



ROS-Industrial Basic Developer's Training Class

March 2022

Southwest Research Institute





Session 4: Motion Planning

Moveit! Planning using C++

Intro to Planners

Intro to Perception

Southwest Research Institute





Motion Planning in C++



Movelt! provides a high-level C++ API:

`moveit_cpp`

```
#include <moveit/moveit_cpp/moveit_cpp.h>
...
moveit_cpp::MoveItCpp::Ptr moveItCpp = make_shared(node);
moveit_cpp::PlanningComponent::Ptr planner = make_shared("arm", moveItCpp);

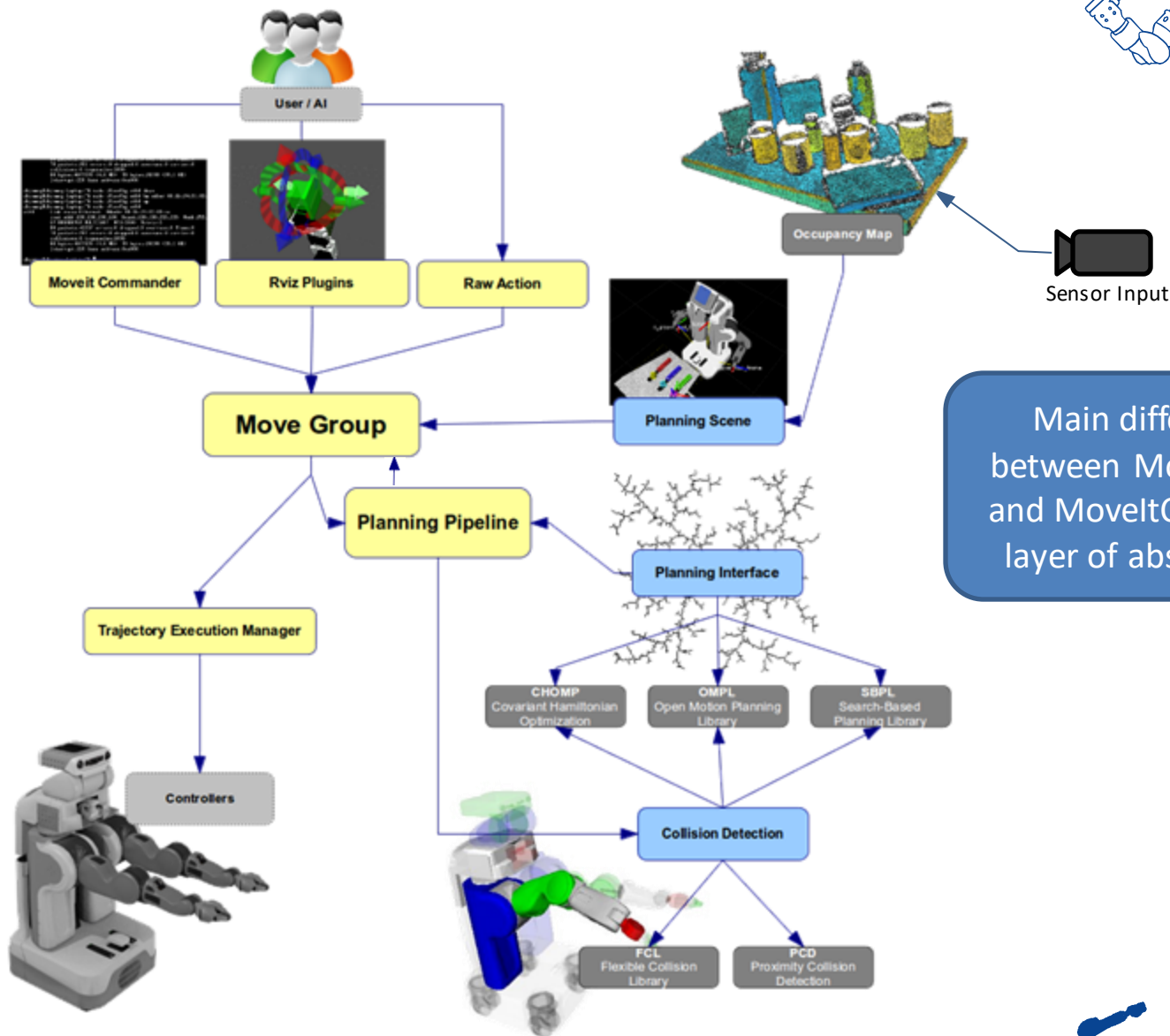
planner->setGoal("home");
planner->plan();
planner->execute();
```

5 lines = collision-aware path planning & execution





Reminder: MoveIt! Complexity



http://moveit.ros.org/wiki/High-level_Overview_Diagram
http://moveit.ros.org/wiki/Pipeline_Overview_Diagram





Motion Planning in C++



Pre-defined position:

```
planner.setGoal("home");
```

Joint position:

```
robot_state::RobotState joints.setStateValues(names, positions);  
planner.setGoal(joints);
```

Cartesian position:

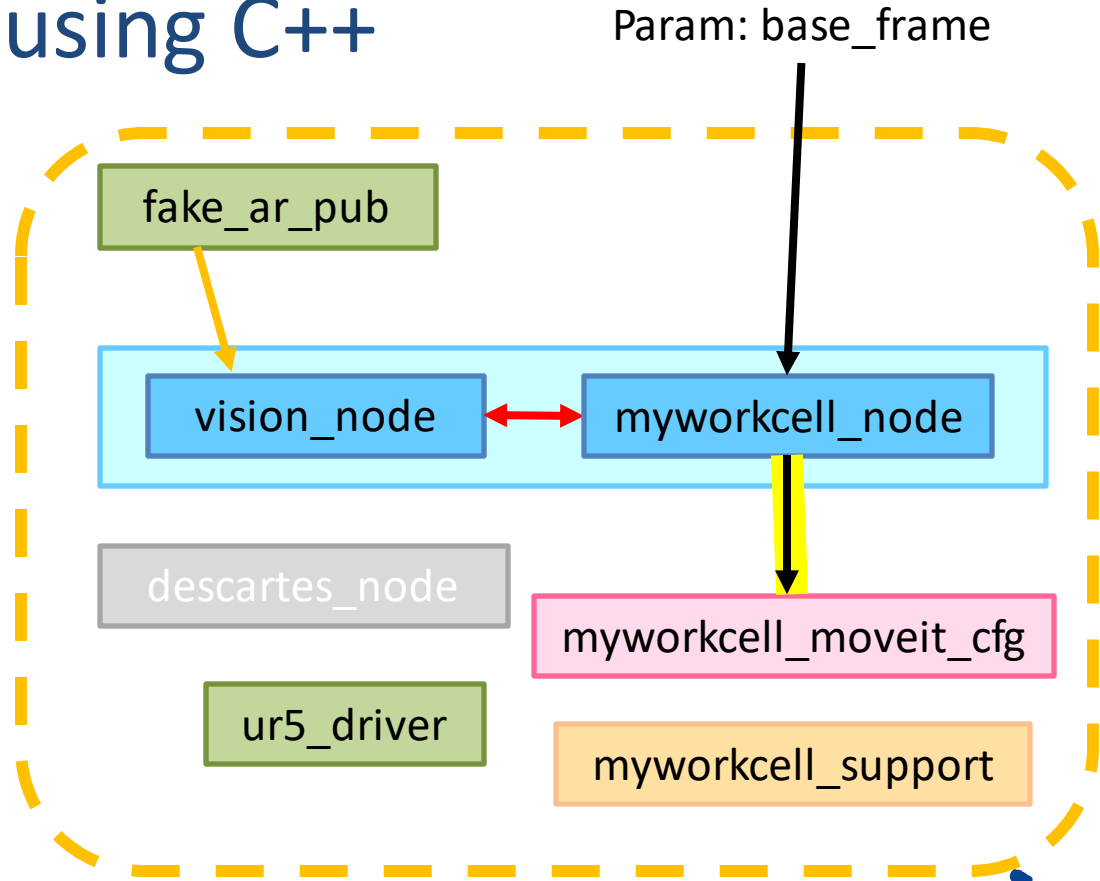
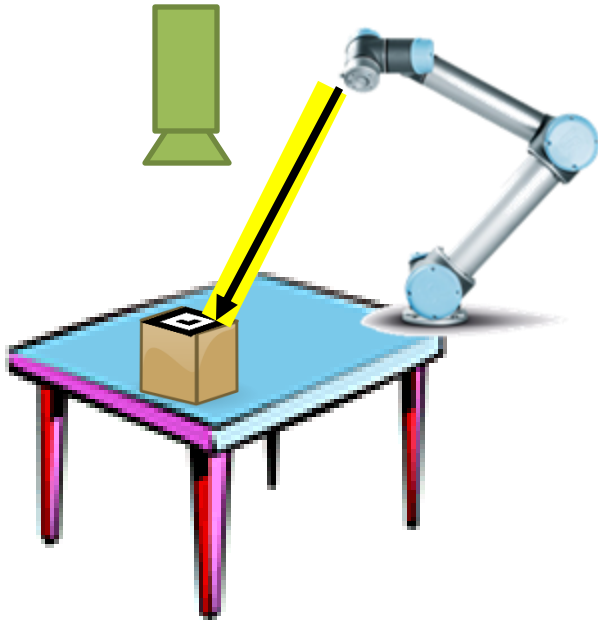
```
Affine3d pose = {x, y, z, r, p, y};  
planner.setGoal(pose);
```





Exercise 4.0

Exercise 4.0: Motion Planning using C++





Intro to Planners



- Types of Motion Plans
- Basic Toolpath Plan
- Planning Workflows
- Common Motion Planners
 - OMPL
 - Descartes
 - TrajOpt
- Motion Planning Frameworks
- Simple Planning Pipelines
- Advanced Planning Pipelines





Types of Motion Plans



Freespace	Process	Combined
Motion plans between far-spaced start and end points	Motion plans optimize robot pose between under-constrained waypoints	Motion plans that can be segmented into portions that are freespace motions and others that are process motions
Example: Moving from a generic, off-the-surface "start pose" to the upper righthand corner of a surface for painting	Example: A continuous line mapped around the edge of a piece to be welded	Example: Moving from a generic, off-the-surface "start pose" to the edge of a jig-held part and then welding the edge at a known EE angle





Toolpath Plan Example

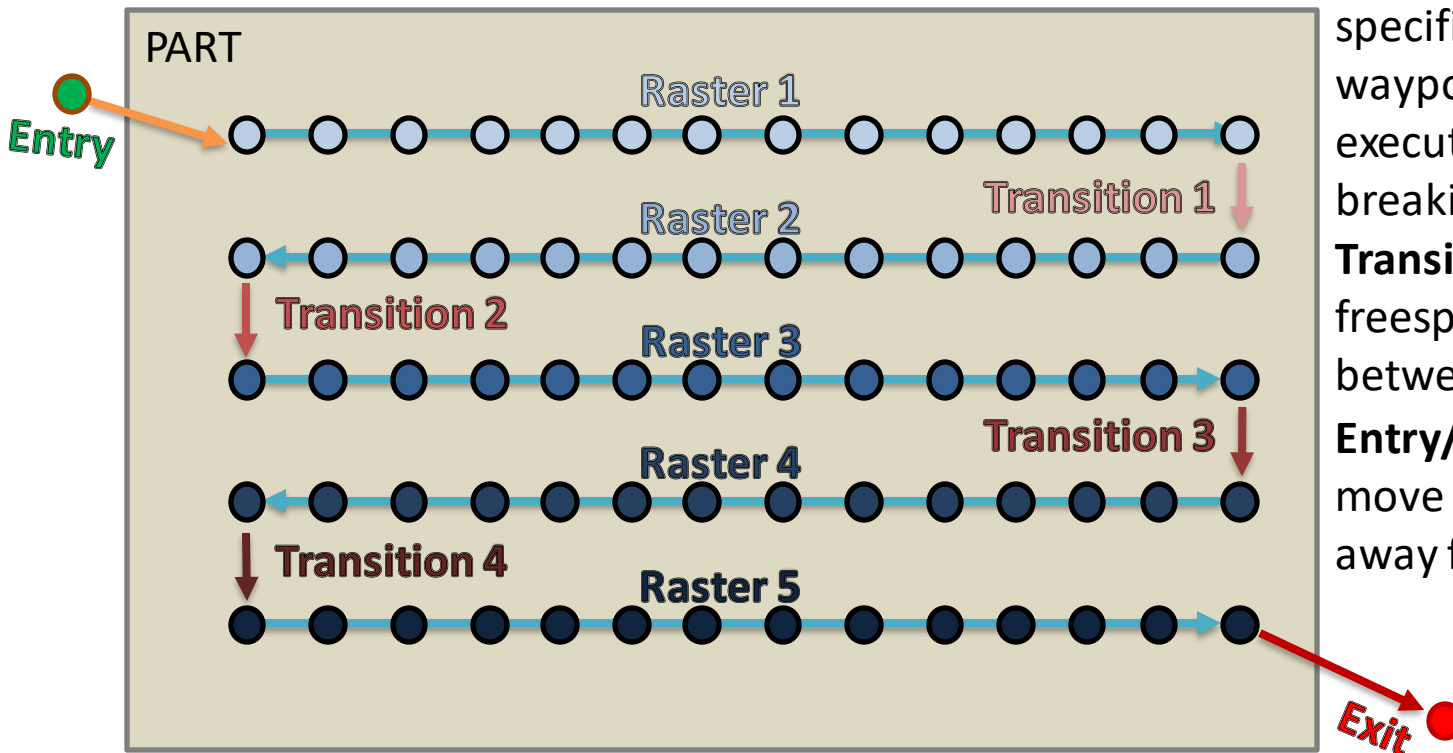
Definitions

Raster - A series of specified Cartesian waypoints to be executed without breaking*

Transition - A freespace move between rasters

Entry/Exit - A freespace move from/to a position away from the part

*depends on application





Common Motion Planners



Motion Planner	Application Space	Notes
OMPL / MoveIt	Free-space Planning	Stochastic sampling; Easy and convenient interface
TrajOpt	Trajectory Optimization	Optimize existing trajectory on constraints (distance from collision, joint limits, etc.)
Descartes	Cartesian path planning	Globally optimum; sampling-based search; Captures “tolerances”
CLIK	Cartesian path planning	Local optimization; Scales well with high DOF; Captures “tolerances”
STOMP	Free-space Planning	Optimization-based; Emphasizes smooth paths
CHOMP	Trajectory Optimization	Gradient-based trajectory optimization for collision avoidance and cost-reduction

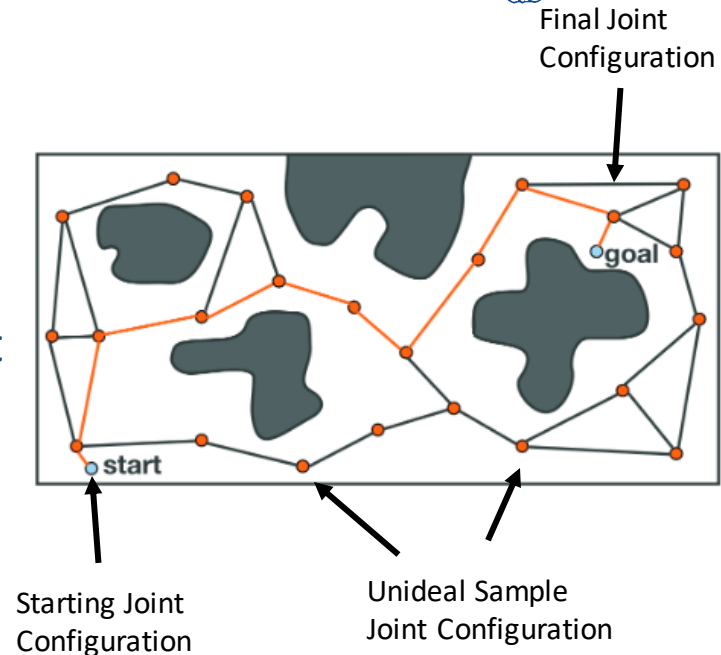




Open Motion Planning Library:
Randomly Sample Valid Joint States then
Solve for Sequence

Planners we often use:

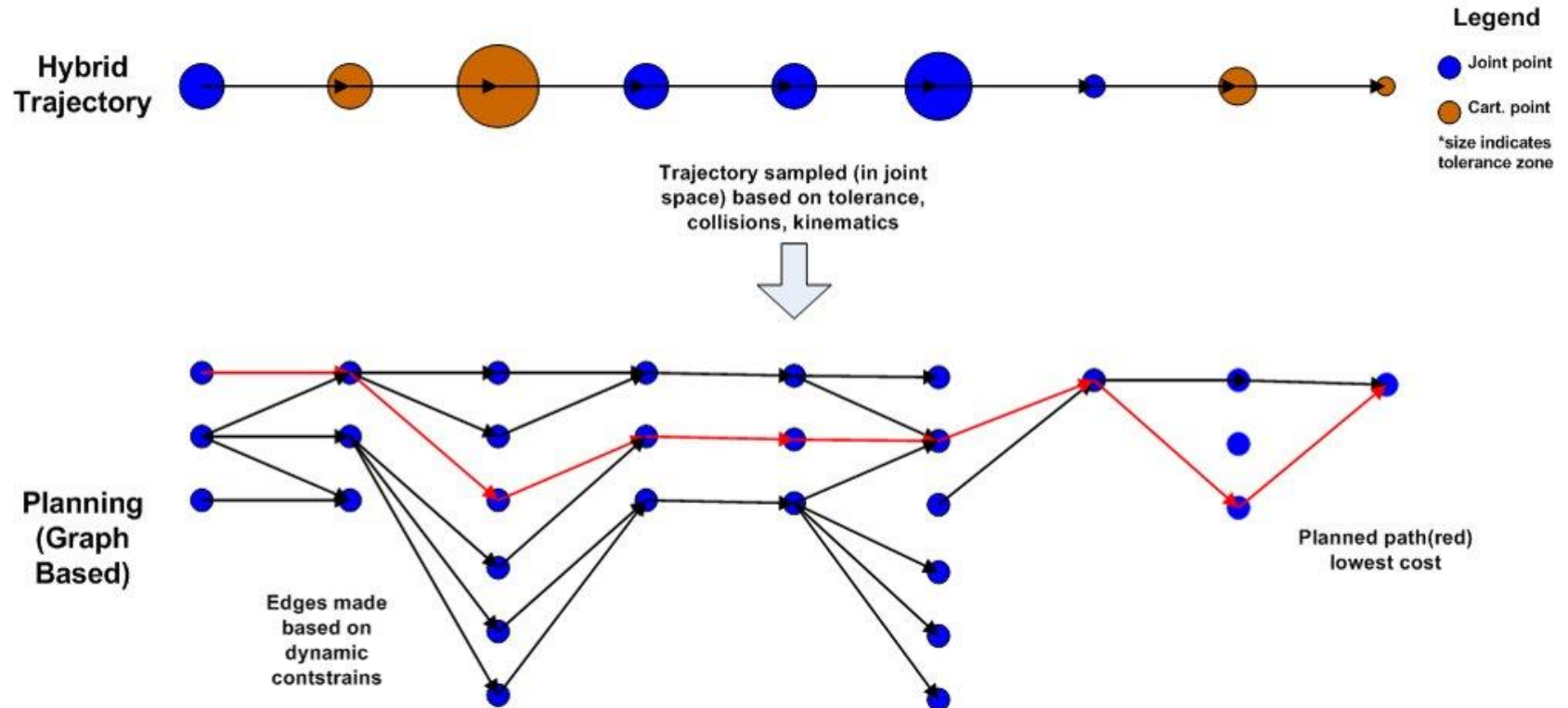
- RRT
 - Build a tree along different potential joint configurations to arrive at the final pose
- RRT-Connect
 - Build a tree from each side and try to *connect* them
 - Parameters
 - Range (same as above)
- See more at
<https://ompl.kavrakilab.org/planners.htm>





Descartes

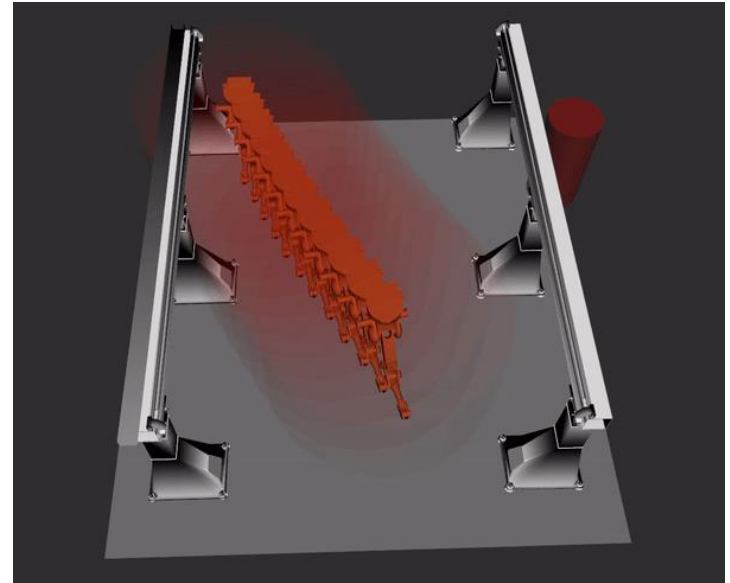
Sample 'all' Possible Solutions then Graph Search for Best Trajectory





Optimize Seed Trajectory based on Weighted Cost Functions (distance from collision, joint limits, etc.)

- All parameters have a coefficient that can be increased/decreased to change its influence
- Example costs:
 - Proximity to a singularity
 - Velocity/Acceleration/Jerk smoothing
 - Avoid collisions
 - Weighed sums of all collision terms
 - Safety margin-based cost
 - Encourage/discourage DOF usage
 - Cartesian: rotation about z encouraged & unconstrained
 - Joint: usage of the wrist discouraged with a high cost
- Constraints are simply infinite costs
 - The absolute limit of the safety margin would be set and anything in collision with it would cause the planner to fail





Motion Planning Environments



Interfaces used to generate motion plans can be:

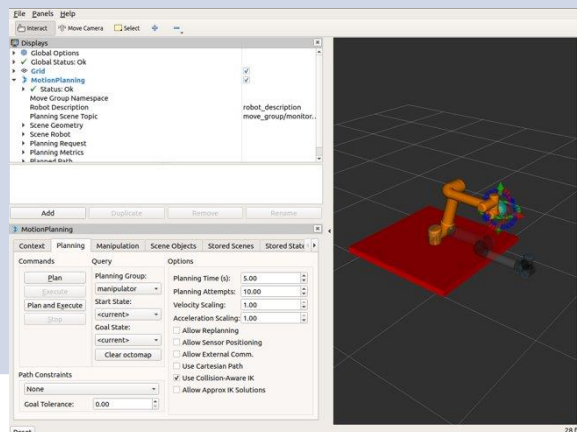
- Open Source or License-based
- UI or script based
- Leverage a variety of planners
- Contain additional hooks to simulation packages

These differ from raw planners with:

- ROS API
- Collision environment management
- Visualization packages
- Planning pipeline/Task Constructor capabilities

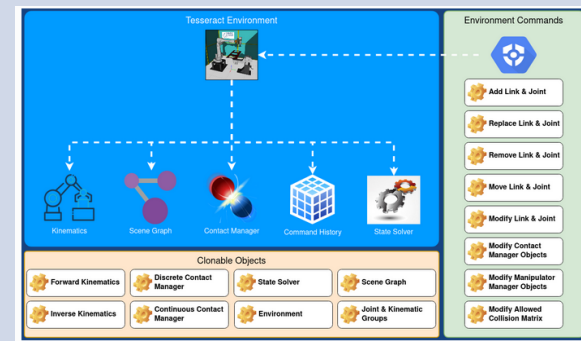
Movelt!/MoveIt!2

Easy to use interface, wizard features, broad toolset



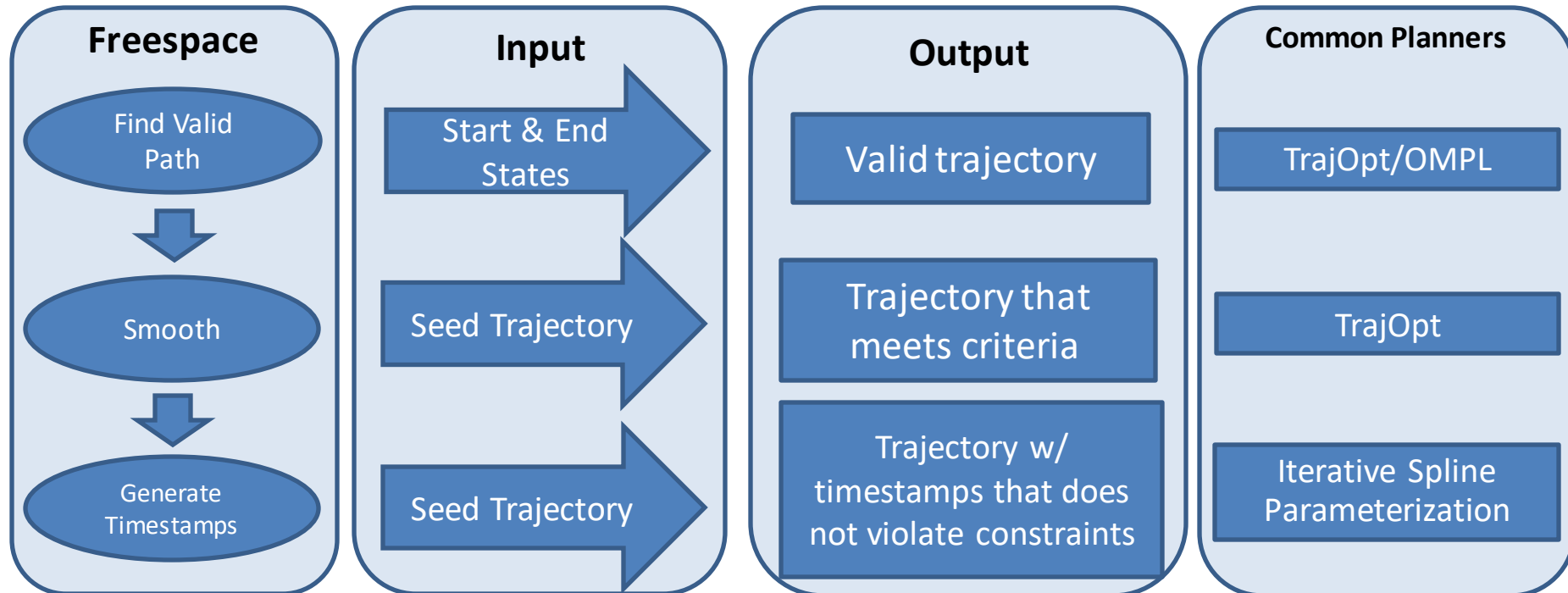
Tesseract

Enables very complex planning, different toolset



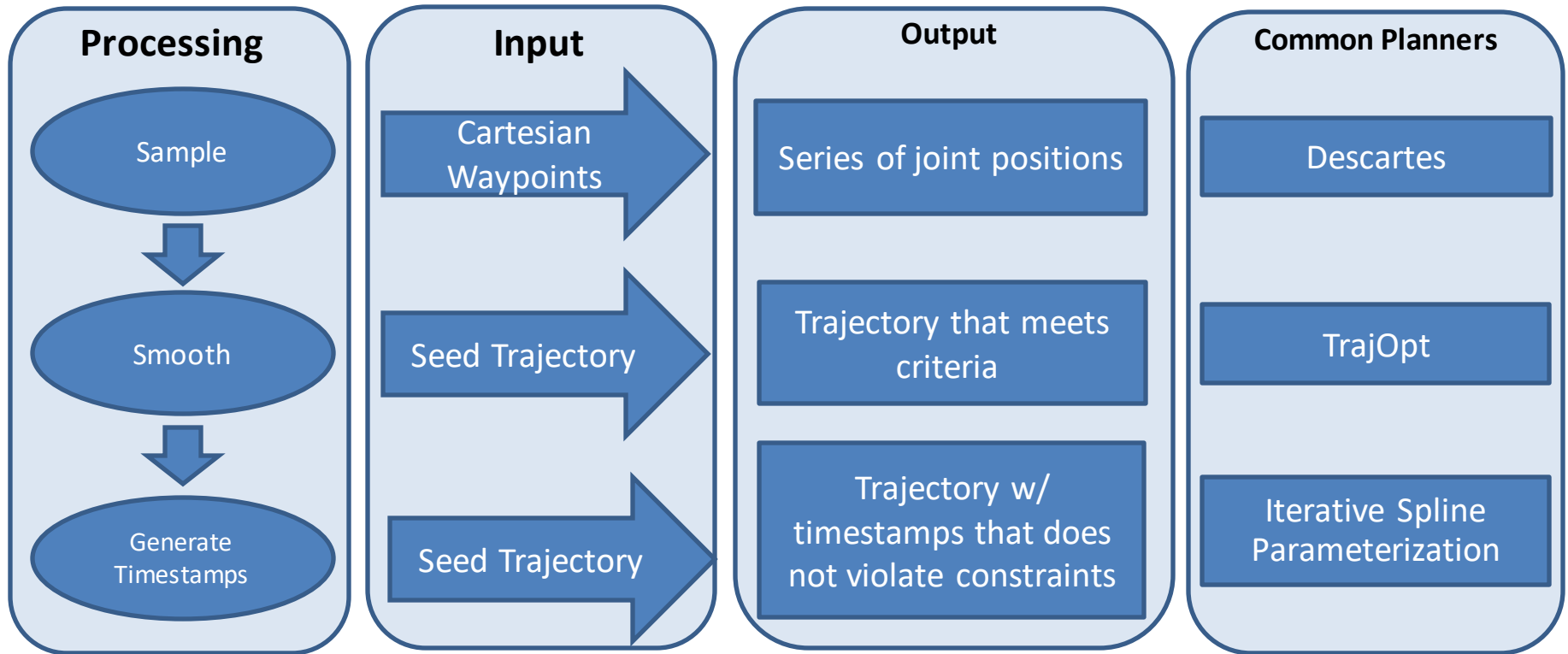


Freespace Planners



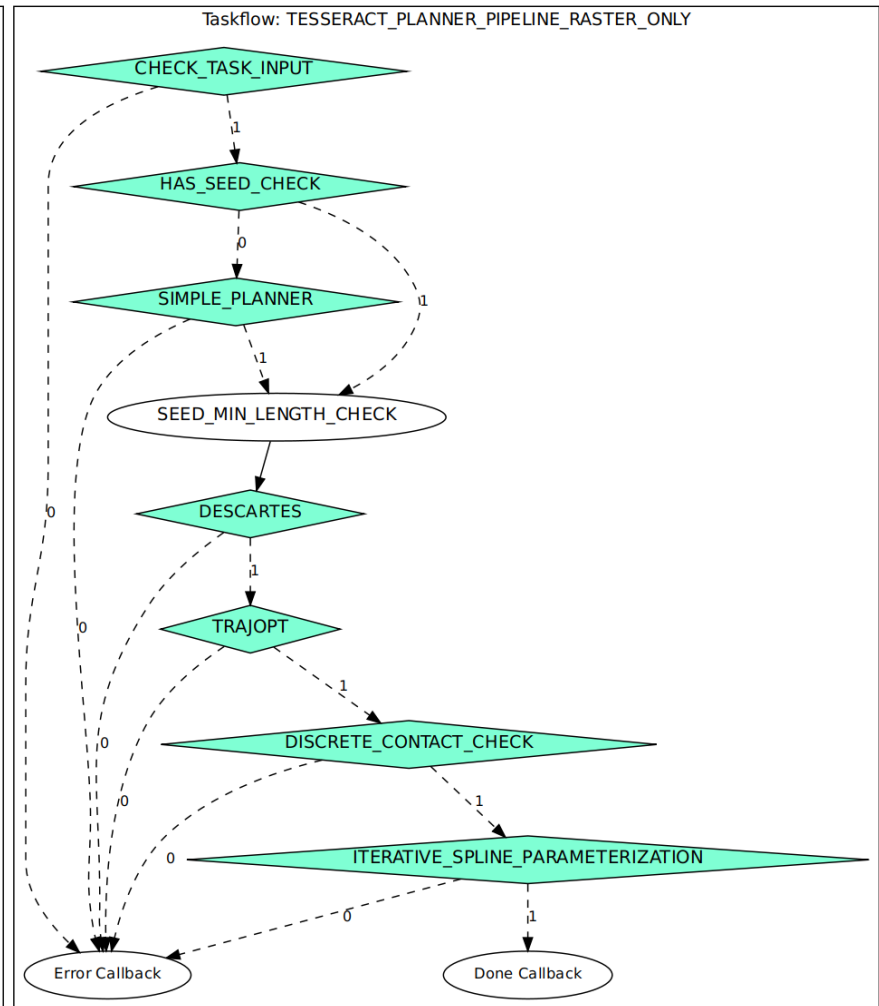
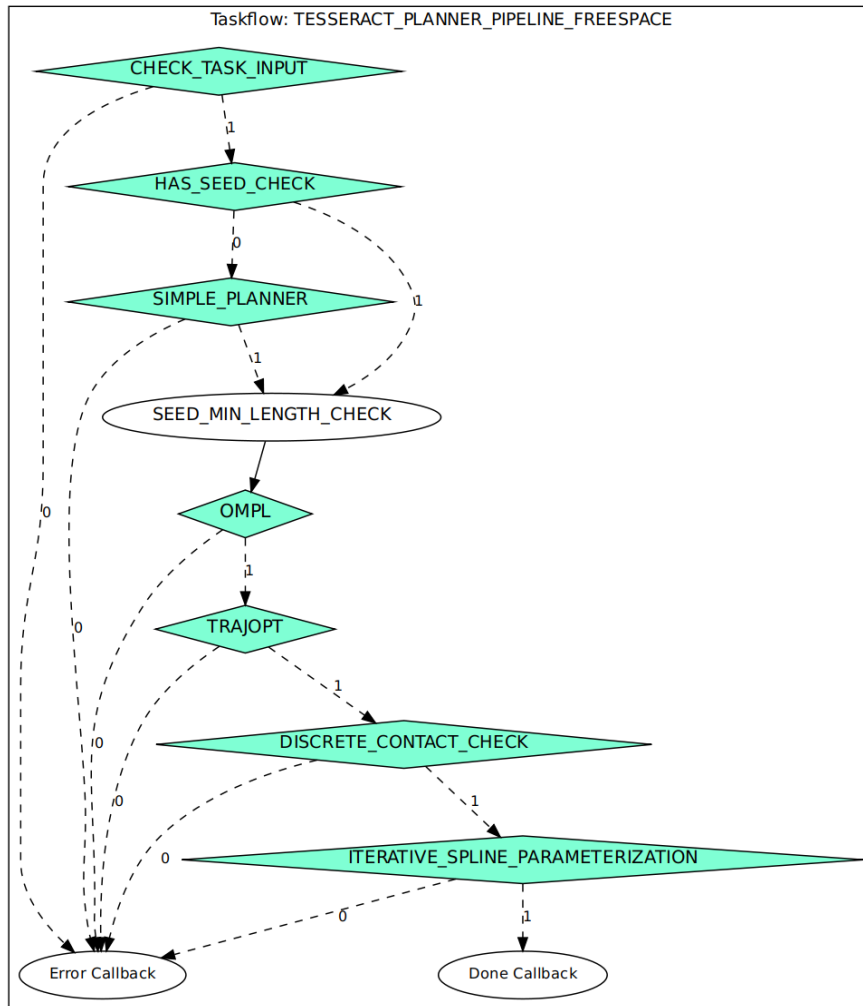


Processing Planners





Planning Pipeline/Task Construction





INTRODUCTION TO PERCEPTION





Outline



- Camera Calibration
- 3D Data Introduction
 - Exercise 4.2
- Explanation of the Perception Tools Available in ROS
- Intro to PCL tools
 - Exercise 4.2





Objectives



- Understanding of the calibration capabilities
- Experience with 3D data and RVIZ
- Experience with Point Cloud Library tools*





Industrial Calibration

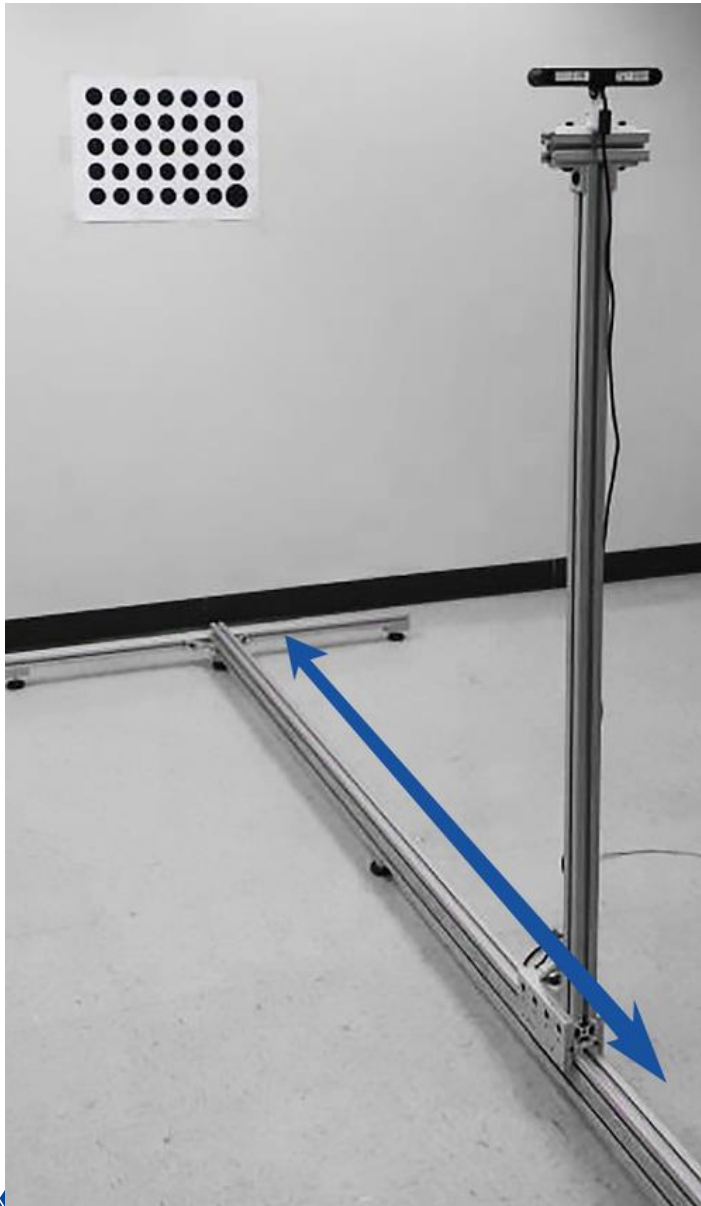


- Perform intrinsic and extrinsic calibration
- Continuously improving library
- Resources, library
 - Github [link](#)
 - Wiki [link](#)
- Resources, tutorials
 - Github industrial calibration tutorials [link](#)
 - Training Wiki [link](#)





Industrial (Intrinsic) Calibration



- The INTRINSIC Calibration procedure requires movement of the camera to known positions along an axis that is approximately normal to the calibration target.
- Using the resulting intrinsic calibration parameters for a given camera yields significantly better extrinsic calibration or pose estimation accuracy.





Industrial (Extrinsic) Calibration



https://www.youtube.com/watch?v=MJFtEr_Y4ak





3D Cameras

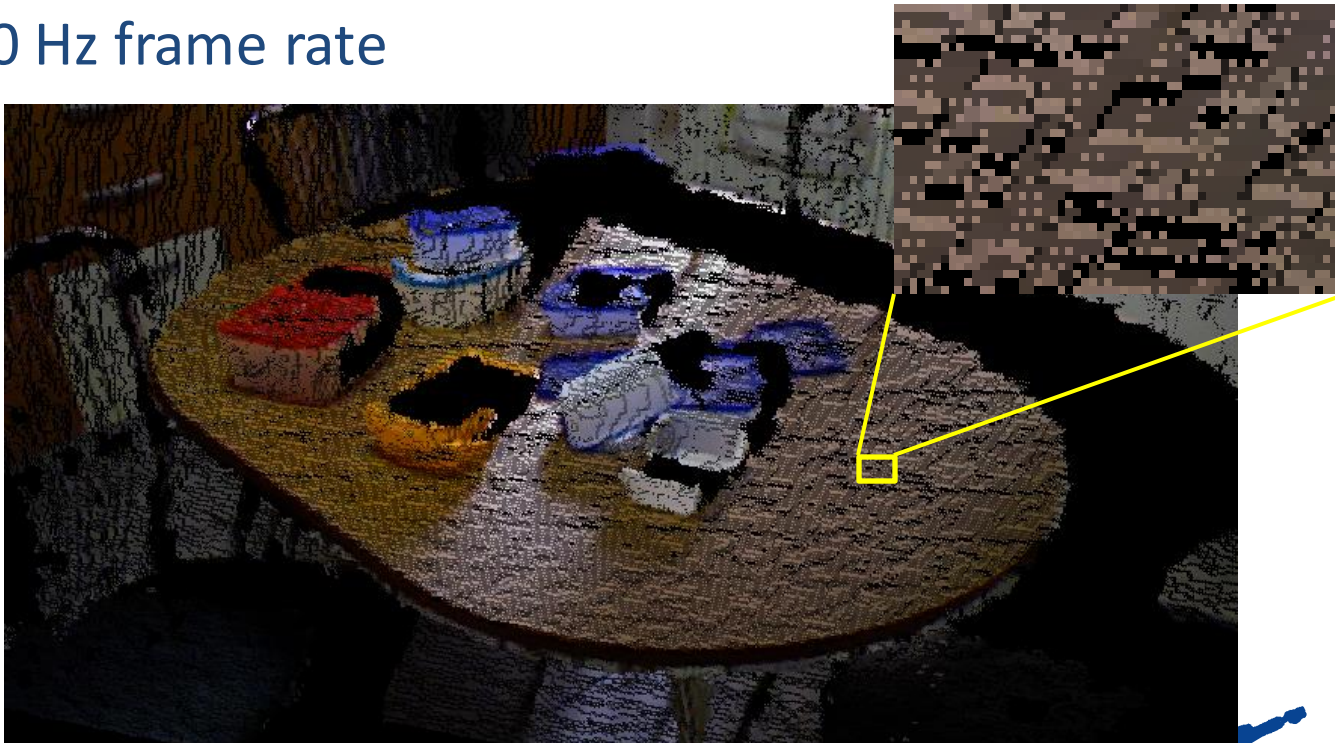
- RGBD cameras, TOF cameras, stereo vision, 3D laser scanner
- Driver for Asus Xtion camera and the Kinect (1.0) is in the package `openni2_launch`
- Driver for Kinect 2.0 is in package `iai_kinect2` ([github link](https://github.com/iai/iai_kinect2))
- <https://rosindustrial.org/3d-camera-survey>





3D Cameras

- Produce (colored) point cloud data
- Huge data volume
 - Over 300,000 points per cloud
 - 30 Hz frame rate

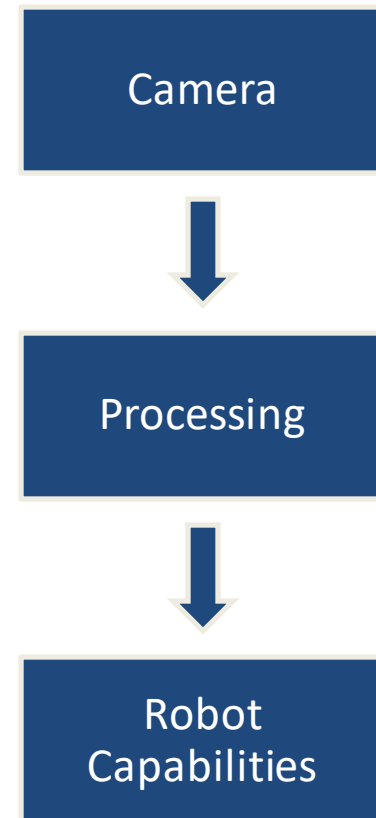




Perception Processing Pipeline



- Goal: Gain knowledge from sensor data
- Process data in order to
 - Improve data quality ➡ filter noise
 - Enhance succeeding processing steps ➡ reduce amount of data
 - Create a consistent environment model ➡ Combine data from different view points
 - Simplify detection problem ➡ segment interesting regions
 - Gain knowledge about environment ➡ classify surfaces





Perception Tools



- Overview of OpenCV
- Overview of PCL
- PCL and OpenCV in ROS
- Other libraries
- Focus on PCL tools for exercise

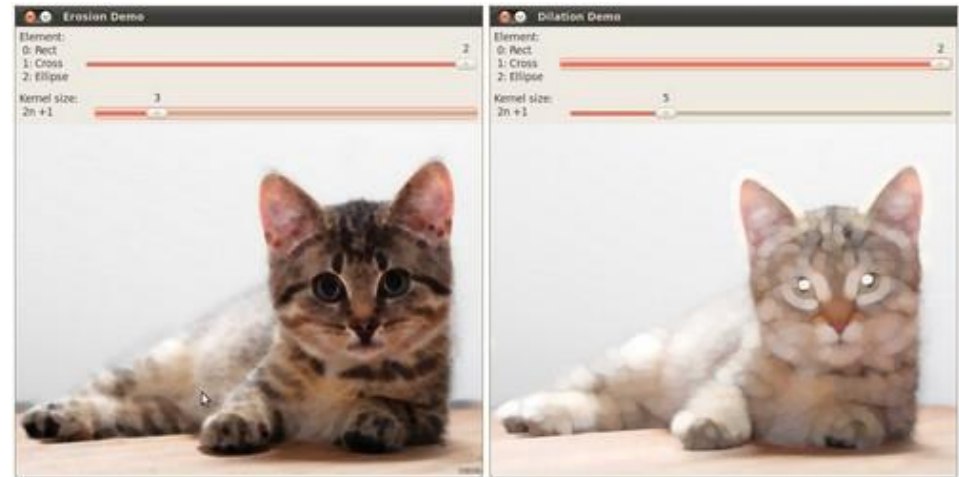




Perception Libraries (OpenCV)



- Open Computer Vision Library (OpenCv) - <http://opencv.org/>
 - Focused on 2D images
 - 2D Image processing
 - Video
 - Sensor calibration
 - 2D features
 - GUI
 - GPU acceleration



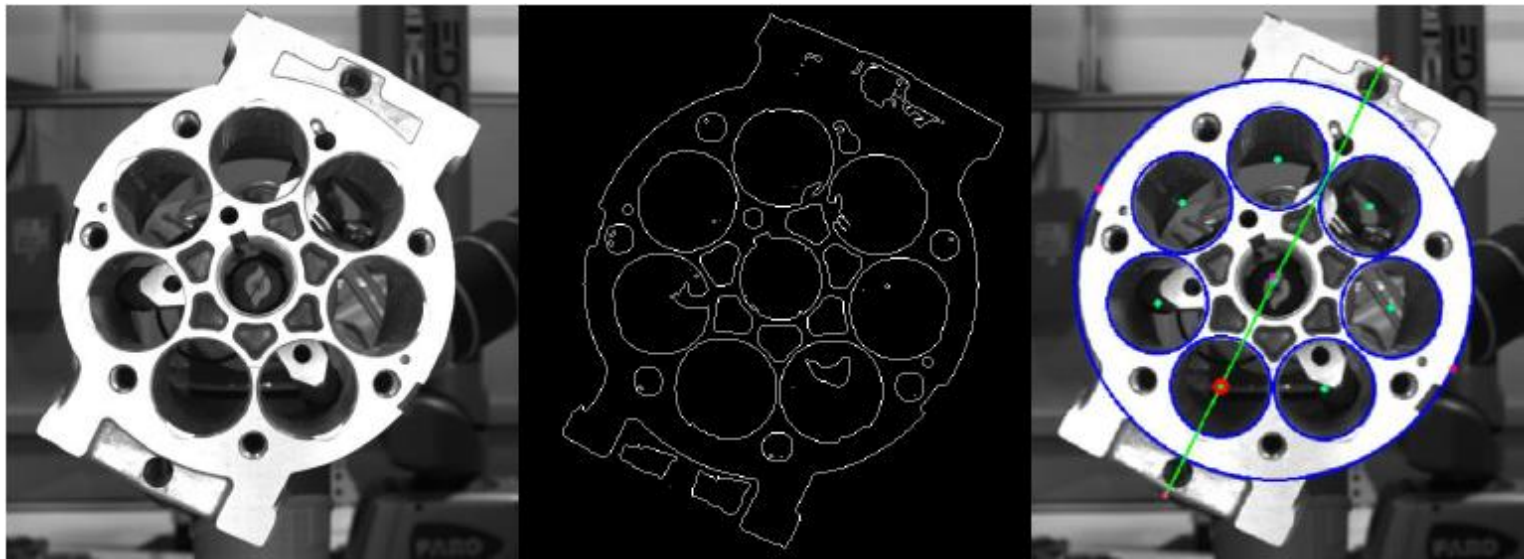
<http://opencv.org>





OpenCV tutorial

- Perform image processing to determine pump orientation (roll angle)
- Github tutorial [link](#)
- Training Wiki [link](#)





Perception Libraries (OpenCV)



- Open CV 3.2
 - Has more 3D tools
 - LineMod
 - <https://www.youtube.com/watch?v=vsThfxzIUjs>
 - PPF
 - Has opencv_contrib
 - Community contributed code
 - Some tutorials

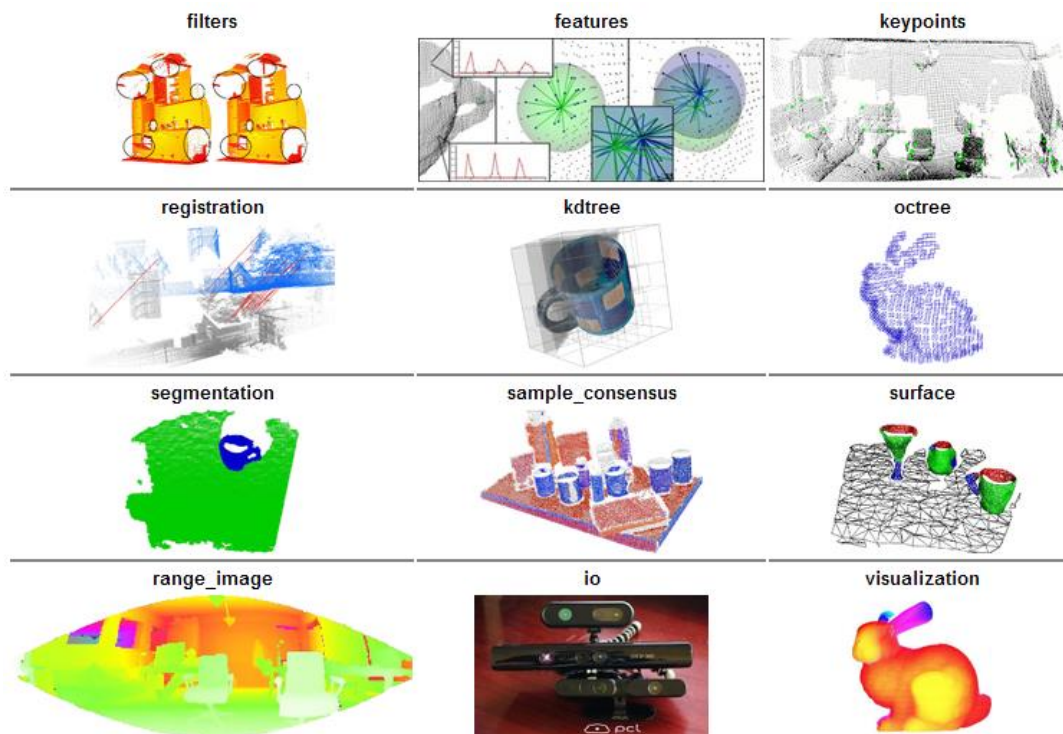




Perception Libraries (PCL)



- Point Cloud Library (PCL) -
<http://pointclouds.org/>
– Focused on 3D Range(Colorized) data



<http://pointclouds.org>





Perception Libraries (PCL)



- PCL Command Line Tools
 - `sudo apt install pcl-tools`
 - Tools (140+)
 - `pcl_viewer`
 - `pcl_point_cloud_editor`
 - `pcl_voxel_grid`
 - `pcl_sac_segmentation_plane`
 - `pcl_cluster_extraction`
 - `pcl_passthrough_filter`
 - `pcl_marching_cubes_reconstruction`
 - `pcl_normal_estimation`
 - `pcl_outlier_removal`





ROS Bridges



- OpenCV & PCL are external libraries
- “Bridges” are created to adapt the libraries to the ROS architecture
 - OpenCV: http://ros.org/wiki/vision_opencv
 - PCL: http://ros.org/wiki/pcl_ros
 - Standard Nodes (PCL Filters):
http://ros.org/wiki/pcl_ros#ROS_nodelets





Many More Libraries



- Many more libraries in the ROS Ecosystem

- AR Tracker

- http://www.ros.org/wiki/ar_track_alvar

- Robot Self Filter

- http://www.ros.org/wiki/robot_self_filter





Exercise 4.2



- Play with PointCloud data
 - Play a point cloud file to simulate data coming from a Asus 3D sensor.
 - Matches scene for demo_manipulation
 - 3D Data in ROS 2
 - Use PCL Command Line Tools
- https://github.com/ros-industrial/industrial_training/wiki/Introduction-to-Perception





Session 3

ROS-Industrial

- Architecture
- Capabilities

Motion Planning

- Examine MoveIt Planning Environment
- Setup New Robot
- Motion Planning (Rviz)
- Motion Planning (C++)

Session 4

MoveIt! Planning

Intro to Planners

Perception

- Calibration
- PointCloud File
- OpenCV
- PCL
- PCL Command Line Tools

