITIONS})

include_directories(... ${PCL_INCLUDE_DIRS})
link_directories(... ${PCL_LIBRARY_DIRS})

add_executable(pcl_test pcl_test.cpp ...)
target_link_libraries( pcl_test ${PCL_LIBRARIES})
```

PCL structure

PCL is a collection of smaller, modular C++ libraries:

- **libpcl_features**: many 3D features (e.g., normals and curvatures, boundary points, moment invariants, principal curvatures, Point Feature Histograms (PFH), Fast PFH, ...)
- **libpcl_surface**: surface reconstruction techniques (e.g., meshing, convex hulls, Moving Least Squares, ...)
- **libpcl_filters**: point cloud data filters (e.g., downsampling, outlier removal, indices extraction, projections, ...)
- **libpcl_io**: I/O operations (e.g., writing to/reading from PCD (Point Cloud Data) and BAG files)
- **libpcl_segmentation**: segmentation operations (e.g.,cluster extraction, Sample Consensus model fitting, polygonal prism extraction, ...)
- **libpcl_registration**: point cloud registration methods (e.g., Iterative Closest Point (ICP), non linear optimizations, ...)
- **libpcl_range_image**: range image class with specialized methods

It provides unit tests, examples, tutorials, ...

Point Cloud file format

Point clouds can be stored to disk as files, into the PCD (Point Cloud Data) format:

```
# Point Cloud Data ( PCD ) file format v.5
FIELDS x y z rgba
SIZE 4 4 4 4
TYPE F F F U
WIDTH 307200
HEIGHT 1
POINTS 307200
DATA binary
...<data>...
```

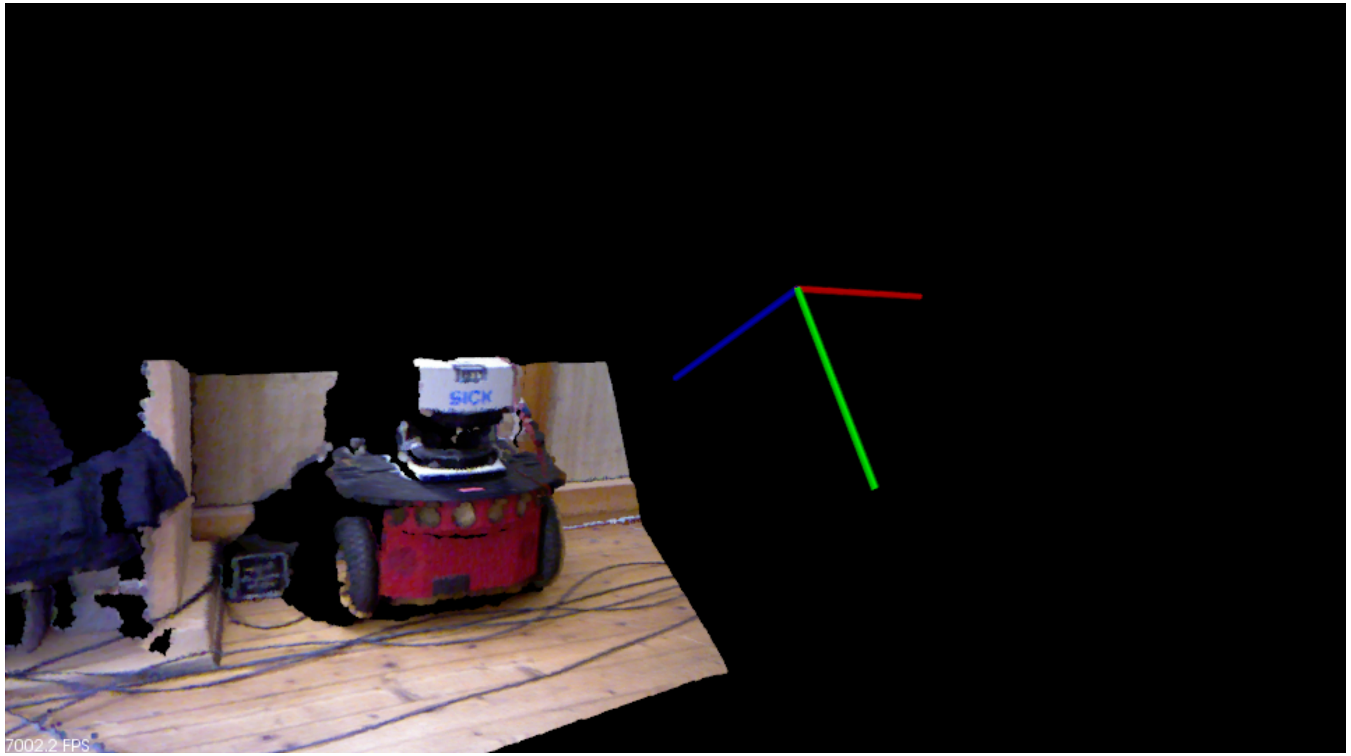
Funtions: pcl::io::loadPCDFile and pcl::io::savePCDFile

Example: create and save a PC

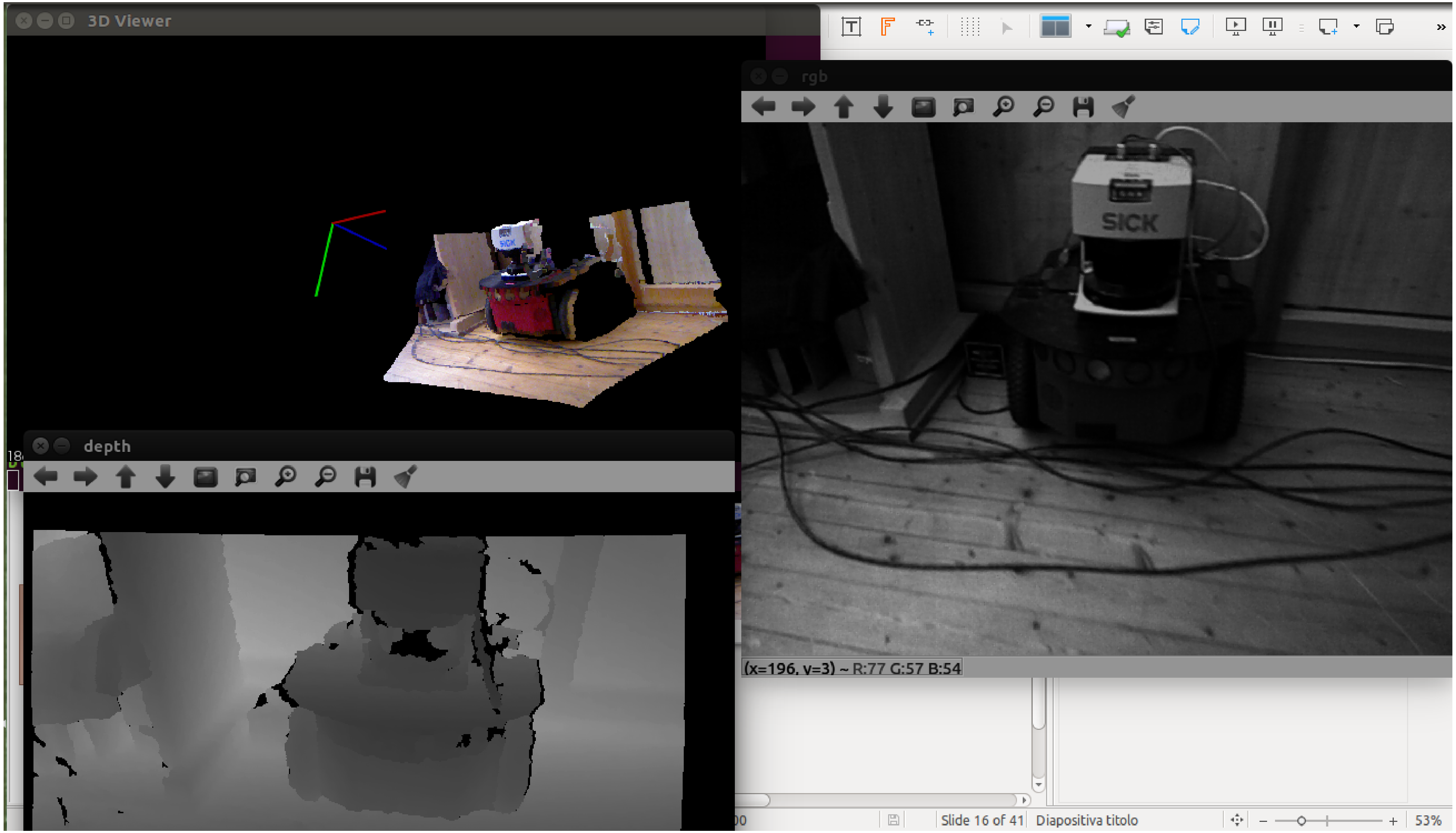
```
#include<pcl/io/pcd_io.h>
#include<pcl/point_types.h>
  //....
  pcl::PointCloud<pcl::PointXYZ>:: Ptr cloud_ptr (new pcl::PointCloud<pcl::PointXYZ>);
  cloud->width=50;
  cloud->height=1;
  cloud->isdense=false;
  cloud->points.resize(cloud.width*cloud.height);
  for(size_t i=0; i<cloud.points.size(); i++){
    cloud->points[i].x=1024*rand()/(RANDMAX+1.0f);
    cloud->points[i].y=1024*rand()/(RANDMAX+1.0f);
    cloud->points[i].z=1024*rand()/(RANDMAX+1.0f);
  }
  pcl::io::savePCDFileASCII("testpcd.pcd",*cloud);
```

Visualize a cloud

```
boost::shared_ptr<pcl::visualization::PCLVisualizer> viewer (new
                    pcl::visualization::PCLVisualizer ("3D Viewer"));
viewer->setBackgroundColor (0, 0, 0);
viewer->addPointCloud<pcl::PointXYZ> ( in_cloud, cloud_color, "Input cloud" );
viewer->initCameraParameters ();
viewer->addCoordinateSystem (1.0);
while (!viewer->wasStopped ())
   viewer->spinOnce ( 1 );
```



depth2cloud.cpp



Basic Module Interface

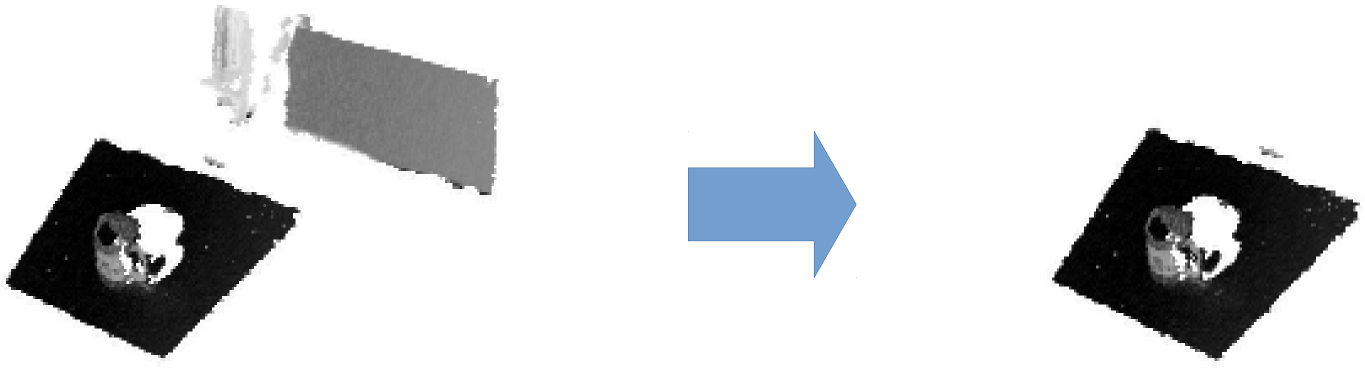
Filters, Features, Segmentation all use the same basic usage interface:

- use **setInputCloud()** to give the input
- set some parameters
- call **compute()** or **filter()** or **align()** or **...** to get the output

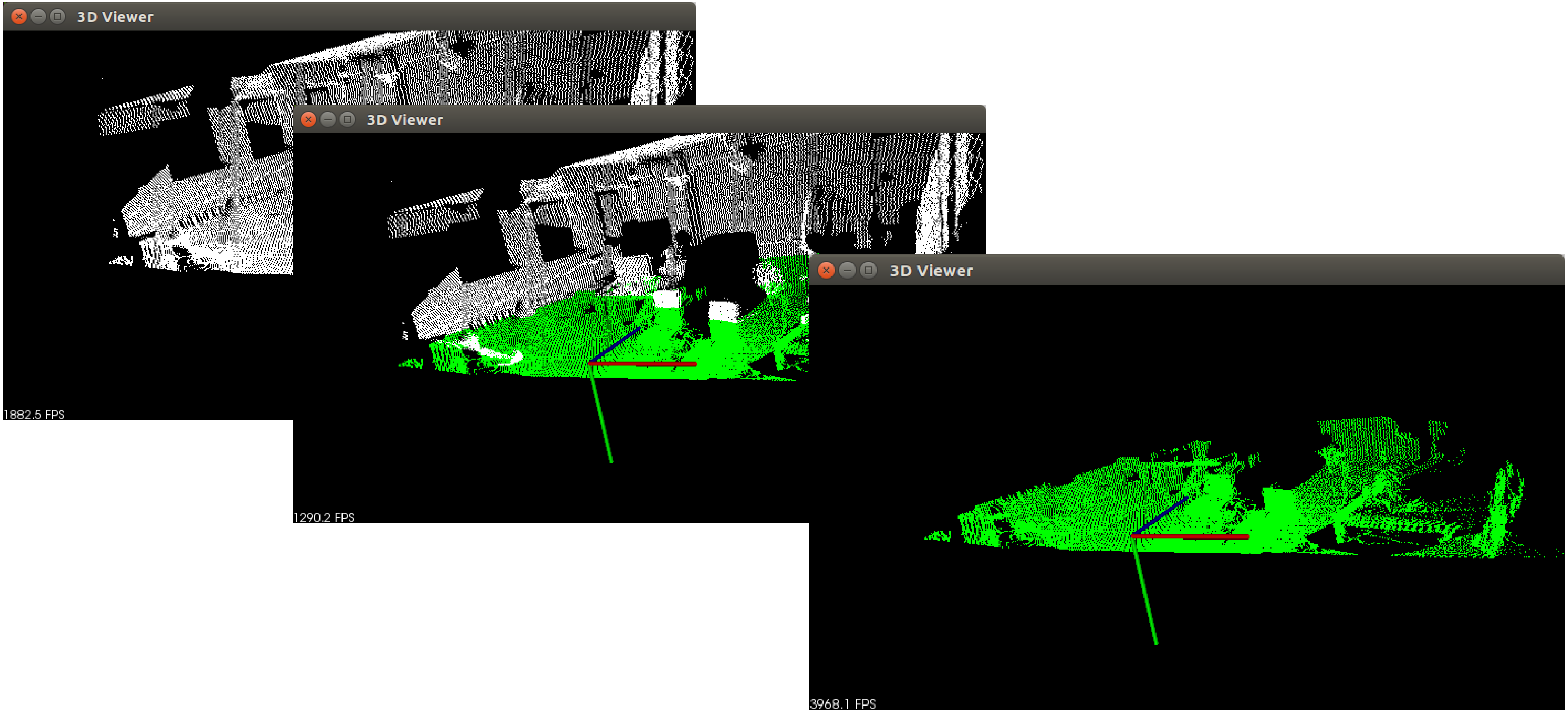
PassThrough Filter

Filter out points outside a specified range in one dimension.

```
pcl::PassThrough<T> pass_through;
pass_through.setInputCloud (in_cloud);
pass_through.setFilterLimits (0.0, 0.5);
pass_through.setFilterFieldName ("z");
pass_through.filter( *cutted_cloud );
```



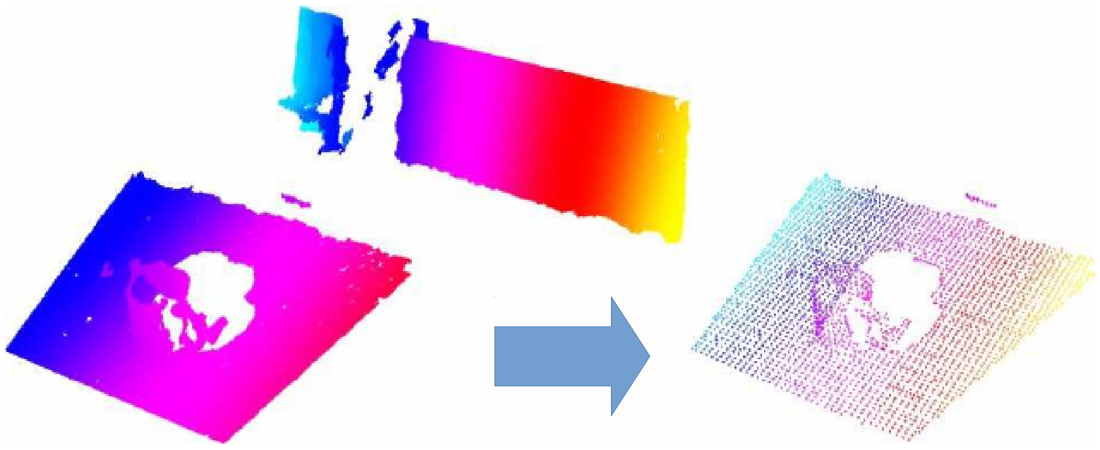
cloud_filters.cpp



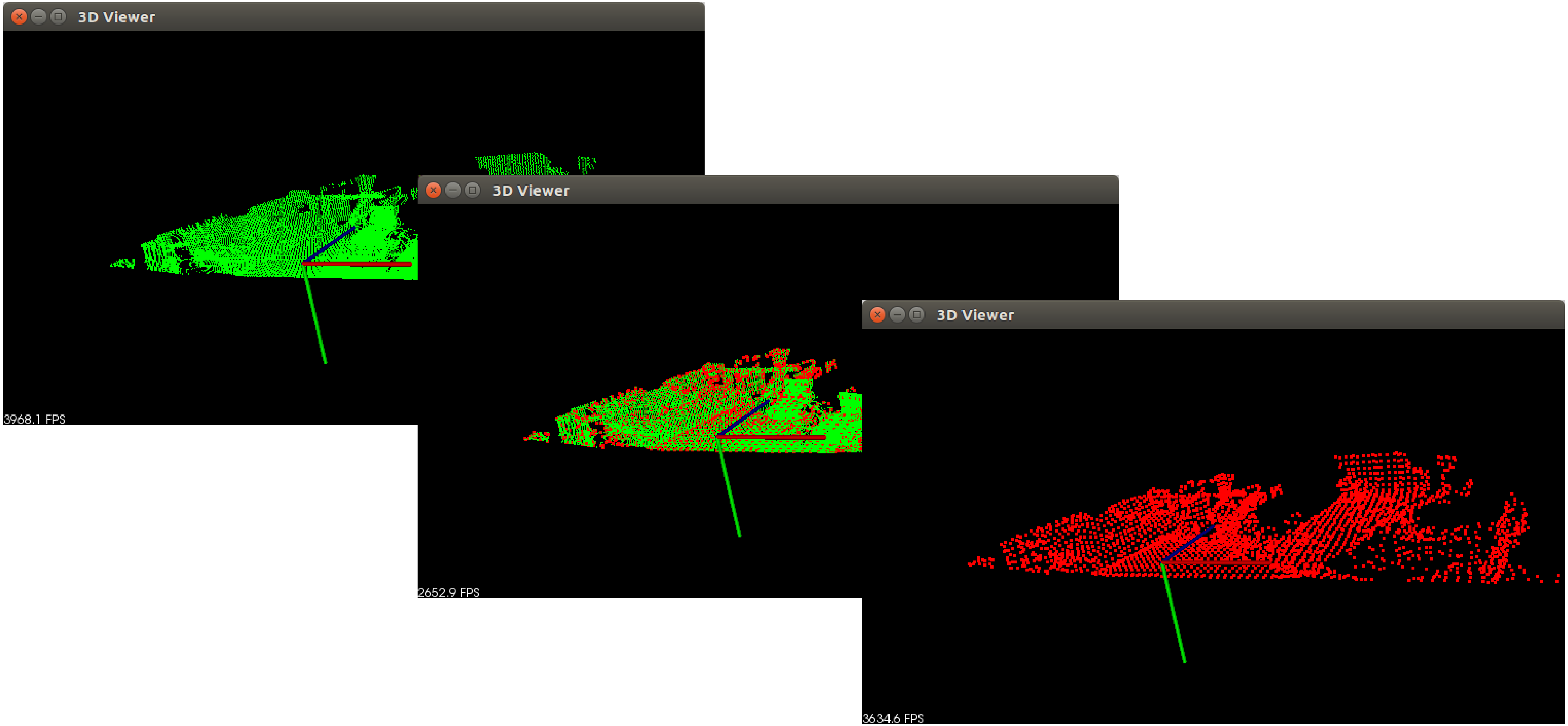
Downsampling

Voxelize the cloud to a 3D grid. Each occupied voxel is approximated by the centroid of the points inside it.

```
pcl::VoxelGrid<T> voxel_grid;
voxel_grid.setInputCloud (input_cloud);
voxel_grid.setLeafSize (0.01, 0.01, 0.01);
voxel_grid.filter ( *subsamp_cloud ) ;
```



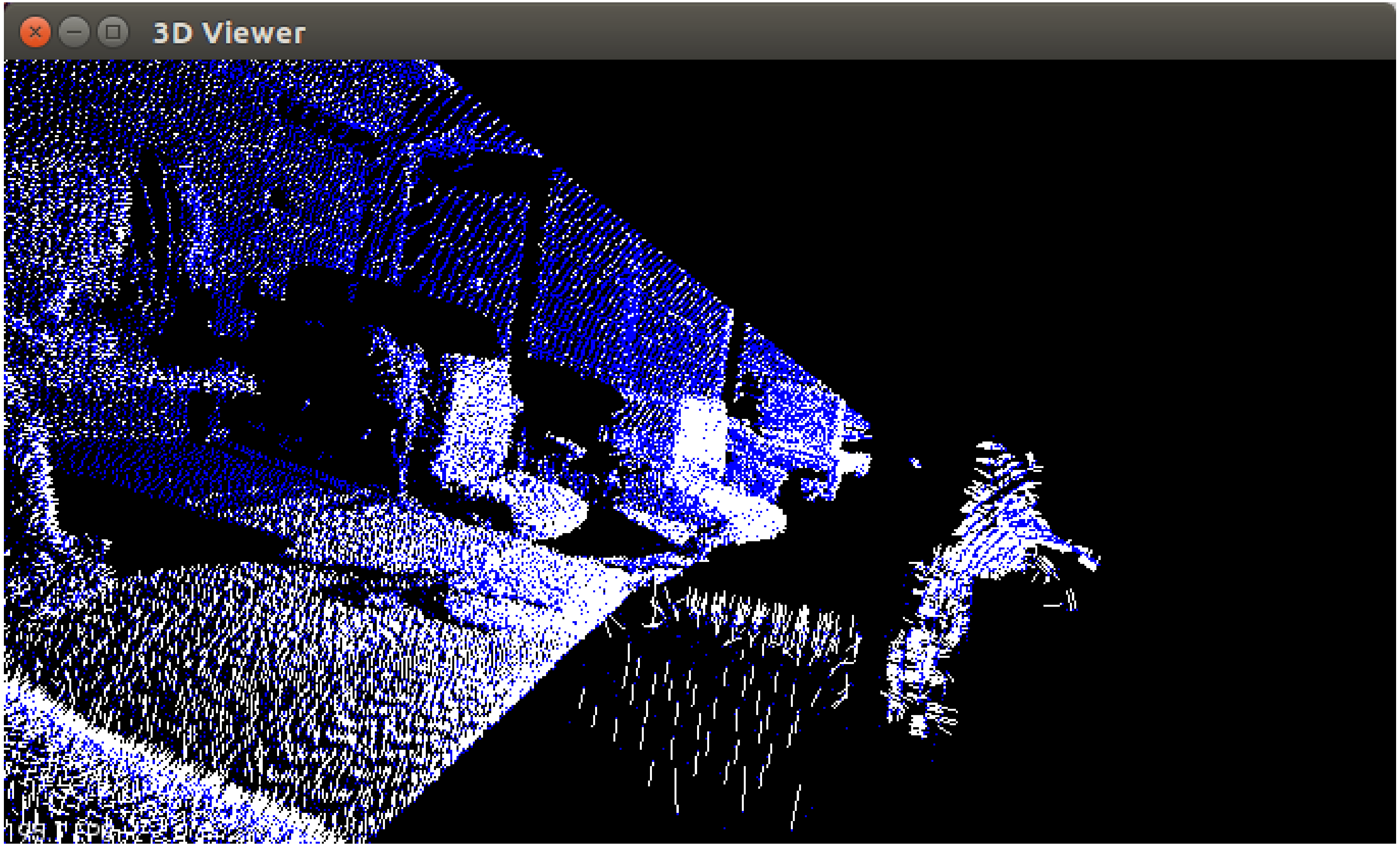
cloud_filters.cpp



Features example: normals

```
pcl::NormalEstimation<T, pcl::Normal> ne;
ne.setInputCloud (in_cloud);
pcl::search::KdTree<pcl::PointXYZ>::Ptr tree (new
                                pcl::search::KdTree<pcl::PointXYZ> ());
ne.setSearchMethod (tree);
ne.setRadiusSearch (0.03);
ne.compute ( *cloud_normals );
```

cloud_normals.cpp



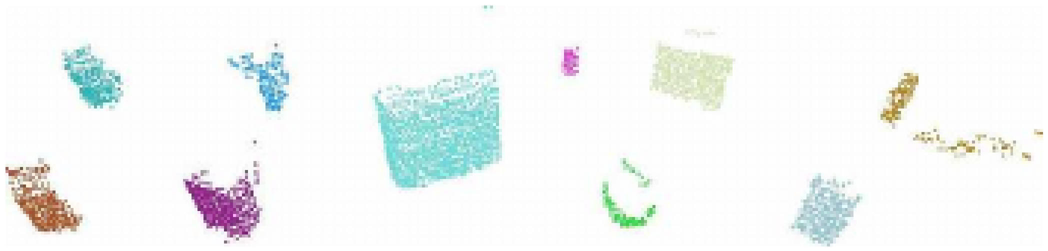
Segmentation example

A clustering method divides an unorganized point cloud into smaller, correlated, parts

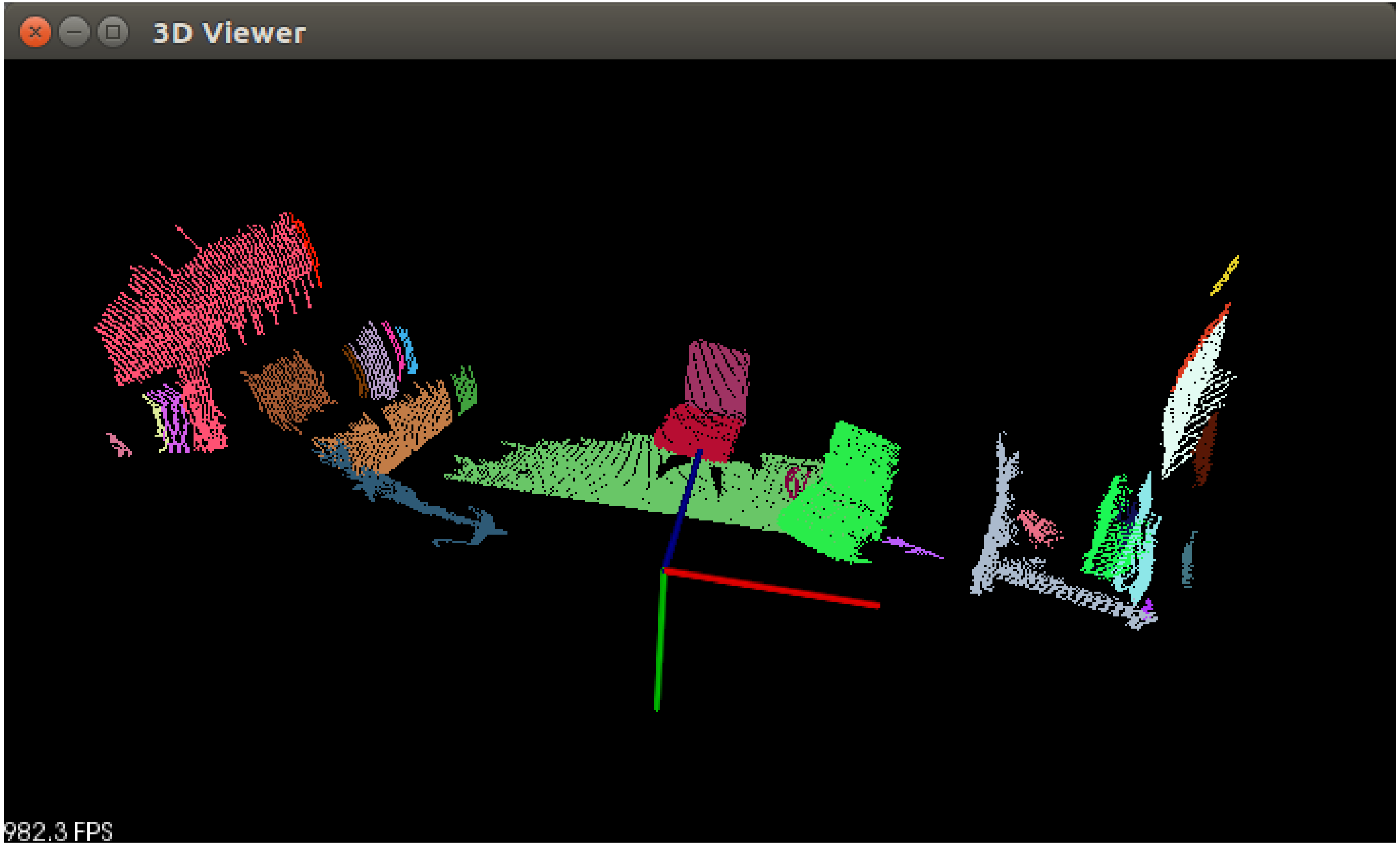
EuclideanClusterExtraction uses a distance threshold to the nearest neighbors of each point to decide if the two points belong to the same cluster.

Segmentation example

```
pcl::EuclideanClusterExtraction<T> ec;
ec.setInputCloud (in_cloud);
ec.setMinClusterSize (100);
ec.setClusterTolerance (0.05); // distance threshold
ec.extract (cluster_indices);
```

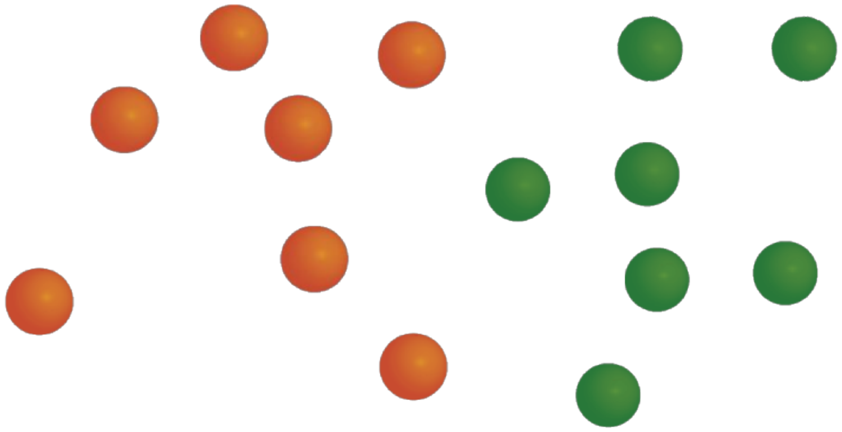


clustering.cpp



Point Cloud Registration

We want to find the translation and the rotation that maximize the overlap between two point clouds



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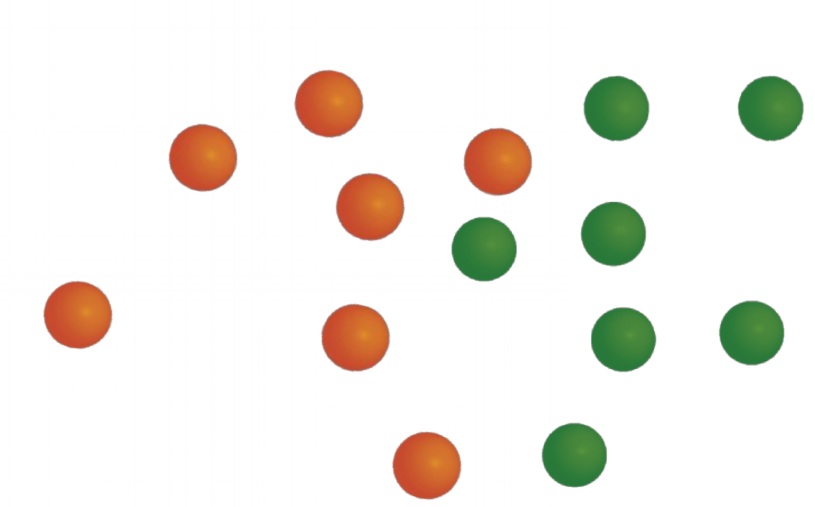

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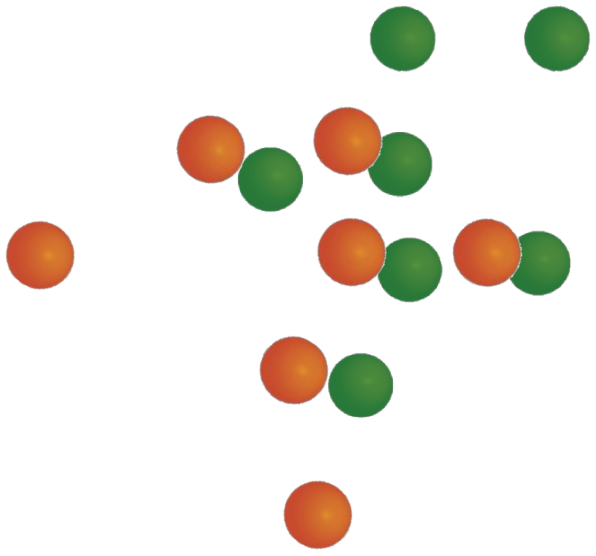

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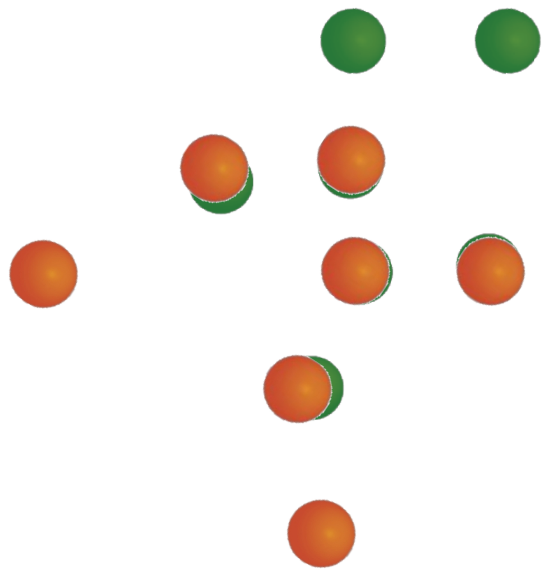

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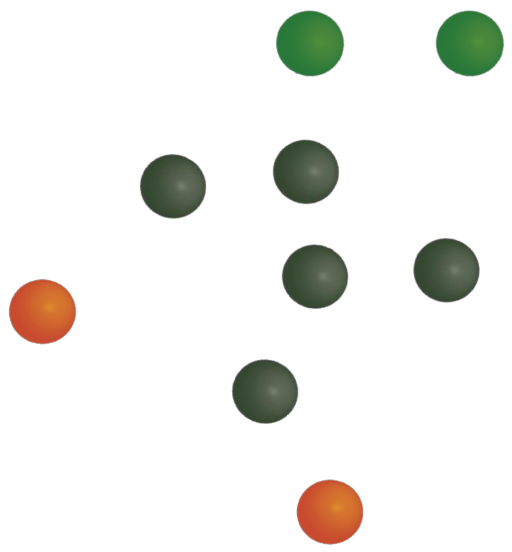


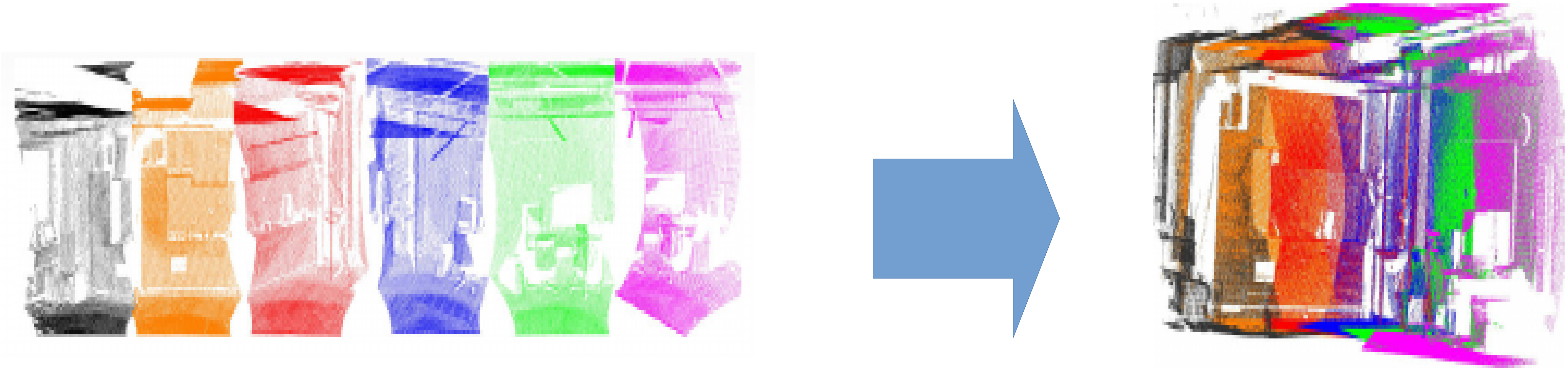
Iterative Closest Point

ICP iteratively revises the transformation (translation,rotation) needed to minimize the distance between the points of two raw scans

Input: points from two raw scans, initial estimation of the transformation, criteria for stopping the iteration

Output: refined transformation

Iterative Closest Point: Example



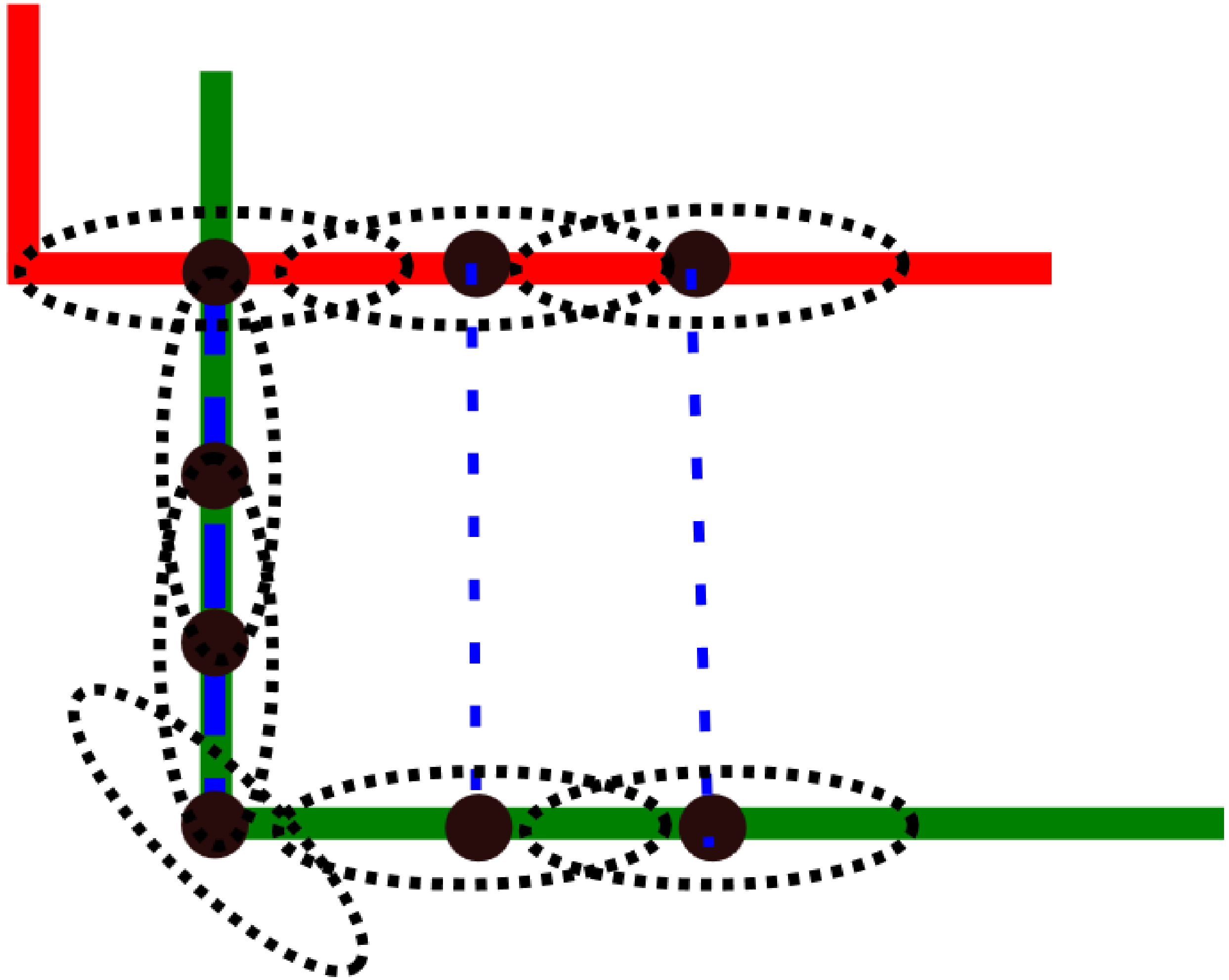
Iterative Closest Point: Algorithm

1. Associate points of the two cloud using the nearest neighbor criteria
2. Estimate transformation parameters using a mean square cost function
3. Transform the points using the estimated parameters
4. Iterate (re-associate the points and so on)

Iterative Closest Point: Code

```
IterativeClosestPoint<PointXYZ, PointXYZ> icp;
// Set the input source and target
icp.setInputCloud (cloud_source);
icp.setInputTarget (cloud_target);
// Set the max correspondence distance to 5cm
icp.setMaxCorrespondenceDistance (0.05);
// Set the maximum number of iterations (criterion 1)
icp.setMaximumIterations (50);
// Set the transformation epsilon (criterion 2)
icp.setTransformationEpsilon (1e-8);
// Set the euclidean distance difference epsilon (criterion 3)
icp.setEuclideanFitnessEpsilon (1);
// Perform the alignment
icp.align (cloud_source_registered);
// Obtain the transformation that aligned cloud_source to cloud_source_registered
Eigen::Matrix4f transformation = icp.getFinalTransformation ();
```

Plane-to-plane



All of the points along the vertical section of the green scan are incorrectly associated with a single point in the red scan

Generalized ICP

- Variant of ICP

- Assumes that points are sampled from a locally continuous and smooth surfaces

- Since two points are not the same it is better to align patches of surfaces instead of the points

Generalized ICP: Code

```
// create the object implementing ICP algorithm
pcl::GeneralizedIterativeClosestPoint<pcl::PointXYZRGBNormal, pcl::PointXYZRGBNormal> gicp;

// set the input point cloud to align
gicp.setInputCloud(cloud_in);
// set the input reference point cloud
gicp.setInputTarget(cloud_out);

// compte the point cloud registration
pcl::PointCloud<pcl::PointXYZRGBNormal> Final;
gicp.align(Final);

// print if it the algorithm converged and its fitness score
std::cout << "has converged:" << gicp.hasConverged()
          << " score: "
          << gicp.getFitnessScore() << std::endl;

// print the output transformation
std::cout << gicp.getFinalTransformation() << std::endl;
```

Esercitazione (1/3)

- Read a sequence of ordered pairs of images (RGB + Depth images) and save the associated point cloud with colors and surface normals on .pcd files (e.g., cloud_005.pcd)

- Download one of the datasets (e.g. desk_1.tar) at: http://rgbd-dataset.cs.washington.edu/dataset/rgbd-scenes/

Esercitazione (2/3)

Then, for each file .pcd read sequentially:

- Align the current point cloud with the previous one by using Generalized ICP
- Save the cloud with its global transformation (either transforming directly the cloud or using the sensor_origin and sensor_orientation parameter provided in the point cloud object)

Esercitazione (3/3)

- Apply a voxelization to the total point cloud (necessary to reduce the dimension in terms of bytes) and visualize it so that the entire scene reconstructed is shown

Suggerimenti (1/2)

Warning: the depth images are stored with 16 bit depth, so in this case calling the `cv::imread()` function you should specify the flag cv::IMREAD_ANYDEPTH :
cv::Mat input_depth = cv::imread("test_depth.png", cv::IMREAD_ANYDEPTH);

WARNING: the input depth image should be scaled by a 0.001 factor in order to obtain distances in meters. You could use the opencv function:

```
input_depth_img.convertTo(scaled_depth_img, CV_32F, 0.001);
```

As camera matrix, use the following default matrix:

```
float fx = 512, fy = 512, cx = 320, cy = 240;
Eigen::Matrix3f camera_matrix;
camera_matrix << fx, 0.0f, cx, 0.0f, fy, cy, 0.0f, 0.0f, 1.0f;
```

As re-projection matrix, use the following matrix:

```
Eigen::Matrix4f t_mat; t_mat.setIdentity();
t_mat.block<3, 3>(0, 0) = camera_matrix.inverse();
```

Suggerimenti (2/2)

For each pixel (x,y) with depth d, obtain the corresponding 3D point as:

```
Eigen::Vector4f point = t_mat * Eigen::Vector4f(x*d, y*d, d, 1.0);
```

(the last coordinate of point can be ignored)

WARNING: Since We are working with organized point clouds, also points with depth equal to 0 that are not valid, should be added to the computed cloud as `NaN`, i.e. in pseudocode:

```
const float bad_point = std::numeric_limits<float>::quiet_NaN();
if( depth(x, y) == 0) { p.x = p.y = p.z = bad_point; }
```

To get the global transform of the current cloud just perform the following multiplication after you computed the registration:

```
Eigen::Matrix4f globalTransform = previousGlobalTransform *
alignmentTransform;
```

`previousGlobalTransform` is the global transformation found for the previous pointcloud

`alignmentTransform` is the local transform computed using Generalized ICP

WARNING: the first global transform has to be initialized to the identity matrix

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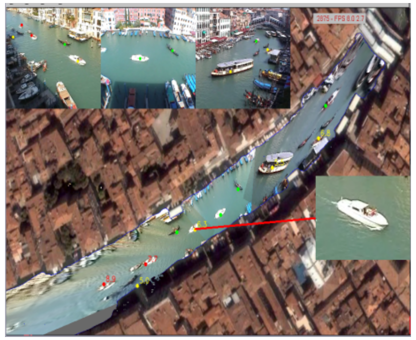
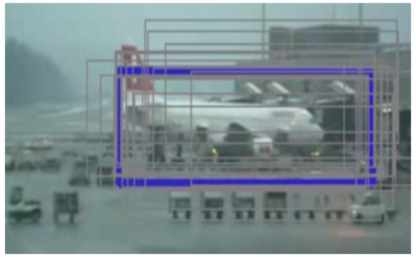


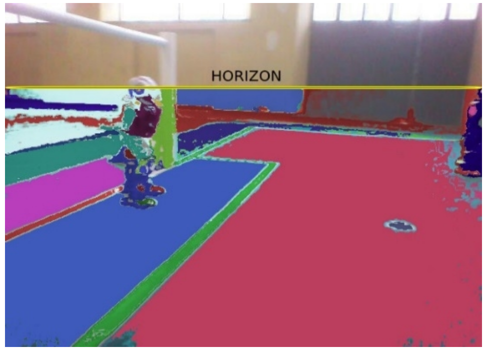
Acquisizione e gestione dati 3D

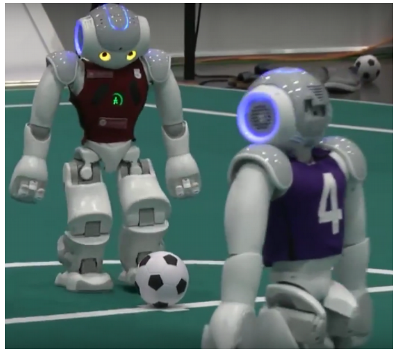
Docente:

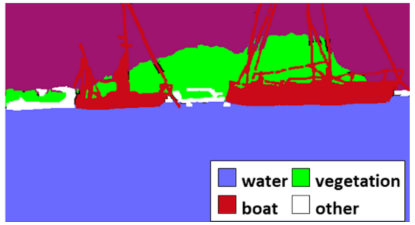
Domenico Daniele Bloisi











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