上海科技大学

ShanghaiTech University

CS283: **Robotics Fall 2020: Maps**

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ARM PLANNING

Kinematic Problems for Manipulation

- Reliably position the tip - go from one position to another position
- Don't hit anything, avoid obstacles
- Make smooth motions
  - at reasonable speeds and
  - at reasonable accelerations
- Adjust to changing conditions -
  - i.e. when something is picked up *respond to the change in weight*

Planning Problem

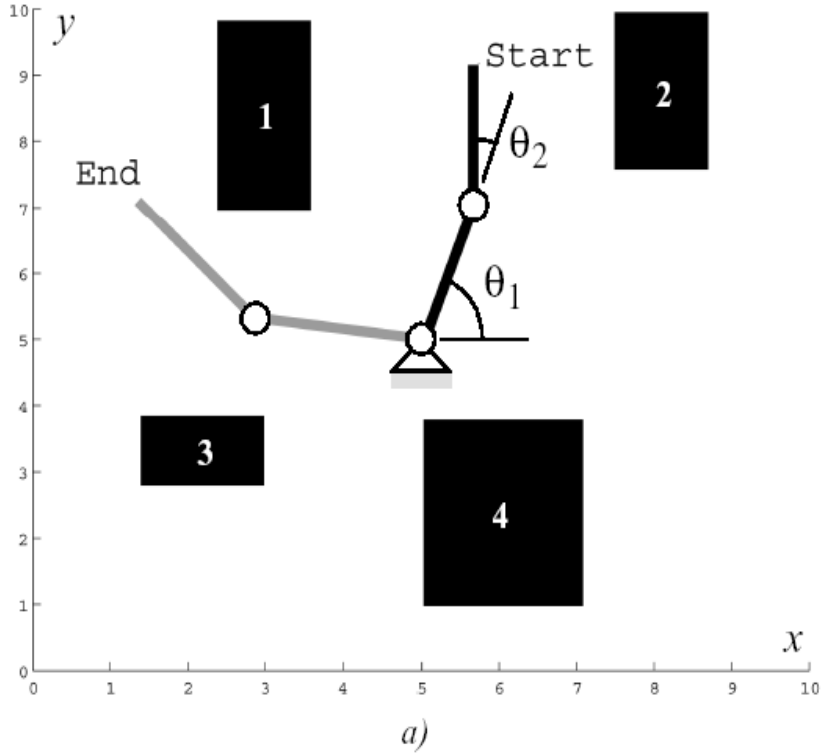
- (Arm) Pose: Set of join values
- (Arm) Trajectory:
  - Given a start pose and an end pose
  - A list of intermediate poses
  - That should be reached one after the other
  - With associated (desired) velocities and accelerations (maxima)
    - Without time (without velocity and acceleration): path! So:
    - Path: poses; Trajectory: poses with speeds (and maybe accelerations)
- Constrains:
  - Don’t collide with yourself
  - Don’t collide with anything else (except: fingers with the object to manipulate!!!)
  - Additional possible constrains:
    - Maximum joint velocities or accelerations
    - Keep global orientation of a joint (often end-effector) within certain boundaries

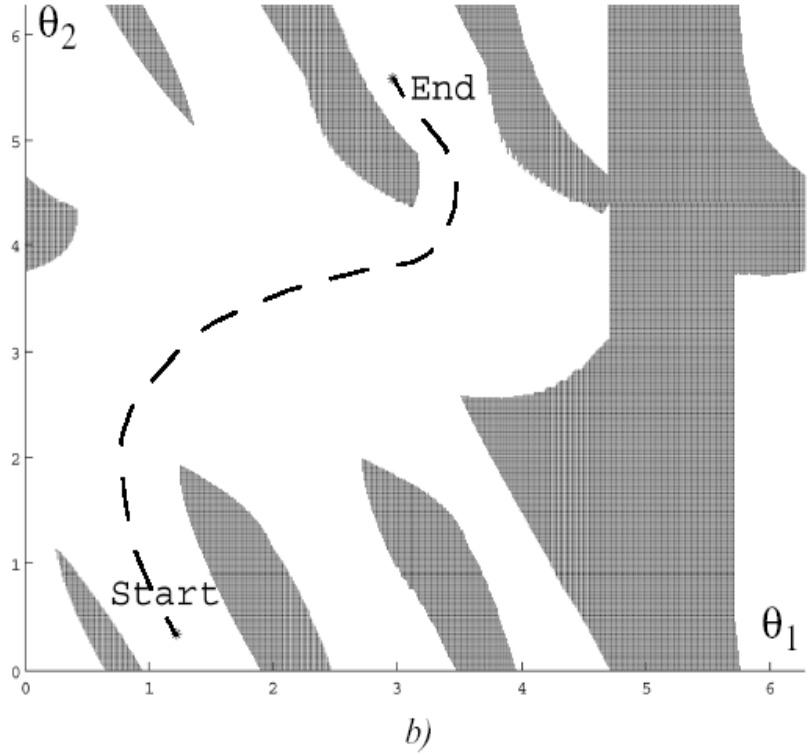
Planning Problem cont.

- Often the goal specified in Cartesian space (not joint space)
- => use IK to get joint space
- => often multiple (even infinitely many) solutions
  - Which one select for planning?
  - Plan for several solutions and select best!?

Work Space (Map) → Configuration Space

- State or configuration q can be described with k values q_i





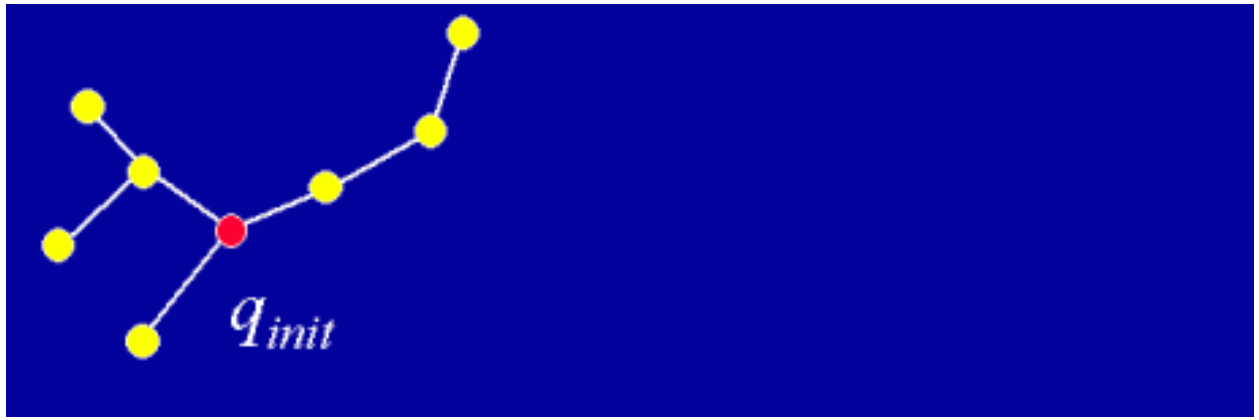
Work Space
Dimension depends on map
Dimension – typically 2D or 3D

Configuration Space:
the dimension of this
space is equal to the Degrees of Freedom (DoF)
of the robot

RRT

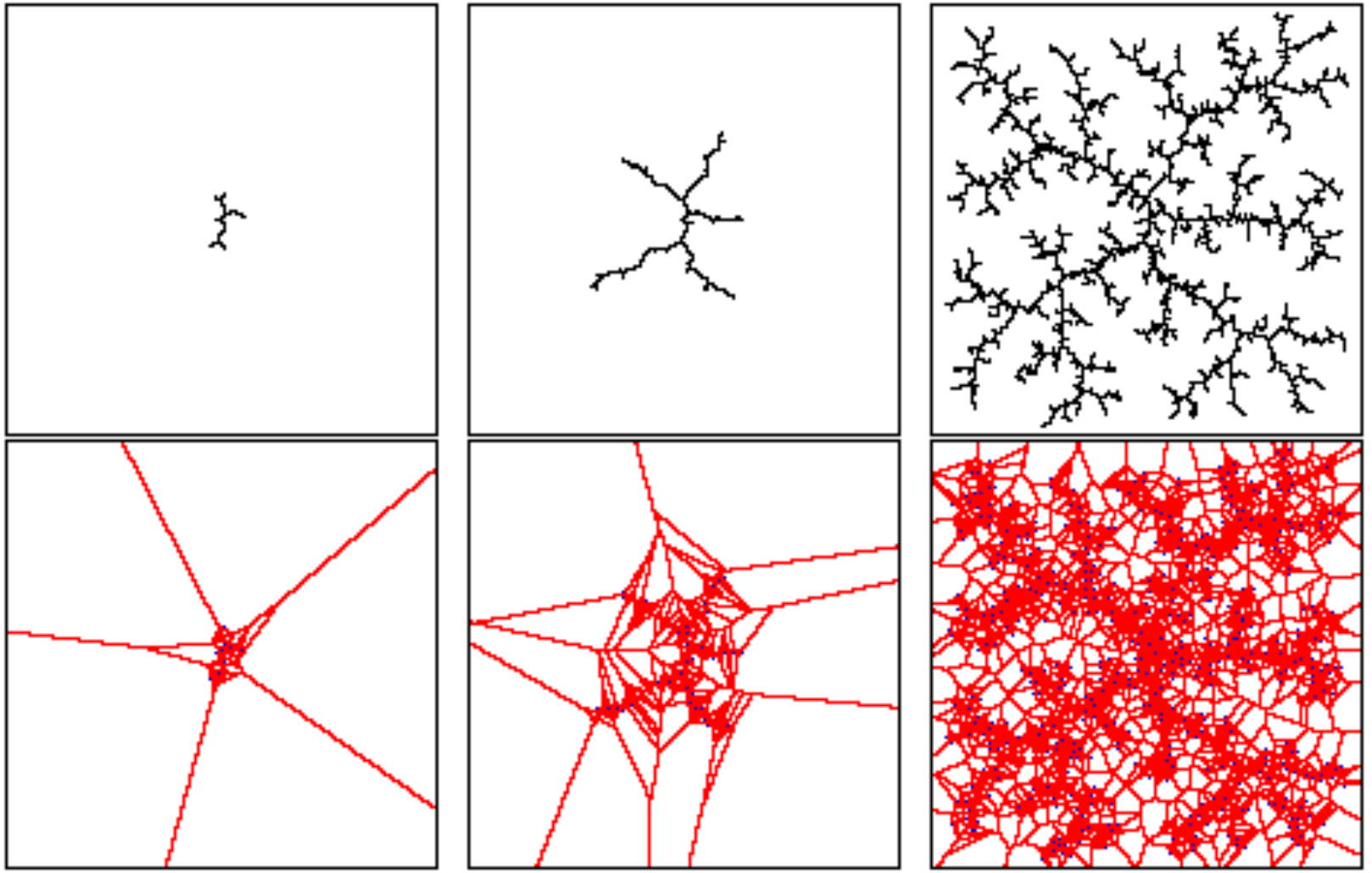
```
BUILD_RRT(q_init)
 1  T.init(q_init);
 2  for k = 1 to K do
 3      q_rand ← RANDOM_CONFIG();
 4      EXTEND(T, q_rand);
 5  Return T
```

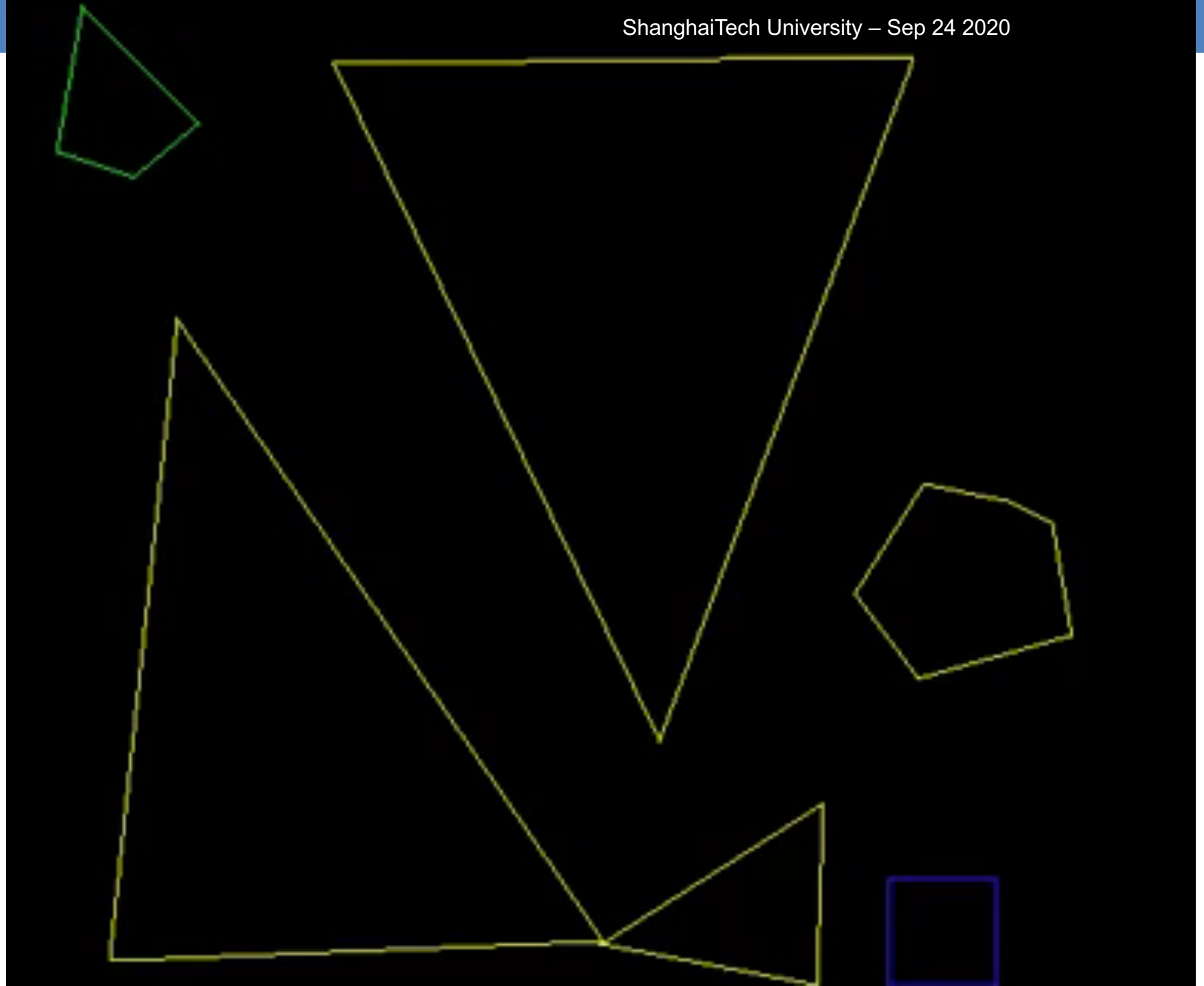
```
EXTEND(T, q)
 1  q_near ← NEAREST_NEIGHBOR(q, T);
 2  if NEW_CONFIG(q, q_near, q_new) then
 3      T.add_vertex(q_new);
 4      T.add_edge(q_near, q_new);
 5      if q_new = q then
 6          Return Reached;
 7      else
 8          Return Advanced;
 9  Return Trapped;
```

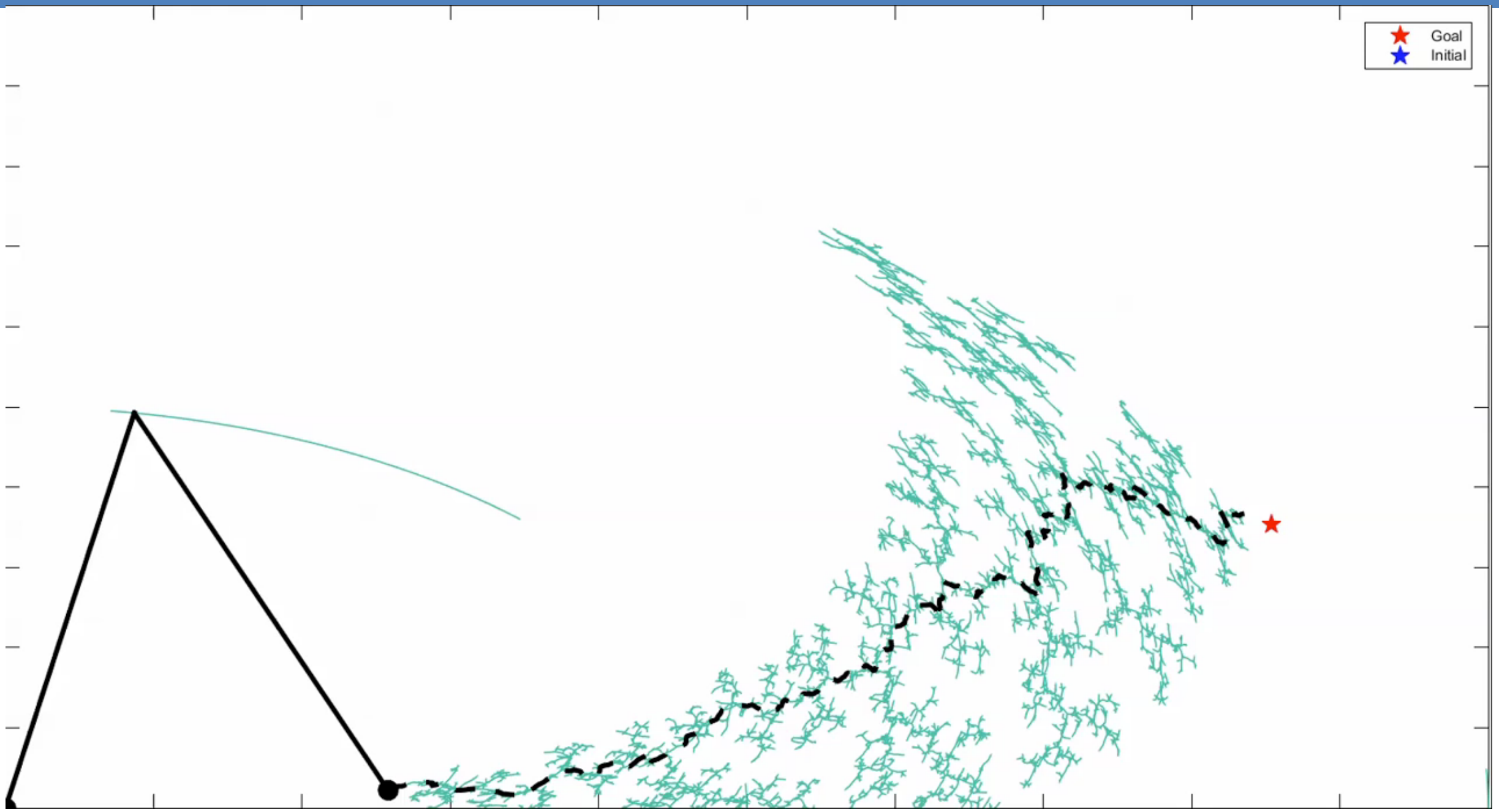


Why are RRT's rapidly exploring?

The probability of a node to be selected for expansion is proportional to the area of its Voronoi region



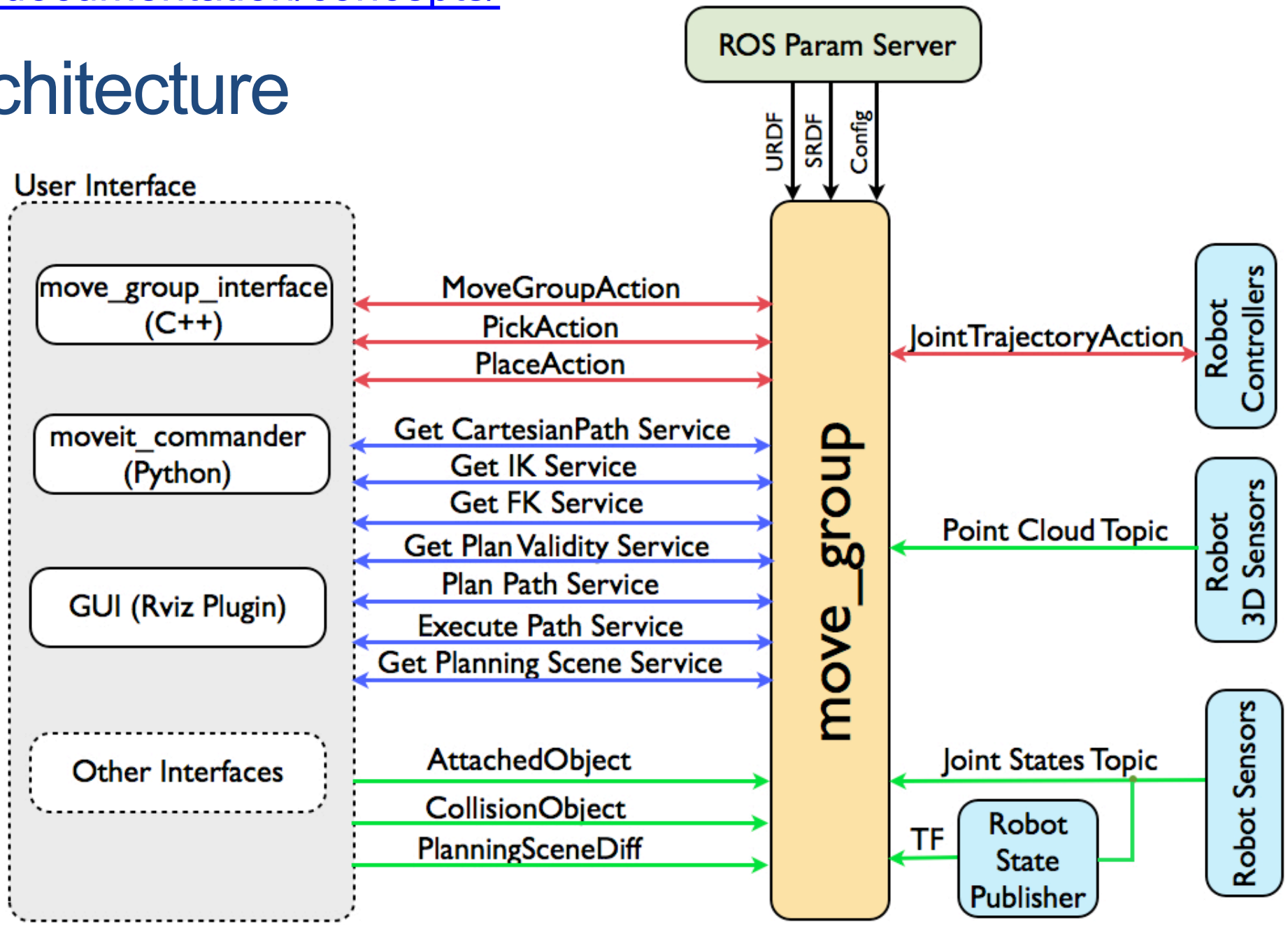



Goal
Initial

MOVEIT & GRASPING

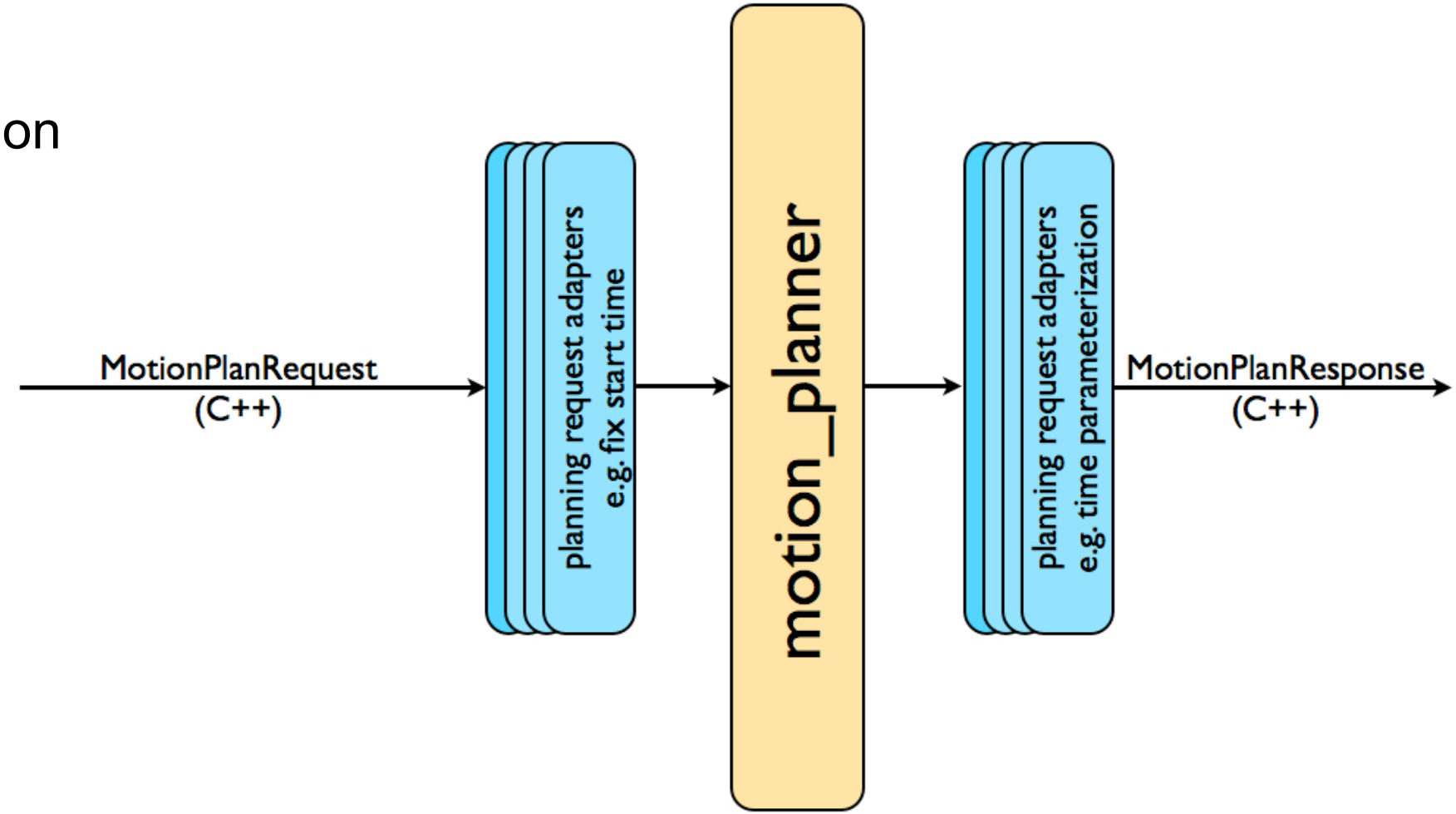
http://moveit.ros.org/documentation/concepts/

System Architecture

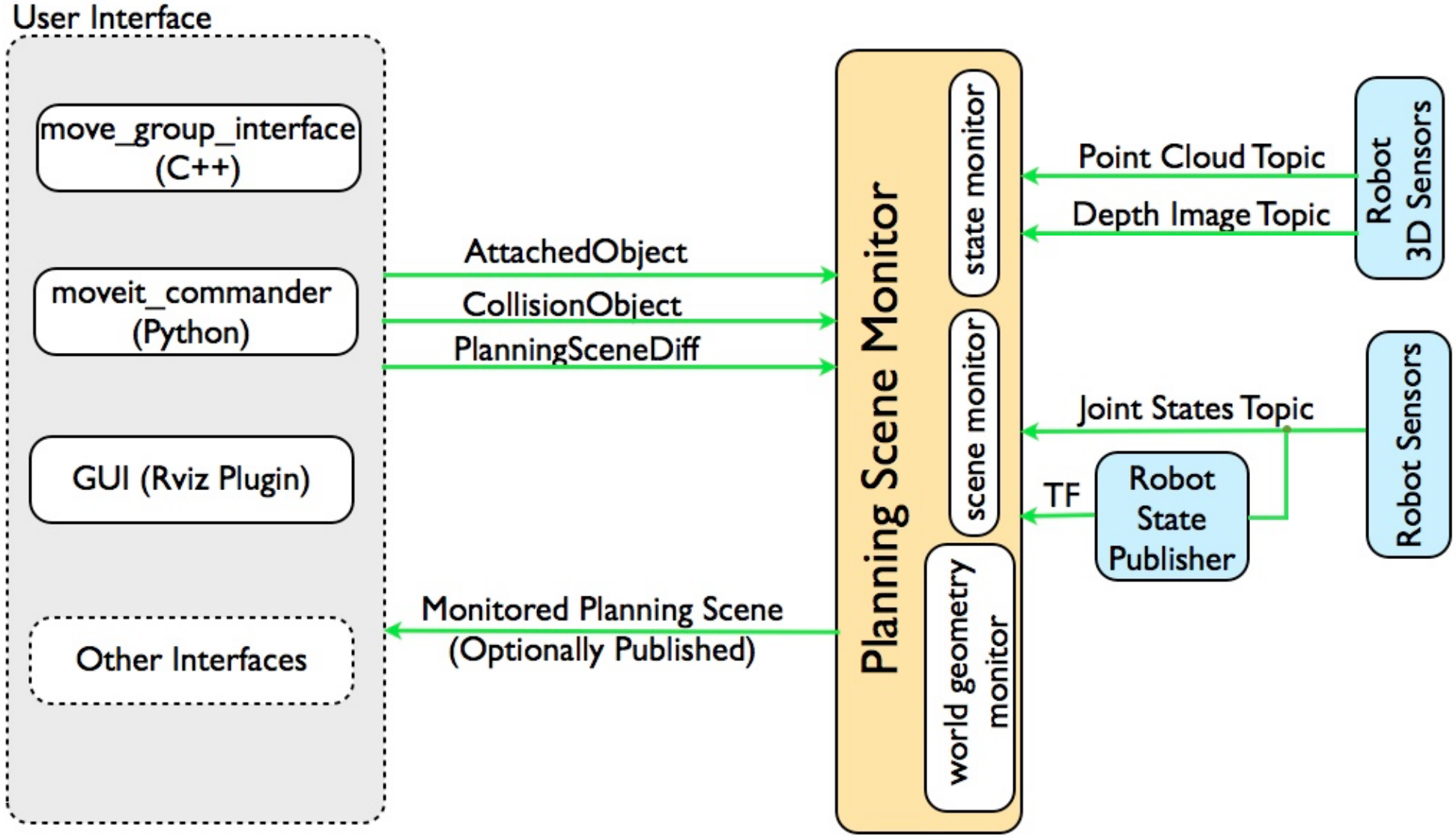


Motion Planning

- Mainly:
- OMPL (Open Motion Planning Library)

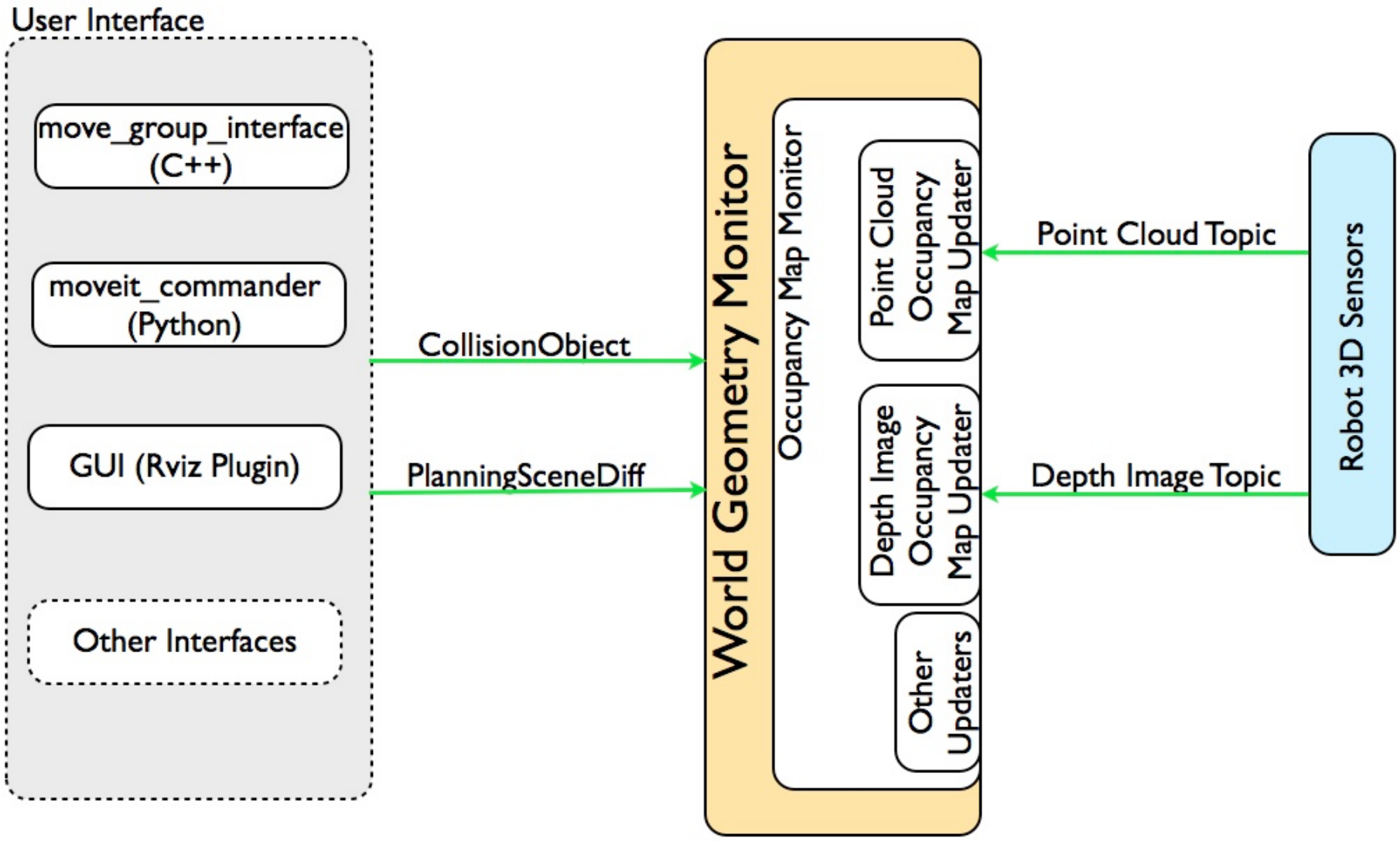


Planning Scene



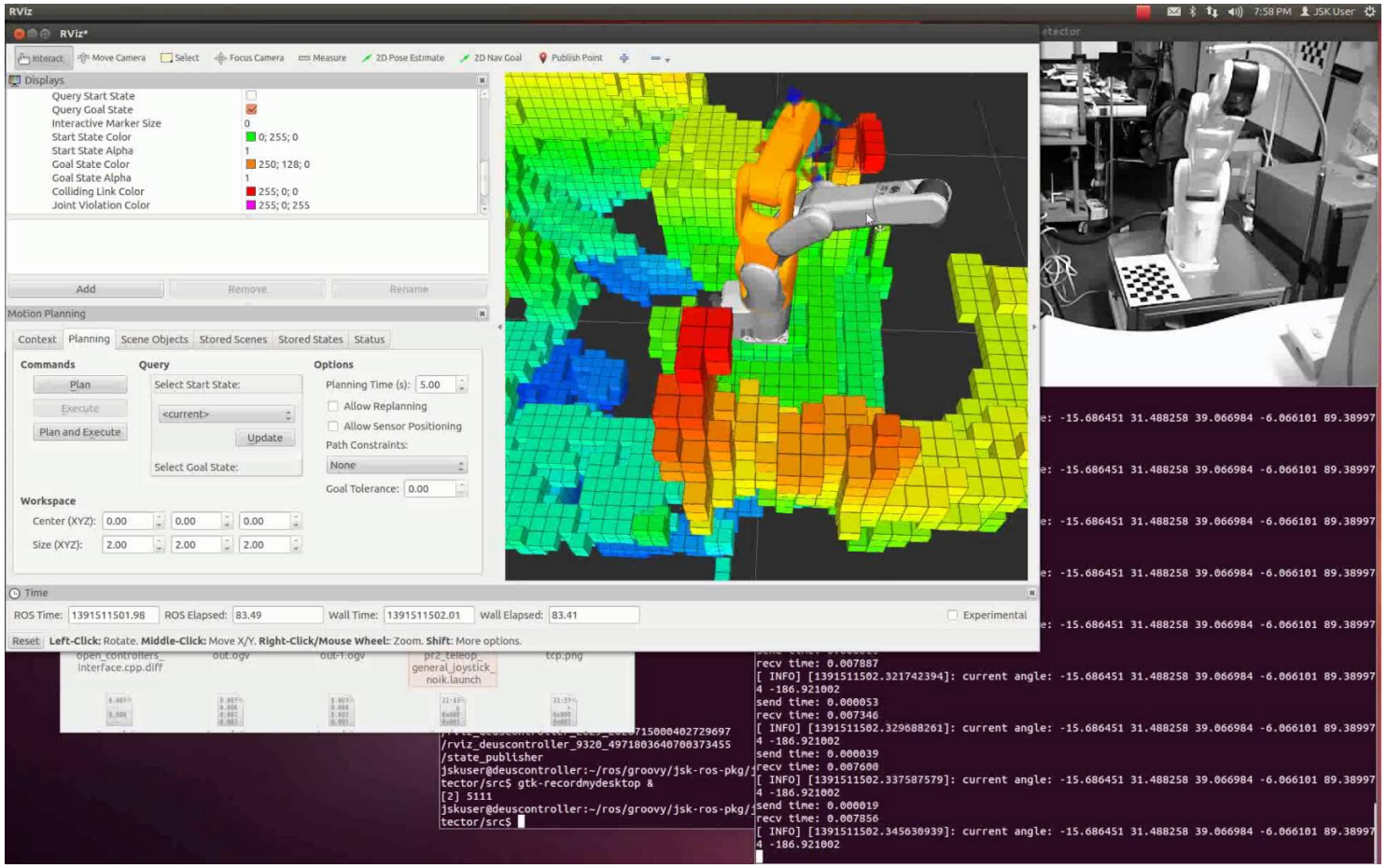
3D Perception

- Octomap



Octomap / Octree

- Depth sensor (usually Kinect)
- http://wiki.ros.org/octomap

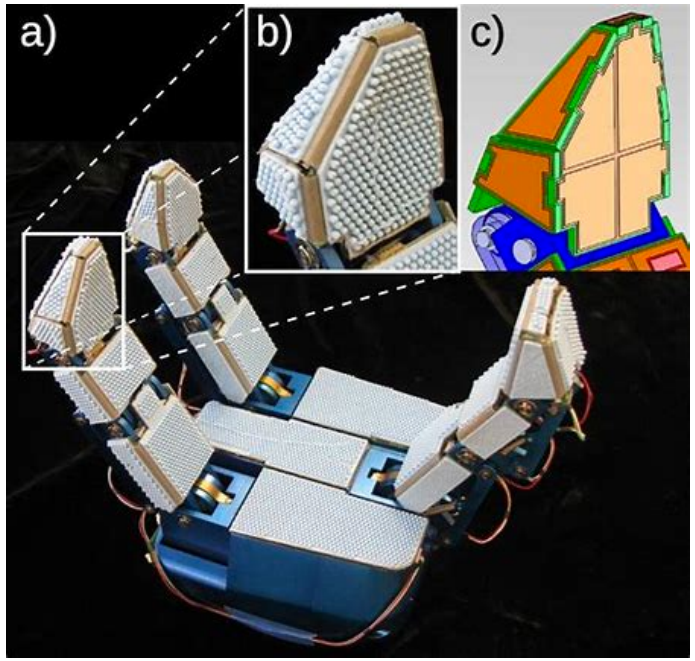


Grasp an Object: Steps

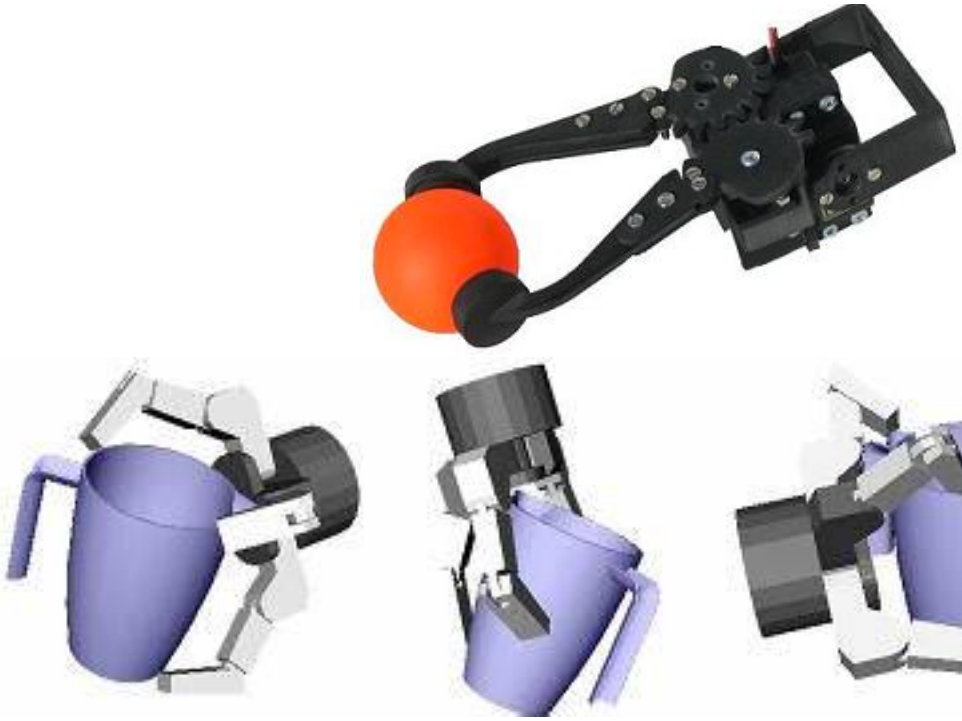
1. Startup robot and sensors
2. Detect object & its pose
3. Select grasping points on the object
4. Scan the scene and environment (for collision checking later)
5. Use IK to check if grasping point can be reached – checks for collisions – may try thousands of possibilities (before concluding that there is always a collision)
6. Use motion planning to plan from current pose to goal pose: Lots of collision checks! Might realize that it is impossible after a long time
7. Execute that trajectory: Check if we reached the intermediate pose (within the time constraint) and command the next
8. Controller: take dynamics into account to move to the next intermediate pose
9. Once goal is reached close fingers.
10. Check if object is in fingers
11. Add the object to the collision description of the robot
12. Plan the path to the goal pose…

Grasping …

- Gripper: Parallel; 3 Finger; Hand; Suction
- Force Sensors
- Tactile Sensors
- Grasp Types
- Grasp Planning



"Biologically inspired tactile classification of object-hand and object-world interactions", by B. Heyneman and M. R. Cutkosky; Stanford University; Robio 2012



Citation for image on page 47: T. Stoyanov *et al*., "No More Heavy Lifting: Robotic Solutions to the Container Unloading Problem," in *IEEE Robotics & Automation Magazine*, vol. 23, no. 4, pp. 94-106, Dec. 2016.

GRASP TYPE

Power

Prismatic

- HW Heavy Wrap
- PW Palmar Wrap
- M&L W Medium and light wrap

C1 Large diameter

F30 Palmar

C3 Medium wrap

C2 Small diameter

F18 Extension Type

C4 Adducted thumb

F22 Parallel extension

C5 Light tool

F31 Ring

Circular

- D Disk
- S Sphere

C10 Disk

C11 Sphere

F26 Sphere 4-fingers

F28 Sphere 3-fingers

Intermediate

- L Lateral
- ST Stick
- W Writing

C16 Pinch

F29 Stick

F20 Writing tripod

F32 Ventral

F25 Lateral tripod

Precision

Prismatic

- 4F 4-fingers
- 3F 3-fingers
- 2F 2-fingers
- 1F 1-finger

C6 Thumb-4 finger

C7 Thumb-3 finger

C8 Thumb-2 finger

F24 Tip pinch

C9 Thumb-1 finger

F33 Inferior pincer

Circular

- D Disk
- S Sphere
- T Tripod

C12 Precision disk

C13 Precision sphere

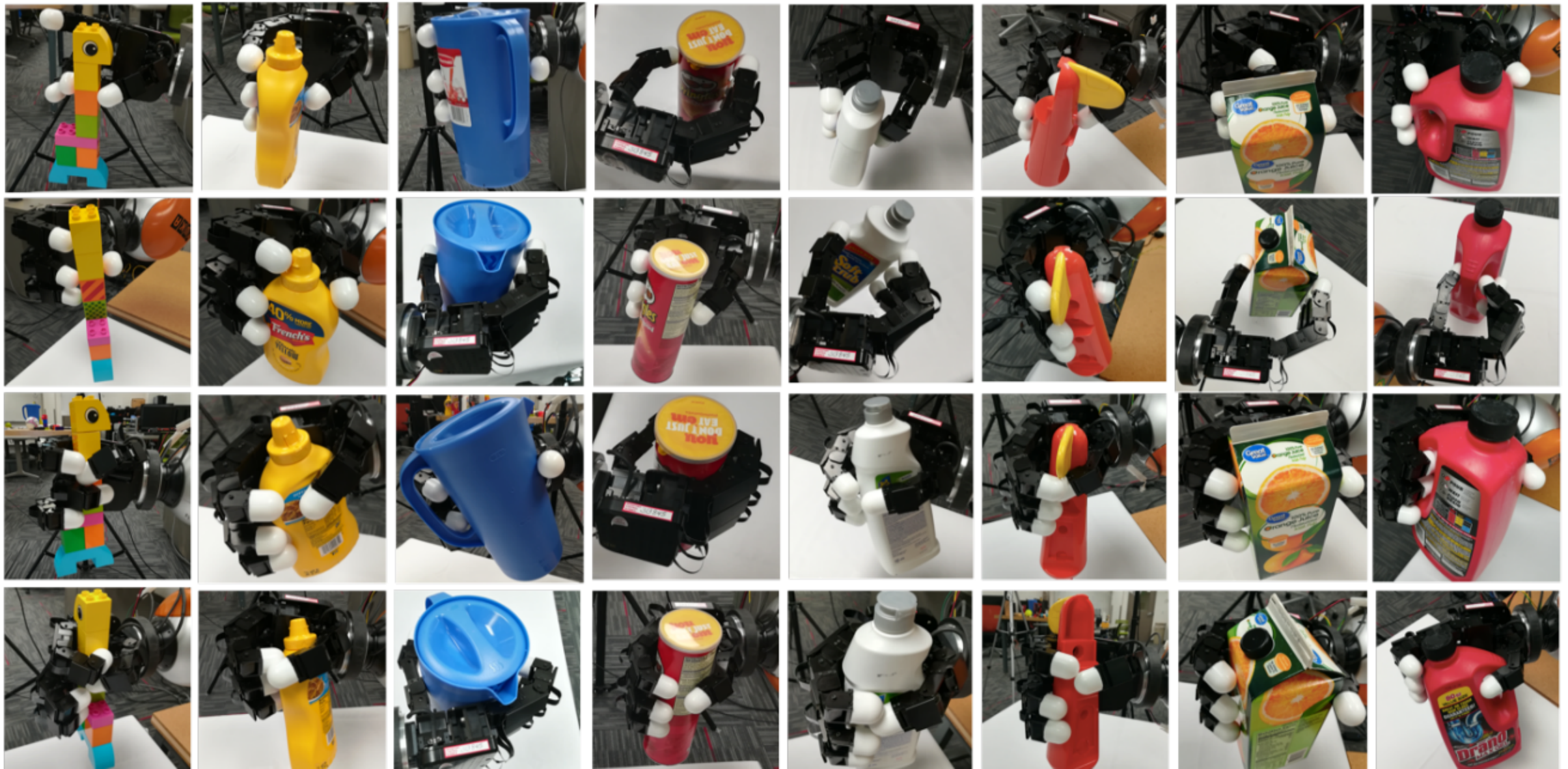
C14 Tripod

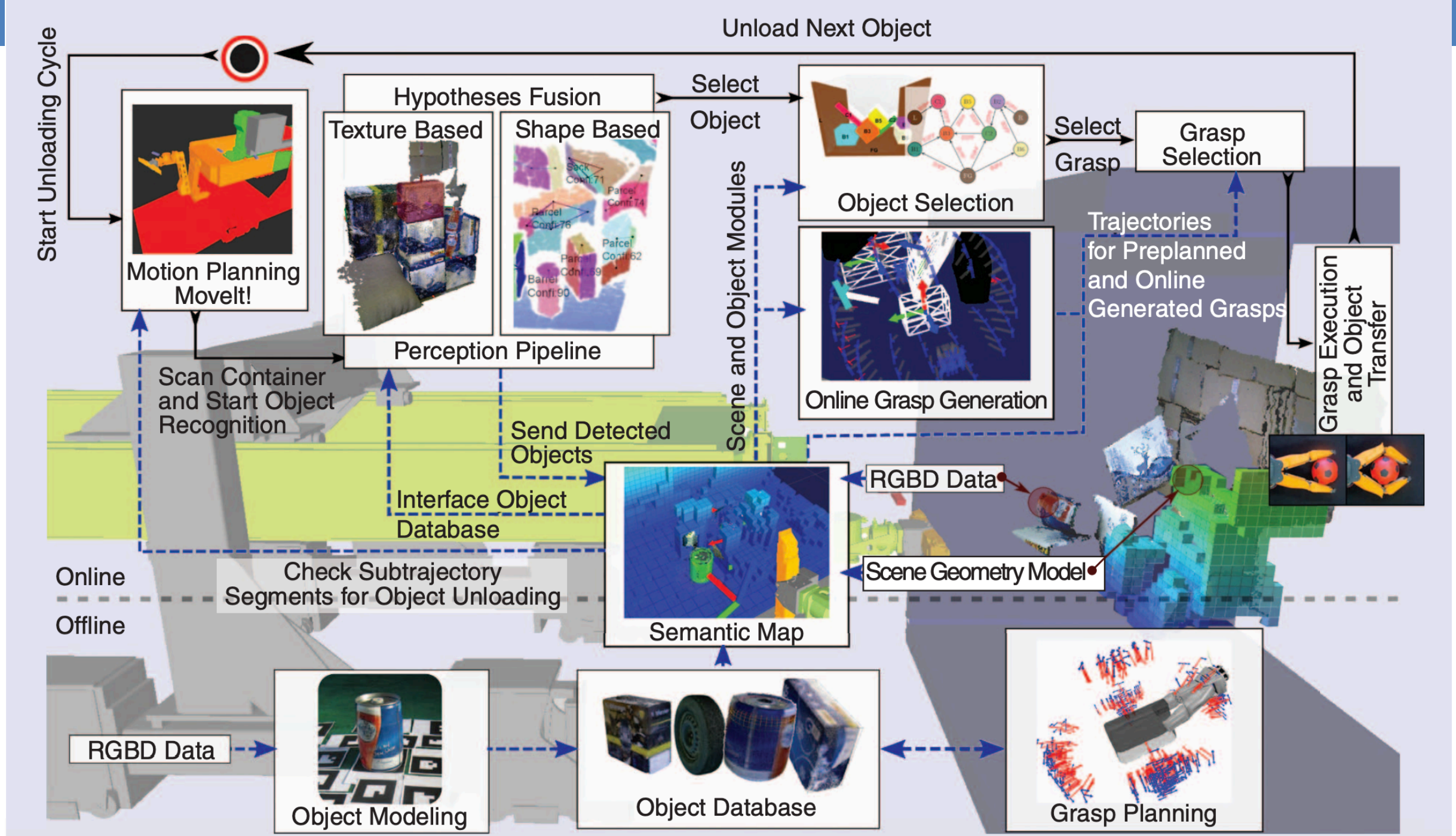
F27 Quadpod

Lu, Qingkai & Hermans, Tucker. (2019). Modeling Grasp Type Improves Learning-Based Grasp Planning.

Precision

Power




Unload Next Object
Start Unloading Cycle
Motion Planning
MoveIt!
Hypotheses Fusion
Texture Based
Shape Based
Perception Pipeline
Select
Object
Object Selection
Select
Grasp
Grasp
Selection
Trajectories
for Preplanned
and Online
Generated Grasps
Online Grasp Generation
Grasp Execution
and Object
Transfer
Scene and Object Modules
Scan Container
and Start Object
Recognition
Send Detected
Objects
Interface Object
Database
RGBD Data
Scene Geometry Model
Semantic Map
Online
Offline
Check Subtrajectory
Segments for Object Unloading
RGBD Data
Object Modeling
Object Database
Grasp Planning

RViz

Robotics

RViz*

Interact | Move Camera | Select | Focus Camera | Measure | 2D Pose Estimate | 2D Nav Goal | Publish Point

Displays

- Global Options
  - Fixed Frame: /BASE
  - Background Color: 48; 48; 48
- Global Status: Ok
  - Fixed Frame: OK
- Grid
- MotionPlanning
  - Status: Ok
  - Robot Description: robot_description

Add | Remove | Rename

Motion Planning

Context | Planning | Scene Objects | Stored Scenes | Stored States | Status

Planning Library

OMPL <unspecified> Publish Current Scene

Warehouse

Host: 127.0.0.1 Port: 33829 Connect

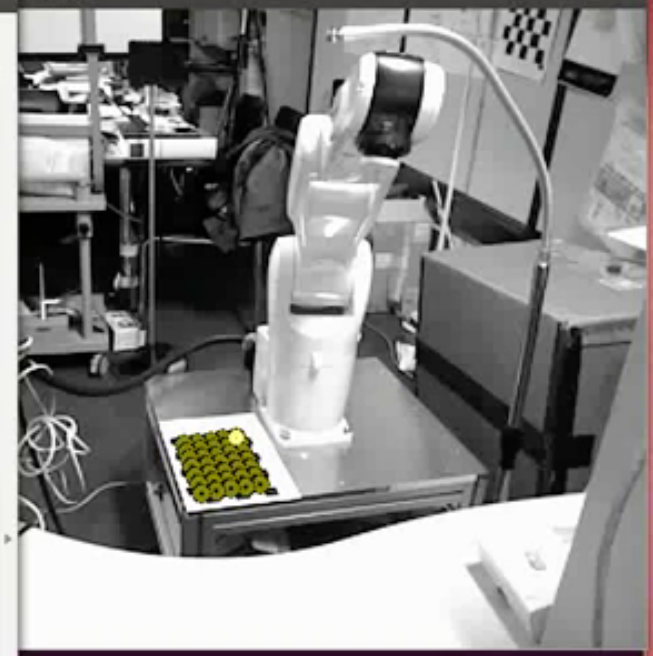
Kinematics

- [x] Use Collision-Aware IK
- [ ] Allow Approximate IK Solutions

Time

ROS Time: 1391511451.87 ROS Elapsed: 33.38 Wall Time: 1391511452.01 Wall Elapsed: 33.38 Experimental

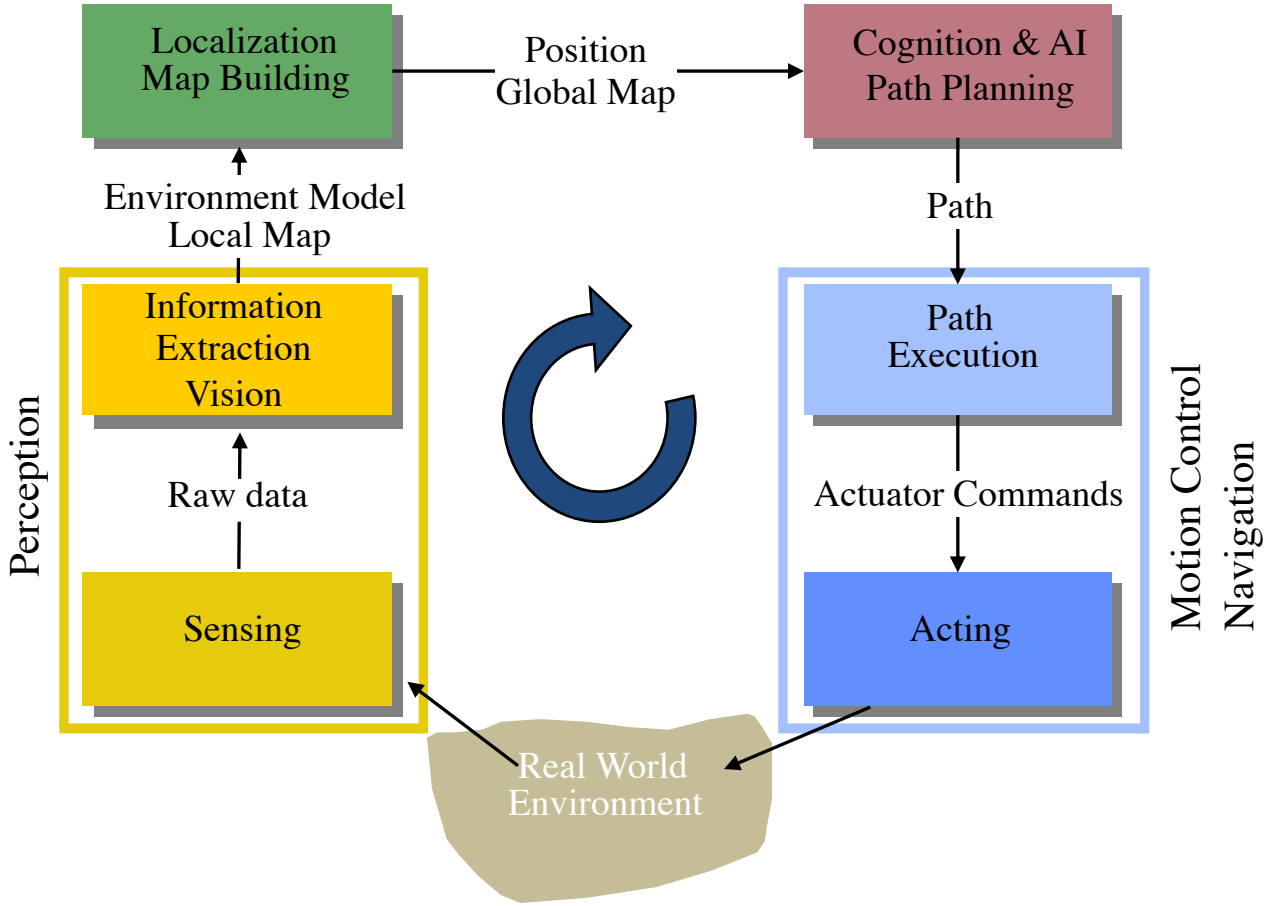
Reset



```
e: -15.686451 31.488258 39.066984 -6.066101 89.38997
e: -15.686451 31.488258 39.066984 -6.066101 89.38997
e: -15.686451 31.488258 39.066984 -6.066101 89.38997
e: -15.686451 31.488258 39.066984 -6.066101 89.38997
e: -15.686451 31.488258 39.066984 -6.066101 89.38997
recv time: 0.007818
[ INFO] [1391511452.321107105]: current angle: -15.686451 31.488258 39.066984 -6.066101 89.38997
4 -186.921002
send time: 0.000017
recv time: 0.007829
[ INFO] [1391511452.329157163]: current angle: -15.686451 31.488258 39.066984 -6.066101 89.38997
4 -186.921002
send time: 0.000023
recv time: 0.007888
/rviz_deuscontroller_9320_4971803640700373455
/state_publisher
jskuser@deuscontroller:~/ros/groovy/jsk-ros-pkg/
```

MAP REPRESENTATION

General Control Scheme for Mobile Robot Systems

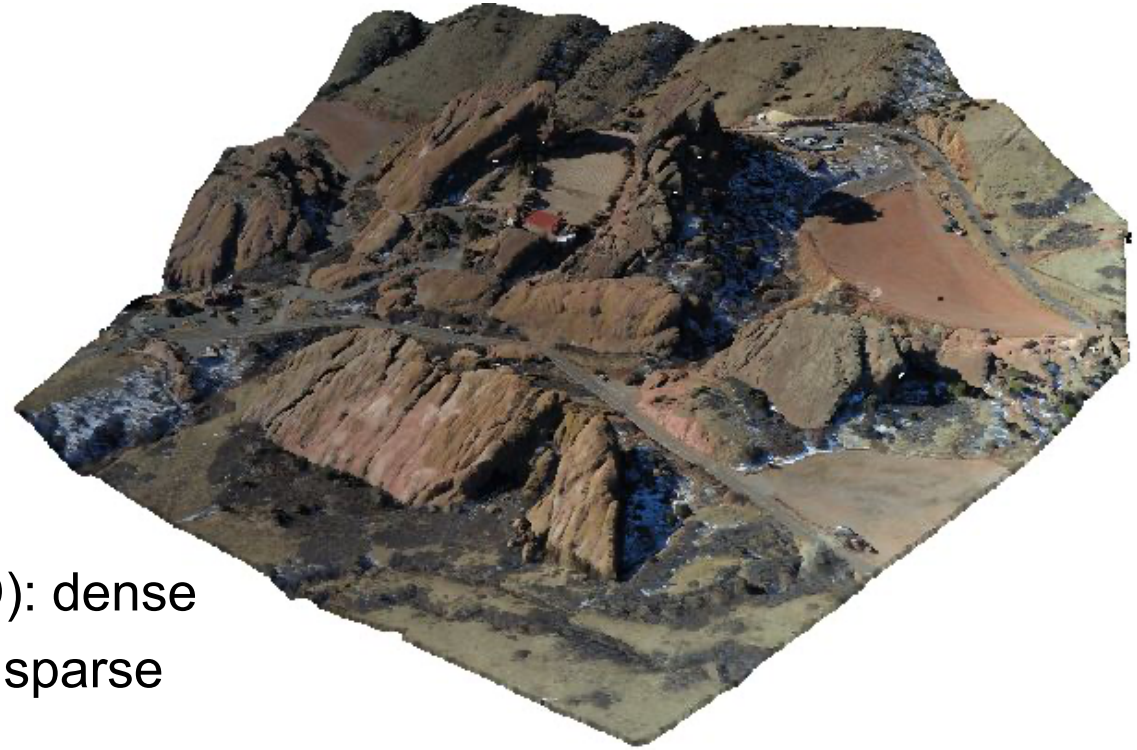


With material from Roland Siegwart and Davide Scaramuzza, ETH Zurich

Map Representation: what is "saved" in the map

- Points (surface of objects, buildings): 2D or 3D
  - What: x,y or x,y,z coordinates;
    Optional: intensity; maybe RGB; maybe descriptor; temperature; …
  - From range sensors (laser, ultrasound, stereo, RGB-D): dense
  - From cameras (structure from motion; feature points): sparse
  - Variant: kd-tree
- Grid-map: 2D or 3D
  - Option: probabilistic grid map
  - Option: elevation map
  - Option: cost map
  - Option: Truncated Signed Distance Field
  - Option: Normal Distributions Transform (NDT)
  - Variant: Quad-tree; Oct-tree
- Higher-level Abstractions
  - Lines; Planes; Mesh
  - Curved: splines; Superquadrics
- Semantic Map
  - Assign semantic meaning to entities of a map representation from above
  - E.g. wall, ceiling, door, furniture, car, human, tree, …
- Topologic Map
  - High-level abstraction: places and connections between them
- Hierarchical Map
  - Combine Maps of different scales. E.g.:
  - Camus, building, floor
- Pose-Graph Based Map
  - Save (raw) sensor data in graph, annotated with the poses; generate maps on the fly
- Dynamic Map
  - Capture changing environment
- Hybrid Map
  - Combination of the above

Point based map



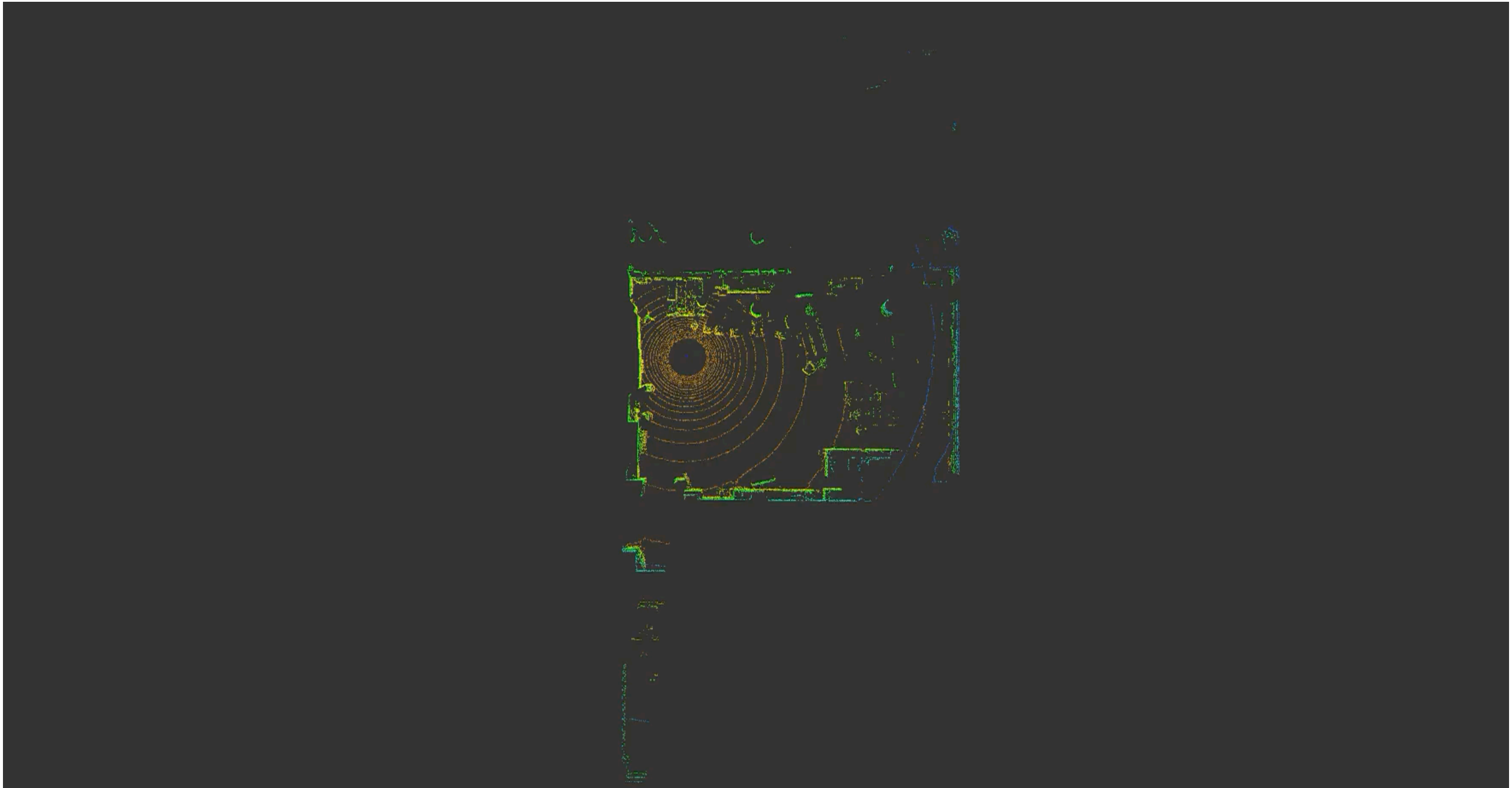
- Point Cloud
  - What: x,y or x,y,z coordinates;
    Optional: intensity; maybe RGB; maybe descriptor; temperature; …
  - From range sensors (laser, ultrasound, stereo, RGB-D): dense
  - From cameras (structure from motion; feature points): sparse
  - Variant: kd-tree
  - Structured point cloud: points are ordered in a 2D grid -> could calculate depth image from it
  - PCL: point cloud library: Used in ROS; https://pointclouds.org/
  - sensor_msgs/PointCloud sensors_msgs/PointCloud2
  - Excellent viewer: CloudCompare https://www.danielgm.net/cc/
  - File formats: PLY (bin & ASCII); XZY (ASCII); PCD (from pcl); LAS (terrestrial scanning); …

RGBD-Inertial Trajectory Estimation and Mapping for Ground Robots

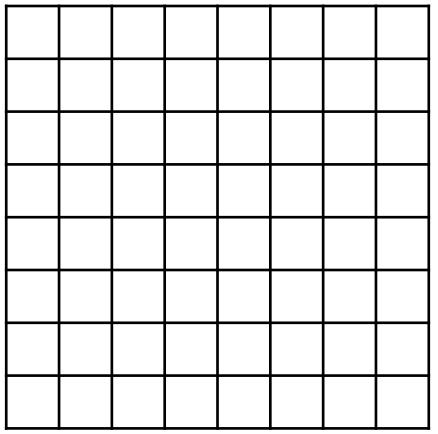
Zeyong Shan, Ruijian Li and Sören Schwertfeger

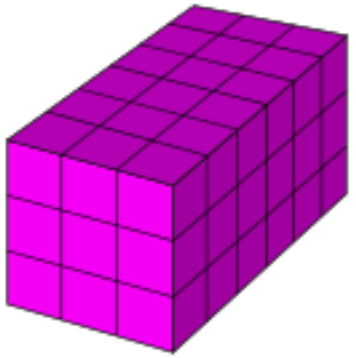
Source code: https://github.com/STAR-Center/VINS-RGBD

Z
Y

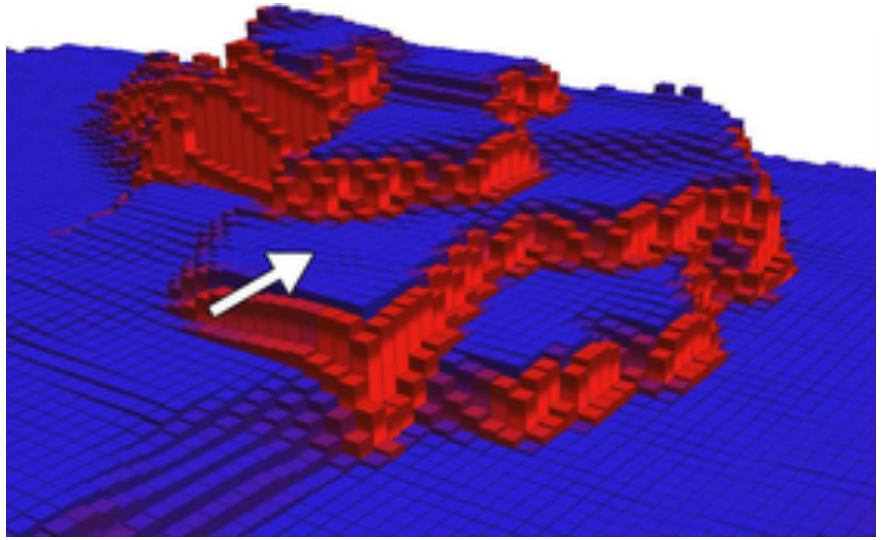


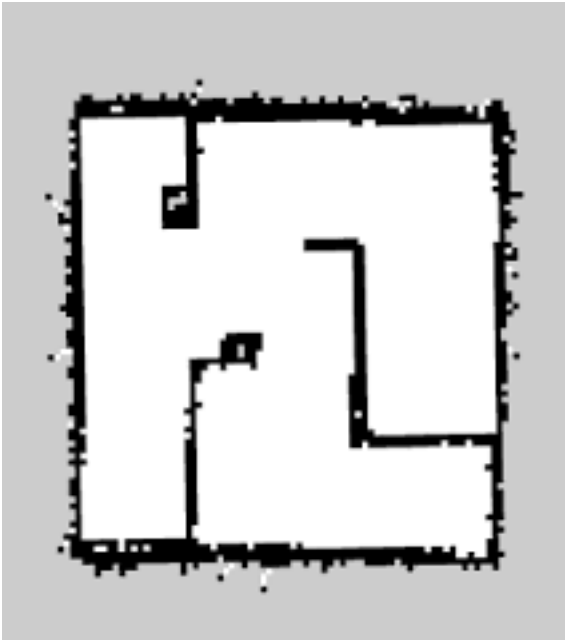
Grid Maps





- Grid-map: 2D or 3D cartesian grid
- What to save in the cell:
  - Binary: Free; Occupied;
  - Colored: +Unknown; +Searched; +Path; …
  - Probability of being occupied 0…1.0
  - Height above ground: Elevation Map
  - Cost map: used for planning (covered later)





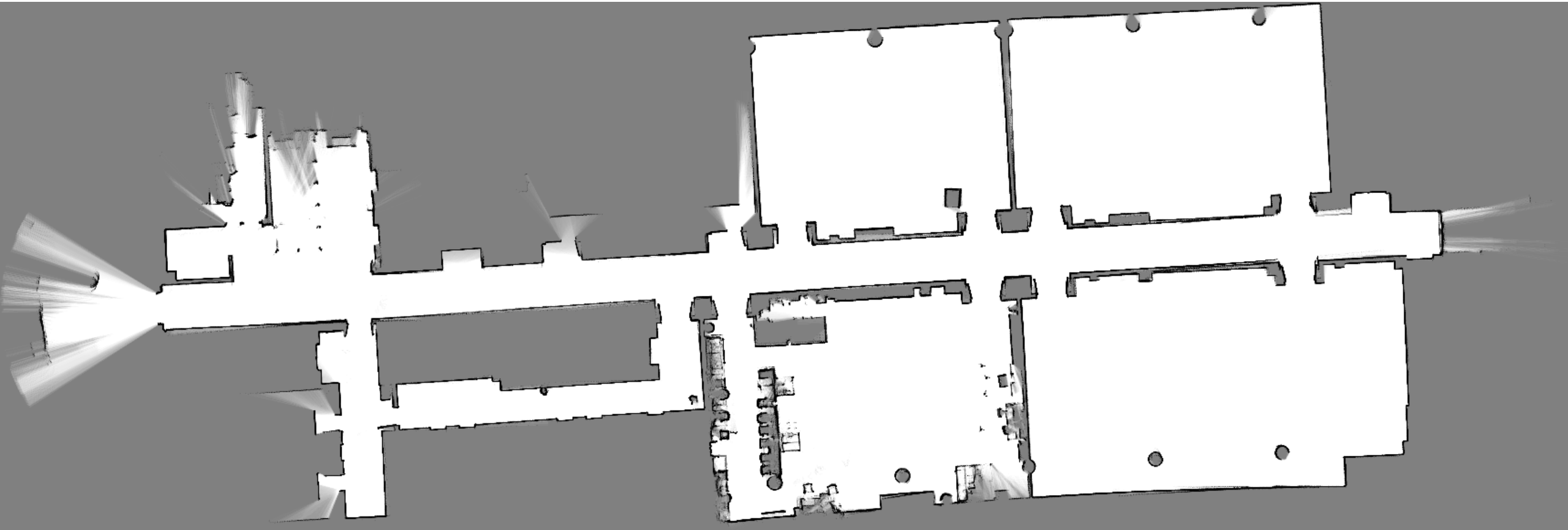
https://emanual.robotis.com/docs/en/platform/turtlebot3/slam/

Grid Maps

- Resolution: e.g. 1 pixel == 5cm
- Size: e.g. 2000 pixel x 2000 pixel
- Scale: e.g. 1:100.000 (2DoF of 3 parameters resolution, size, scale)
- Frame
  - A map has a frame. Where? In the center of the image? Top left corner?
- Time stamp
- Formats:
  - Image: png, pgm (grey scale), tiff, jpeg (lossy!)
  - GeoTIFF: georeferenced TIFF (inlined tfw World File): map projection, coordinate systems, ellipsoids, datums (see GPS slide)
  - 3D: bt (octomap)
- QGIS: open source Geographic Information System for raster (image) and vector data http://qgis.org/en/site

Probabilistic grid map

- 1: occupied; 0: free; 0.5: unknown
- Need error model of sensor (and of localization) to properly update cells with a scan
- Can remove dynamic (moving) objects (by observing the free space multiple times)



Normal Distributions Transform (NDT)

- Sparse Gaussian mixture model
- Each cell has NDT Computed from covariance matrix of points inside the cell
- Useful for scan matching/ registration

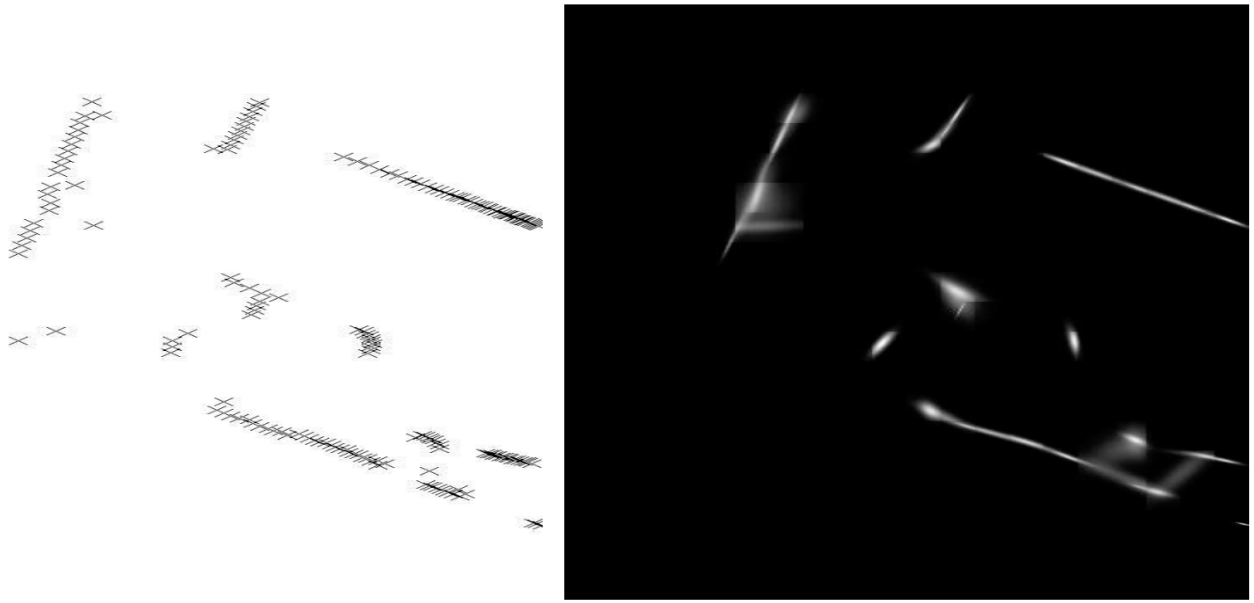
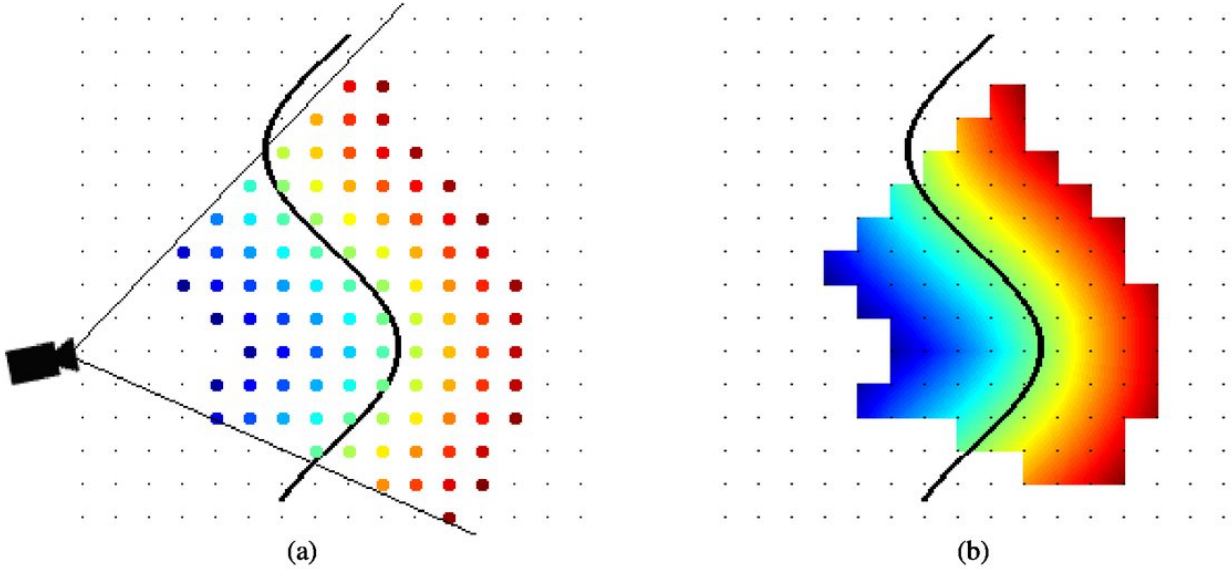


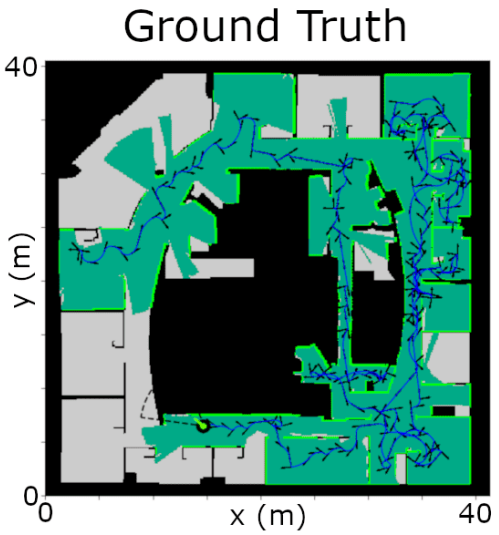
Fig. 1. An example of the NDT: The original laser scan and the resulting probability density.

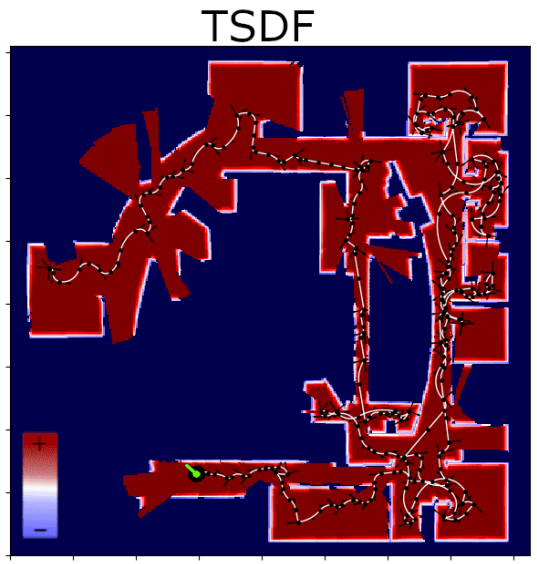
Truncated Signed Distance Field

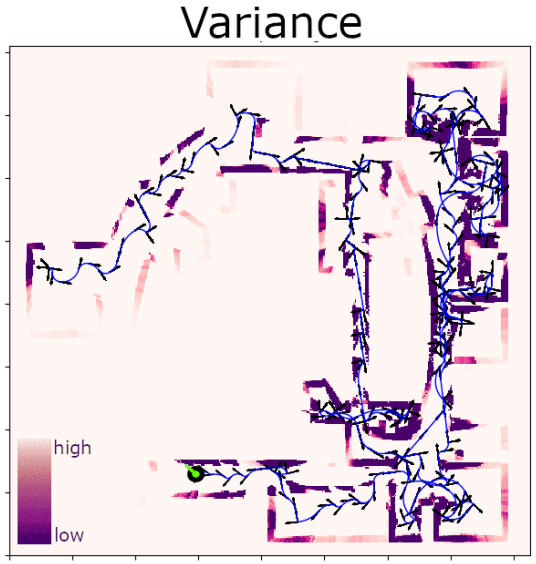
https://www.dcist.org/2020/03/20/active-exploration-in-signed-distance-fields/
https://www.spiedigitallibrary.org/conference-proceedings-of-spie/9091/909117/Real-time-reconstruction-of-depth-sequences-using-signed-distance-functions/10.1117/12.2054158.short?SSO=1&tab=ArticleLinkFigureTable

- Distance to surface:
- positive in free space; negative behind
- Up to a certain distance (truncated)
- Useful for collision checking; planning; meshing
- Can be modeled using Gaussian random variable in each cell

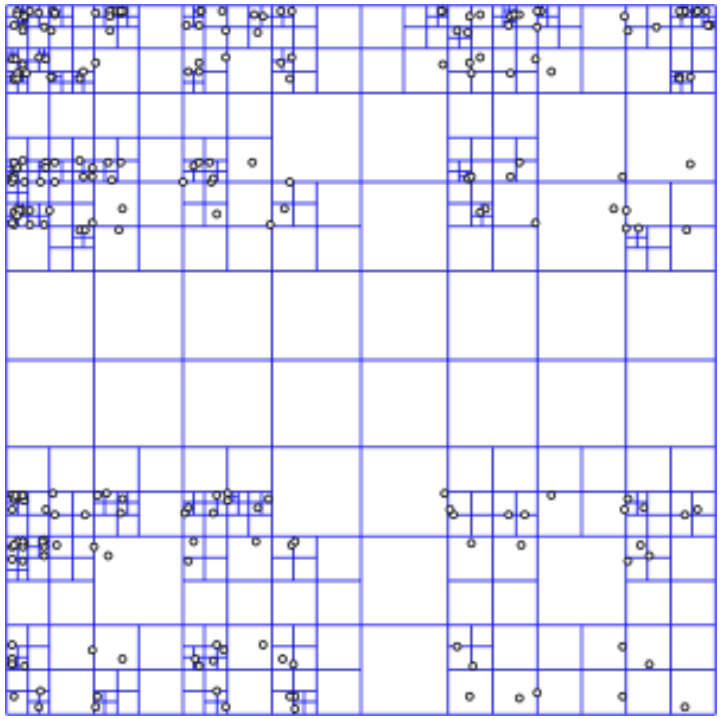








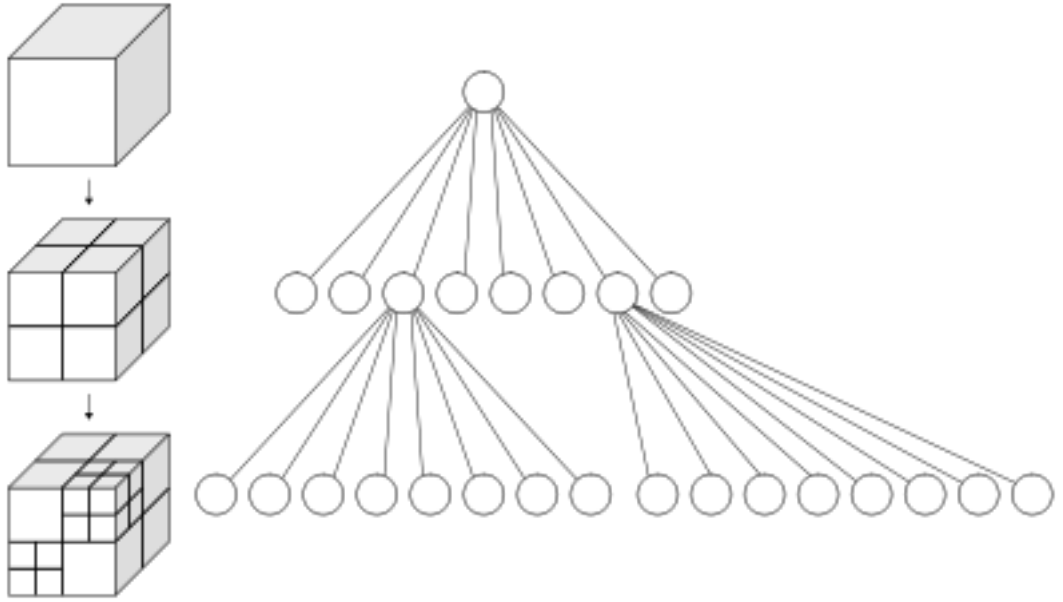
Adaptive Cell Decomposition

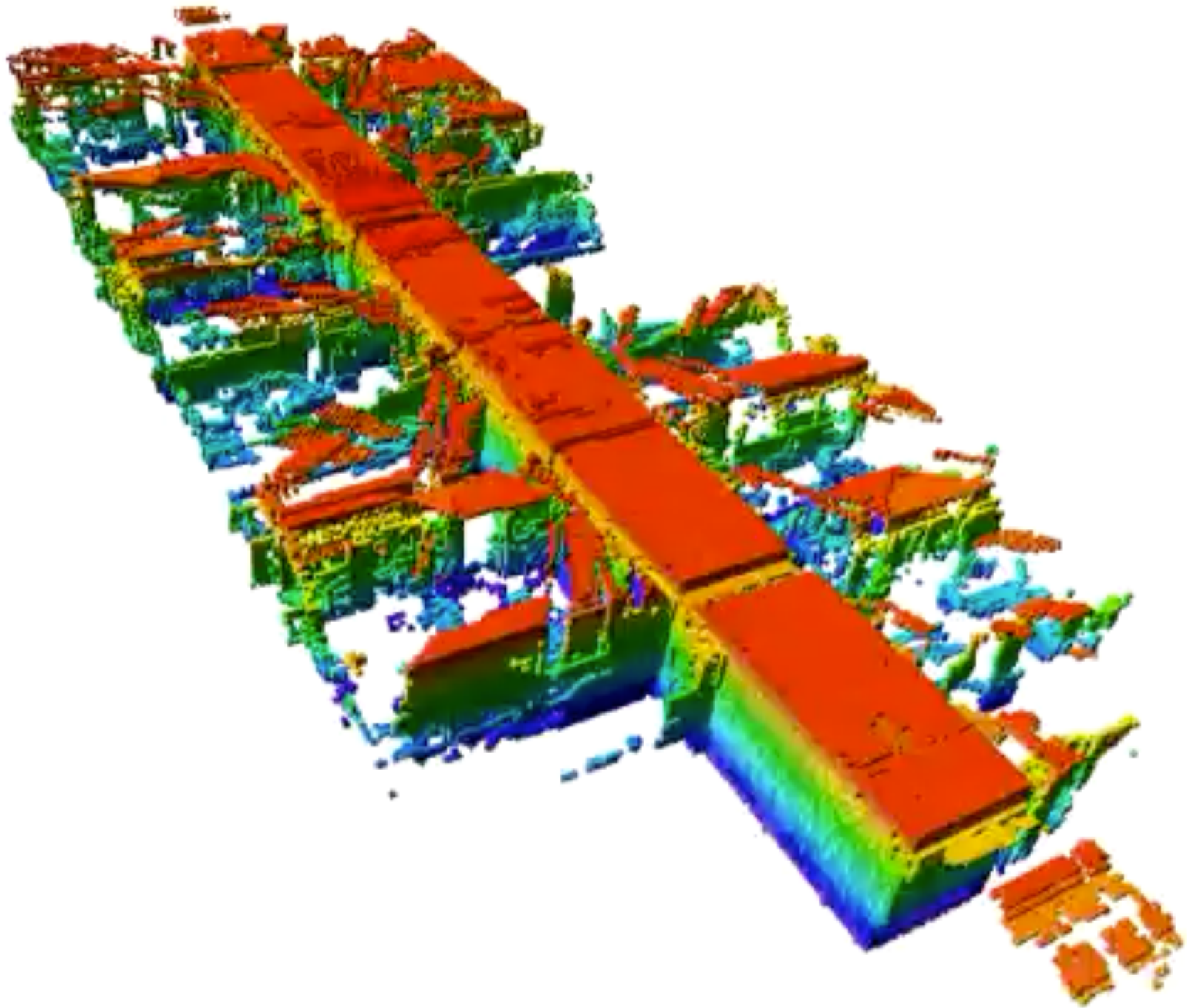


- Quad-tree
  - 2D map/ grid is recursively divided into 4 smaller cells
  - Only cells with different values/ points get divided further =>
  - Compact representation of big space (if many cells stay merged)

- Oct-tree
  - 3D grid divided into 8 smaller cells
  - Very compact! (There is lots of free space!)

- OctoMap: probabilistic oct-tree!
  - http://octomap.github.io
  - Good support in ROS (e.g. MoveIt!)





Multi-level surface maps

- 2D grid map
- Each cell can store multiple levels (saves mean and variance of height plus depth for each level)
- Useful for terrain classification and planning

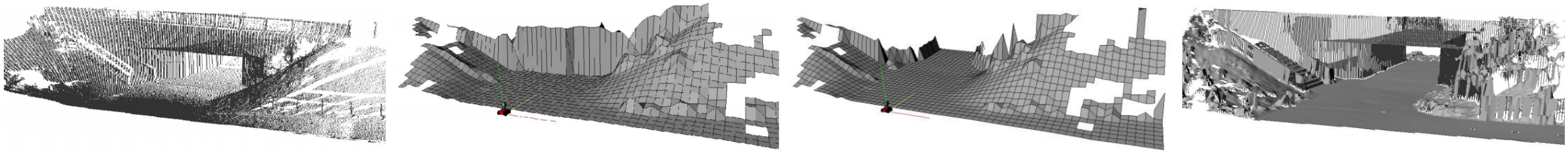


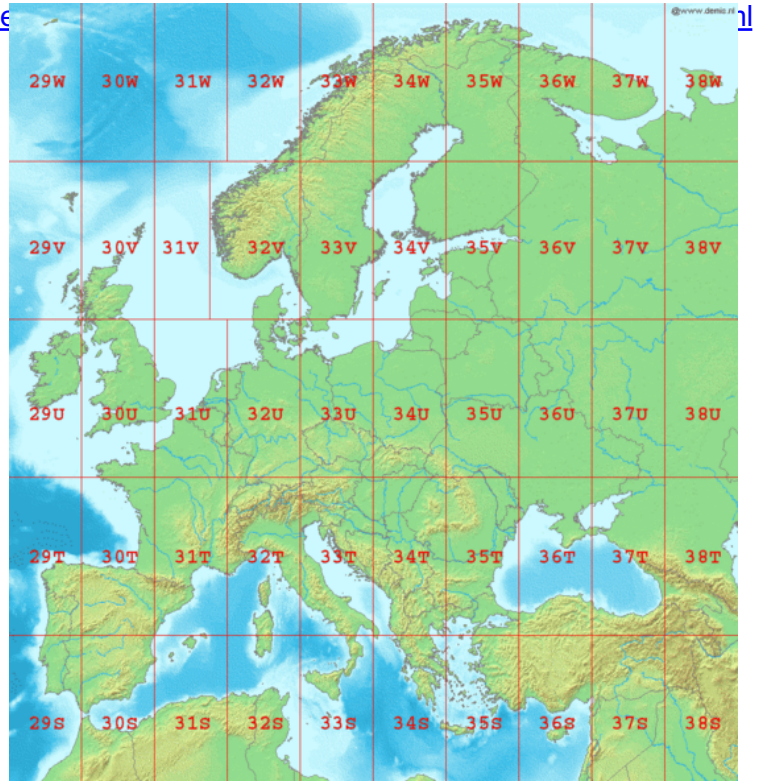
Fig. 1. Scan (point set) of a bridge (a), standard elevation map computed from this data set (b), extended elevation map which correctly represents the underpass under the bridge (c), and multi level surface map that correctly represents the height of the vertical objects (d)

Big Maps/ GPS

- World is NOT flat! =>
- Have to project 2D cartesian map onto a sphere!
- Different Projections, e.g. Mercator (preserves local directions and shapes, but not sizes)
- GPS polar coordinates: longitude & latitude of earth
- Universal Transverse Mercator (UTM): specify 60 planes on the surface of earth; specify location as Cartesian x,y,z coordinates on those planes
- World Geodetic System WGS 84 datum: used by GPS: model lang and lat to ellipsoid (Earth is not a perfect sphere!) from center of gravity …
- China: GCJ-02: WGS 84 plus random offsets (about 300-500m) (for national safety) – makes robotics difficult :/

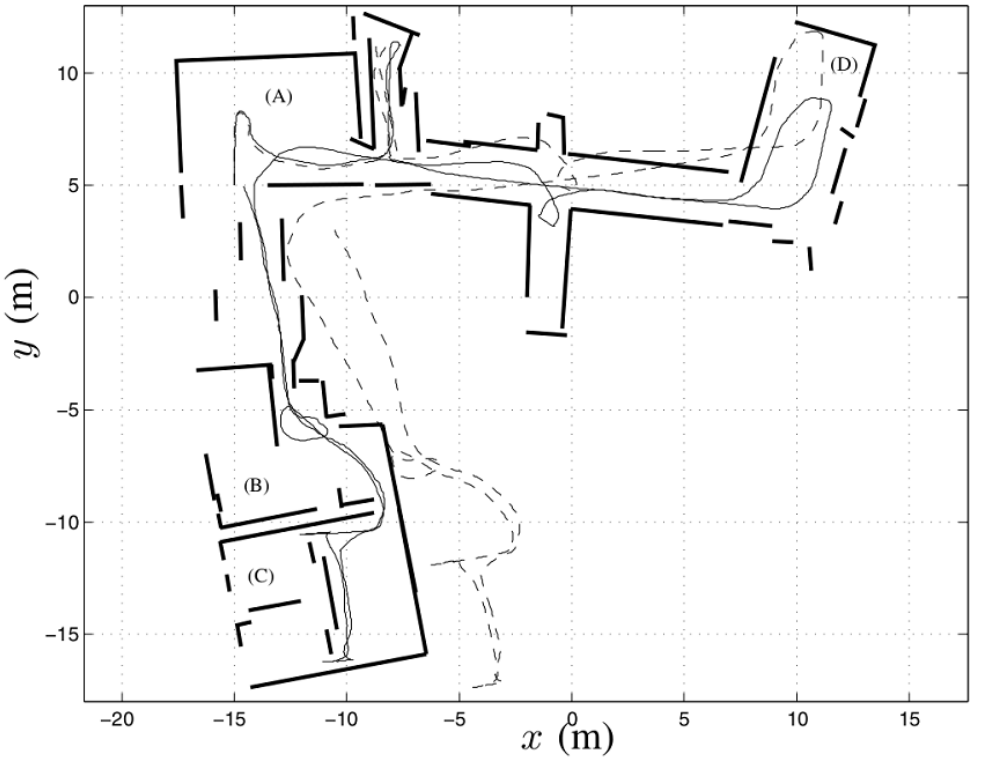
  地形图非线性保密处理算法
- Baidu: BD-09 further offsets (so competitors don't copy)

https://www.livescie

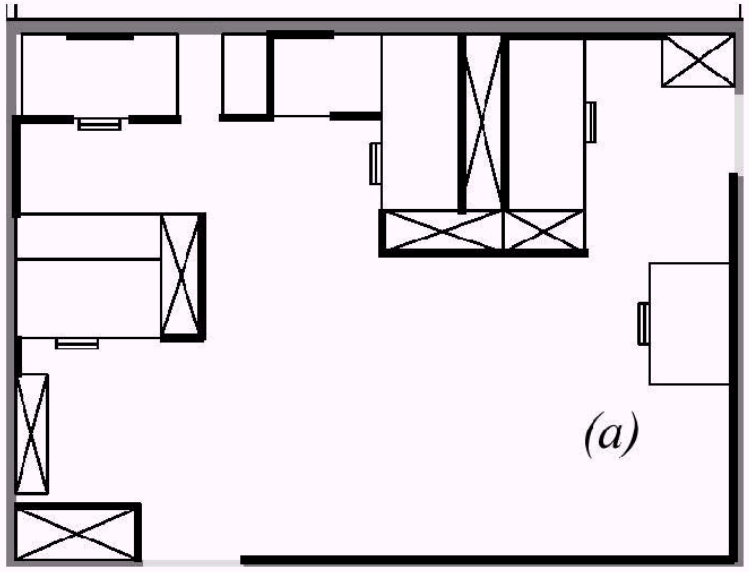


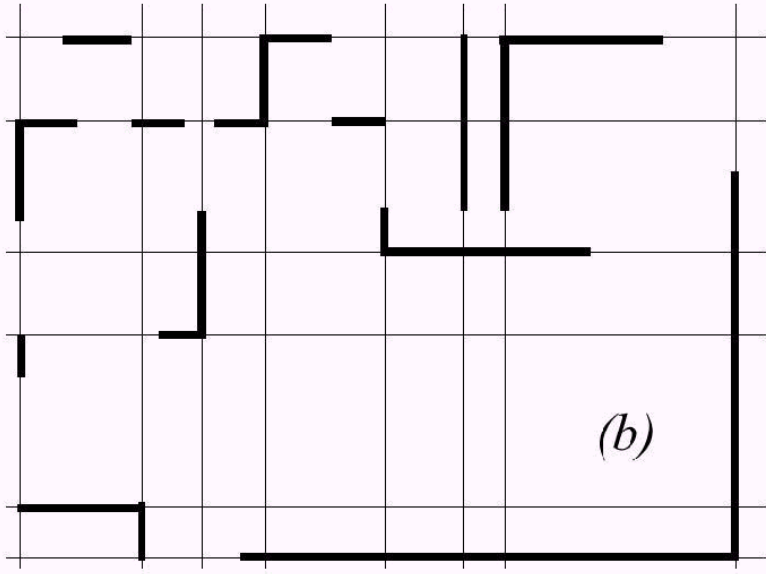
Line Map

- Abstract from points =>
- Extract features (e.g. lines, planes)
- E.g. using RANSAC, Hough Transform
- E.g. region growing, e.g. via normals



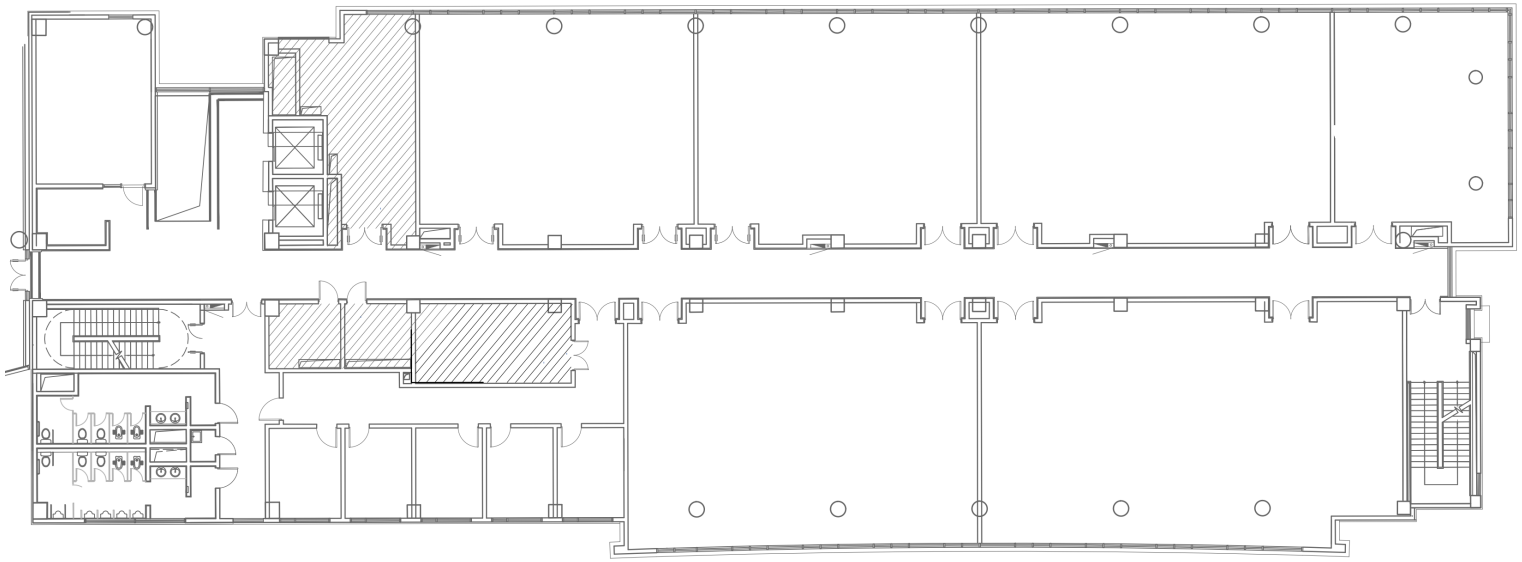
- Finite lines (a)
- Infinite lines (b)



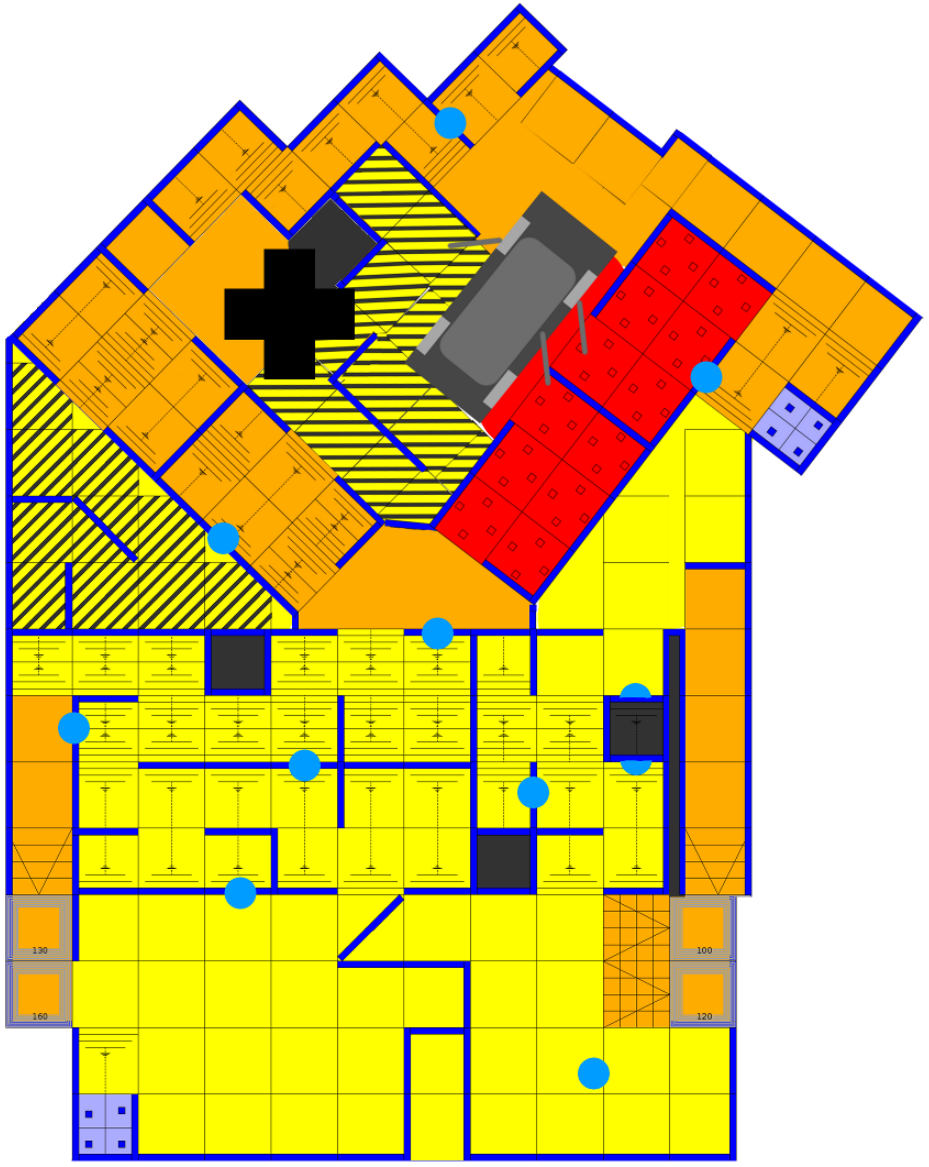


- Very compact
- Can do scan-matching (e.g. against laser scan)

Ground Truth Maps

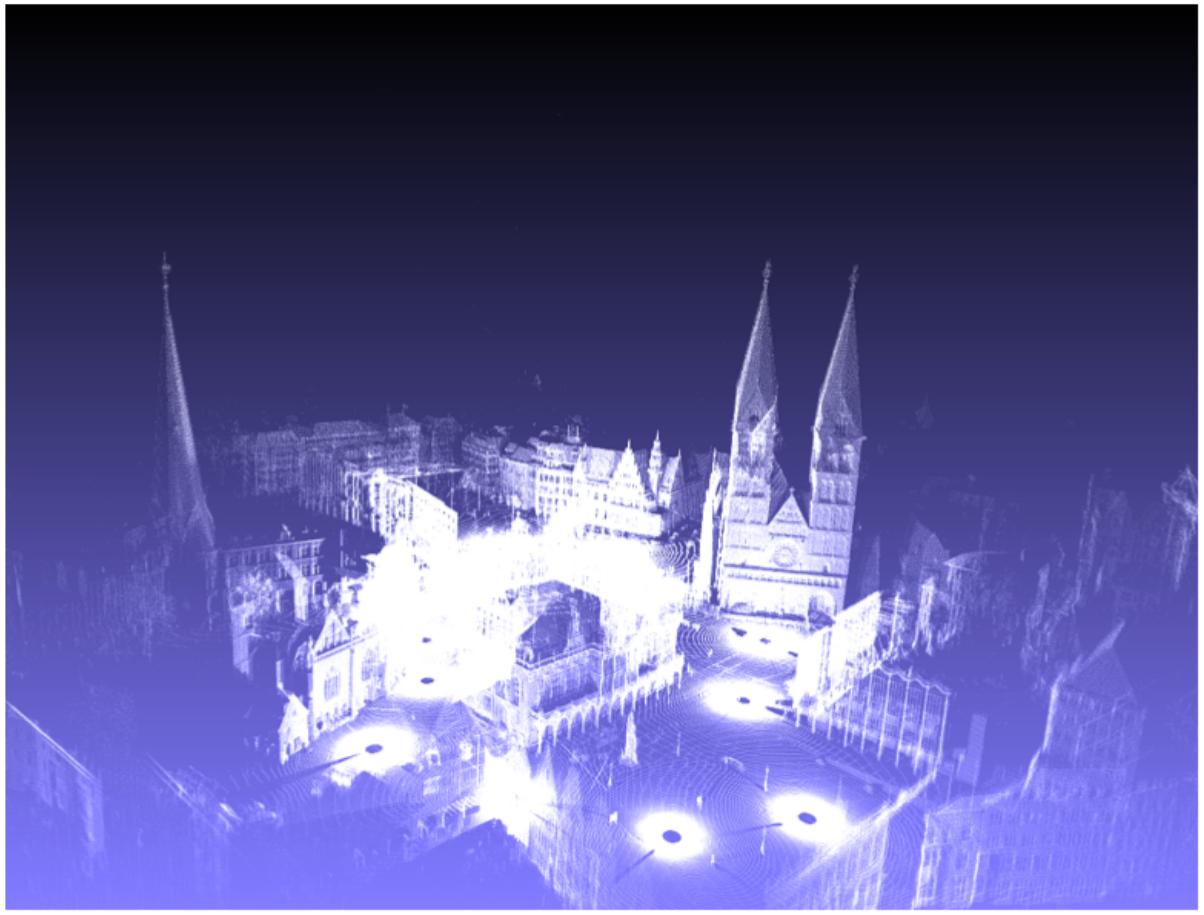


CAD drawing (STAR Center)
Vector format (lines, circles, …)

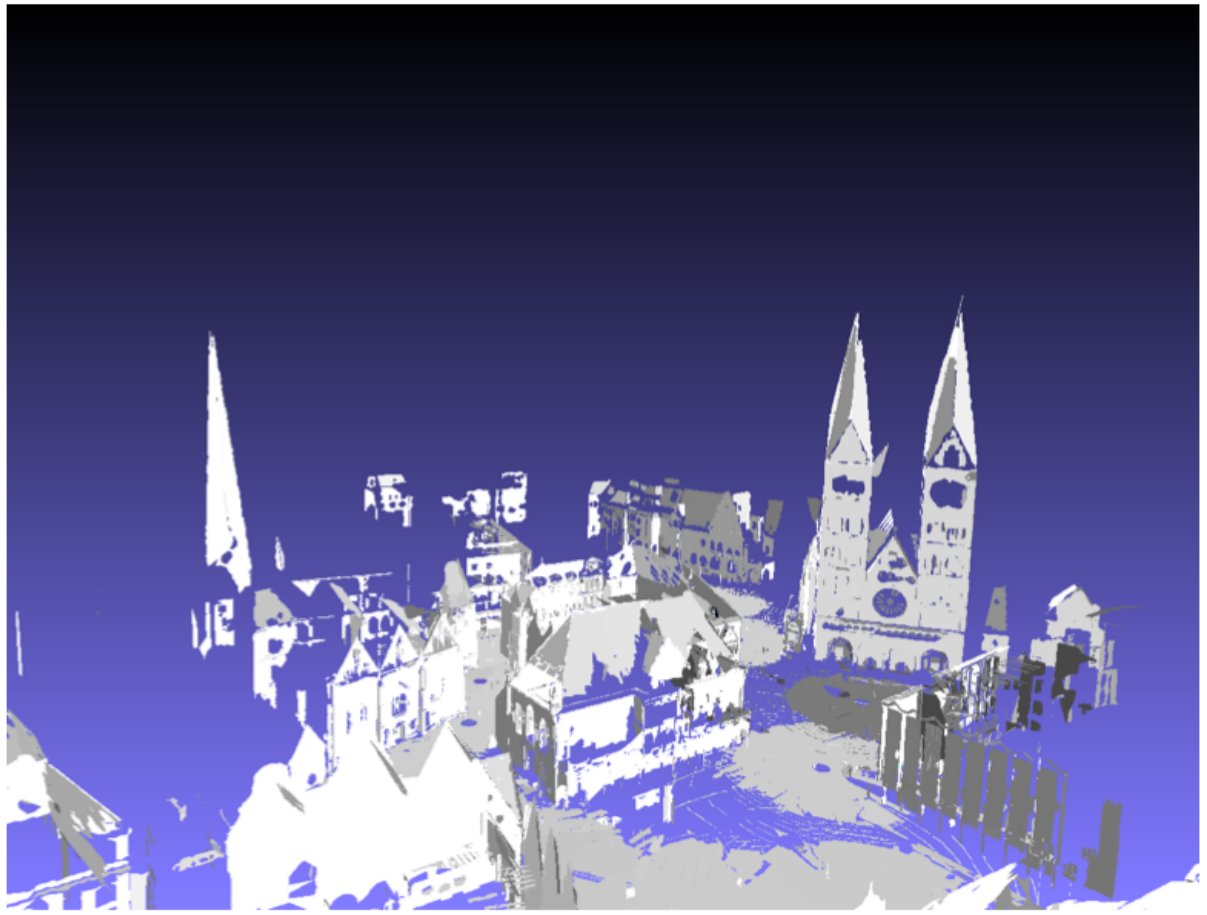


Grid Map (from vector map)

Bremen: 3D Point Cloud & 3D Plane Map

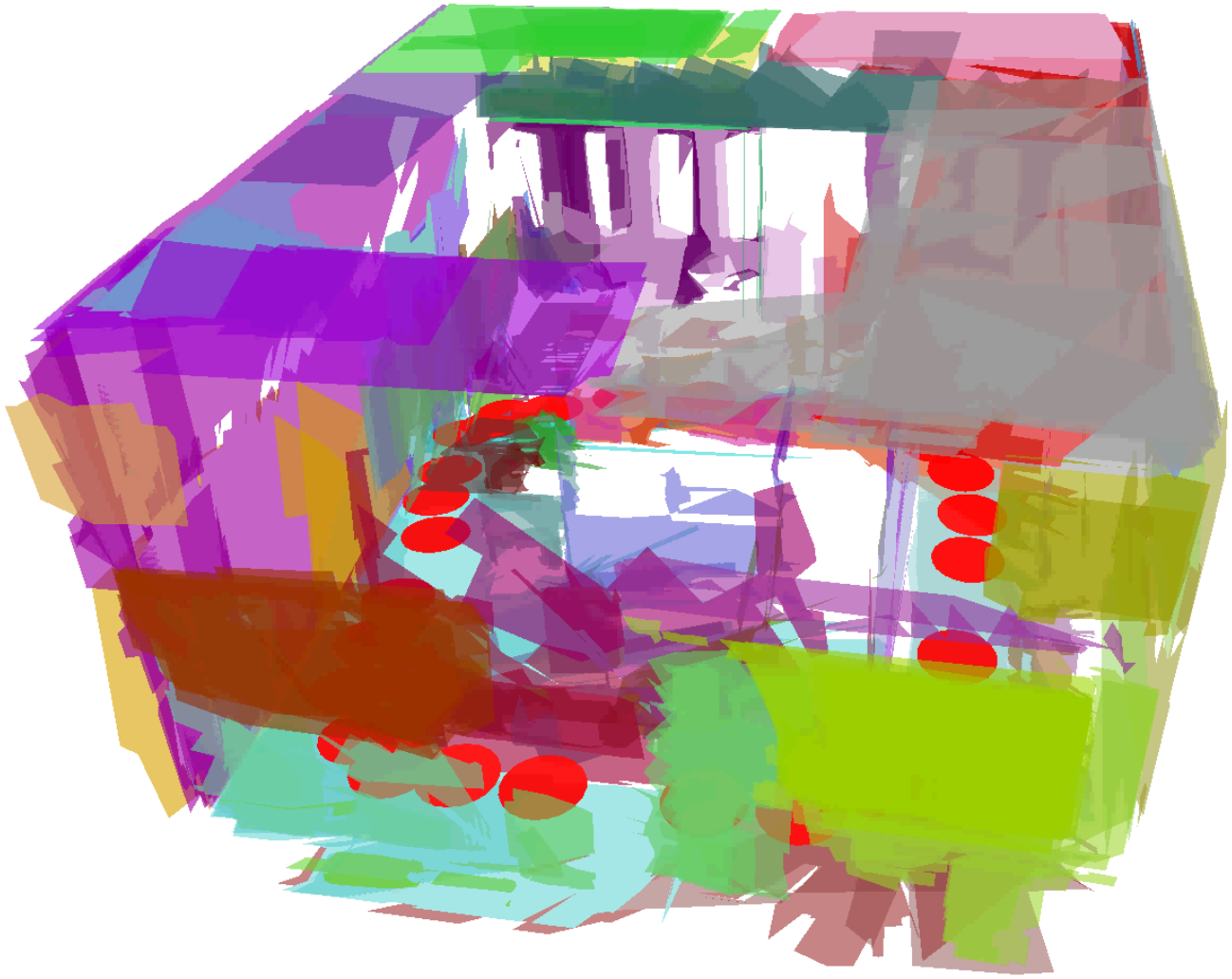


(a) 3D Point Cloud



(b) 3D Plane Map

Plane map: 29 poses; each with several planes

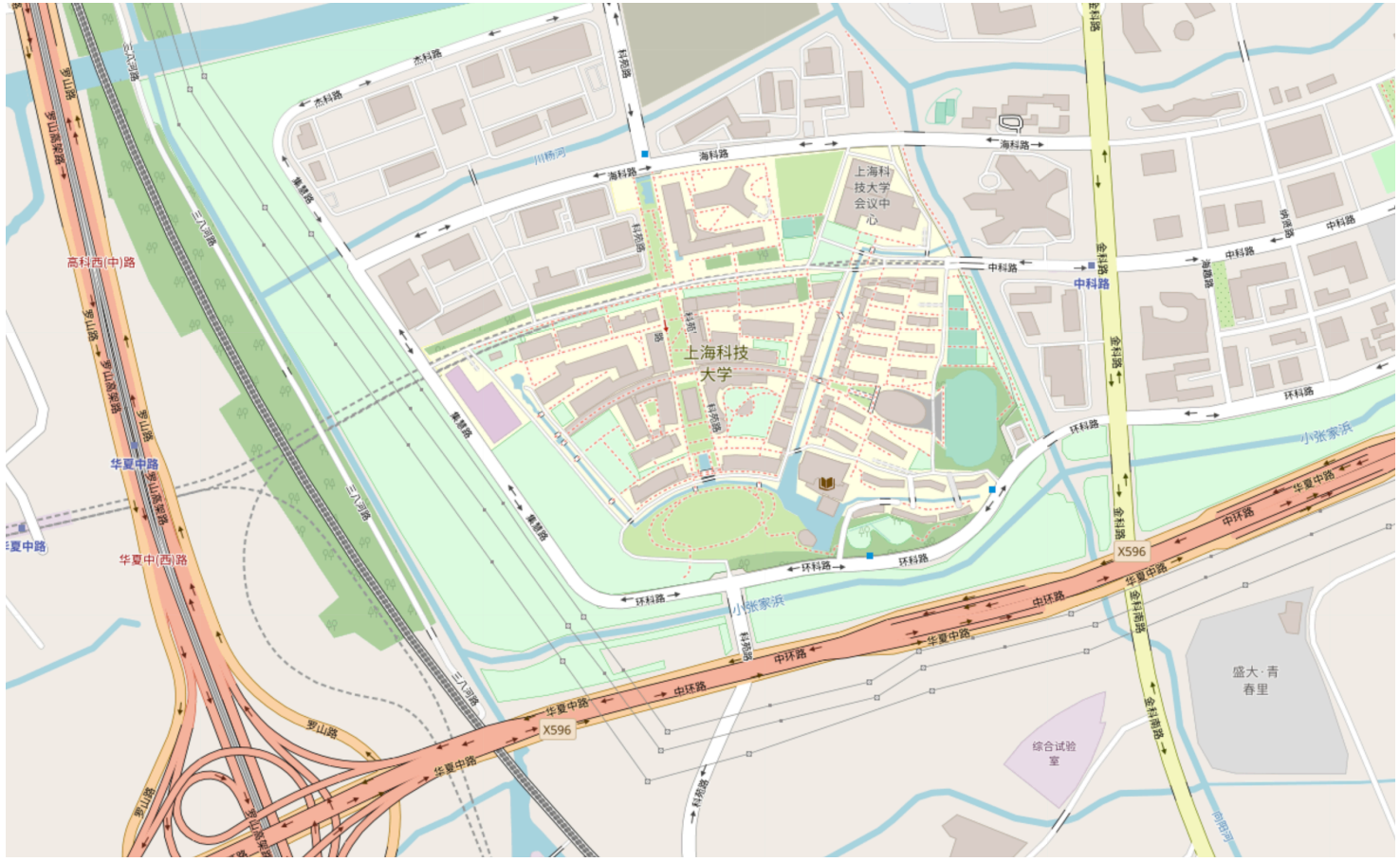


Vector Maps

- E.g. Open Street Maps
- Represented as OSM files (xml) or PBF (binary)

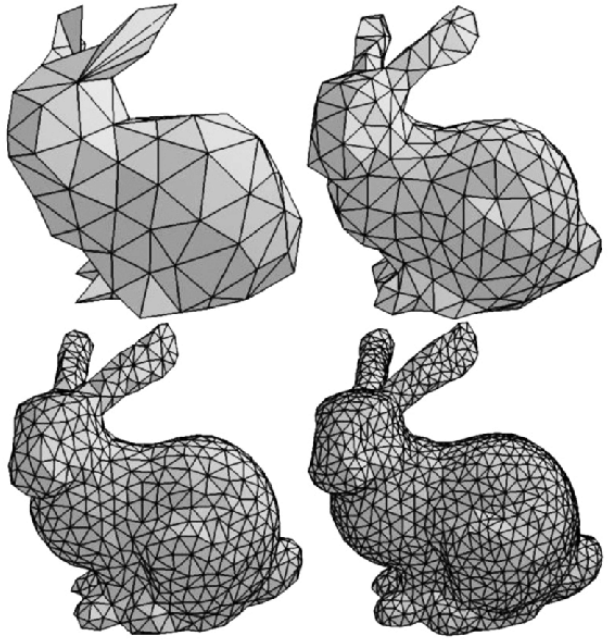
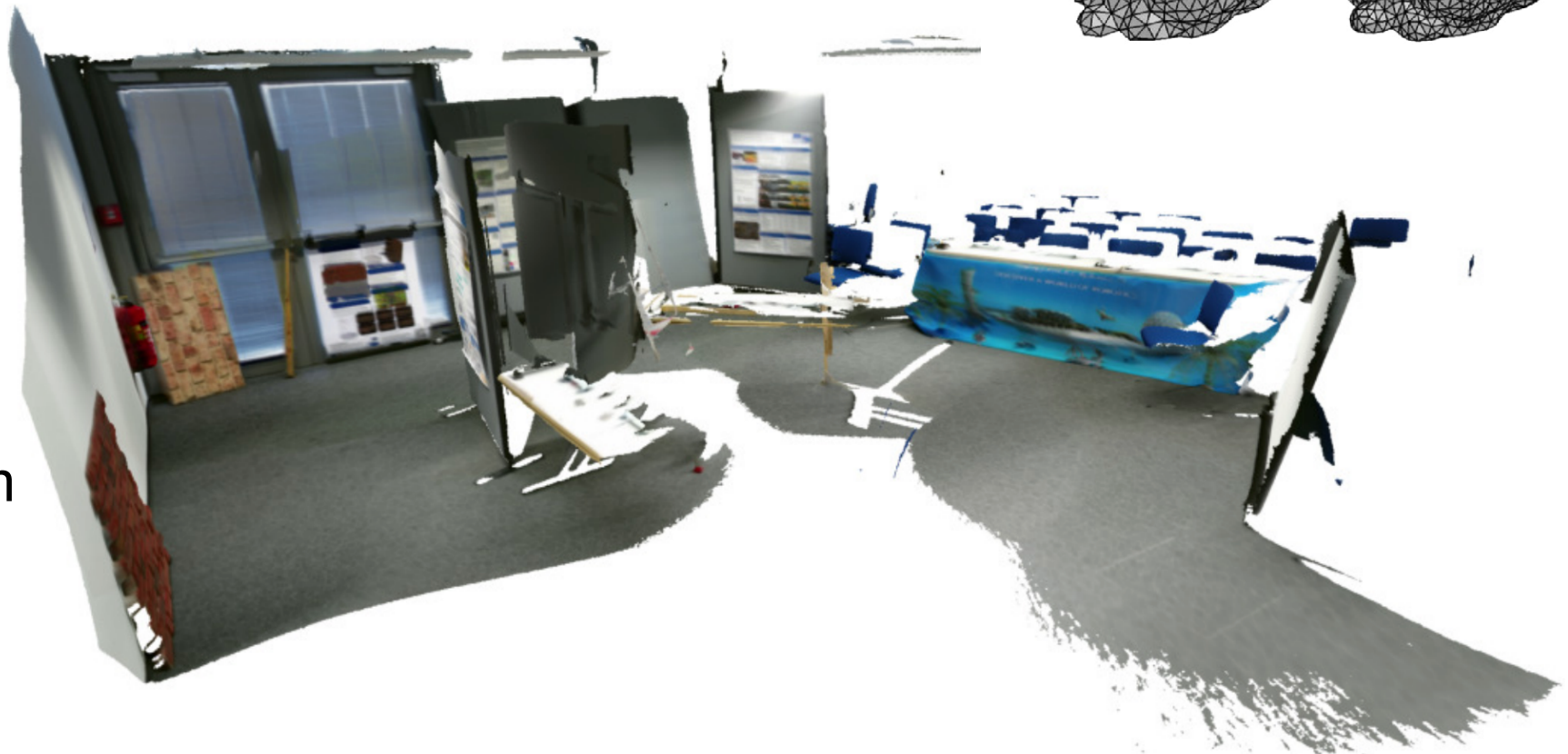
- Nodes in WGS 84 (vertices)
  - Only entity with position
  - Just for ways or
  - Object (e.g. sign)

- Ways:
  - Open polygon (street)
  - Closed polygons
  - Areas
  - With tags (e.g. name, type, …)



Mesh

- Often build via Signed Distance Field

- Close relation to 3D reconstruction from Computer Vision

- Often with texture (RGB information from camera)