

# CS 1501: Intro to Robotics

## Autonomy, AI, and Applications

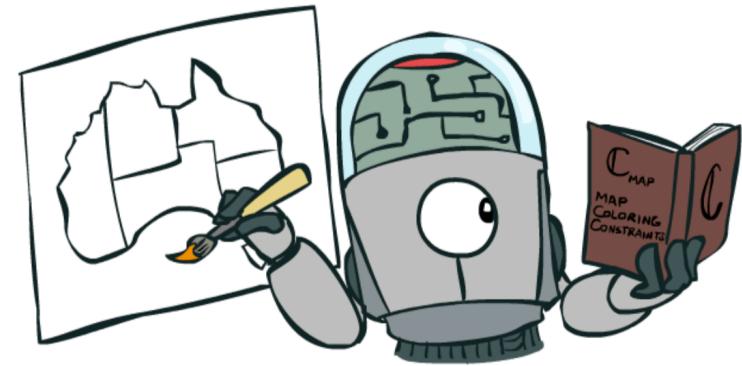
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## Mapping

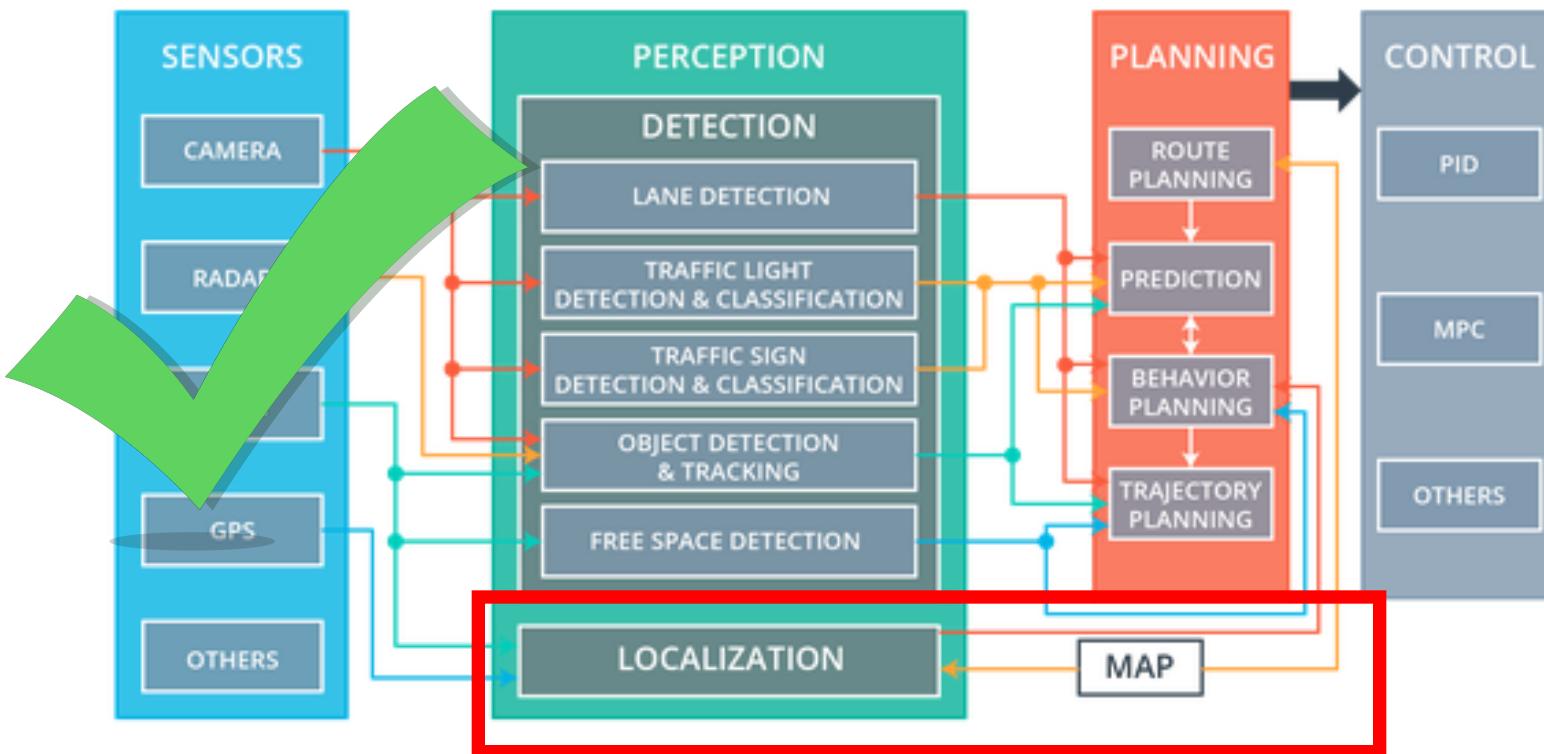
Rohan Raval

Monday 1-1:50pm, MEC 213



# Recap: See-Think-Act

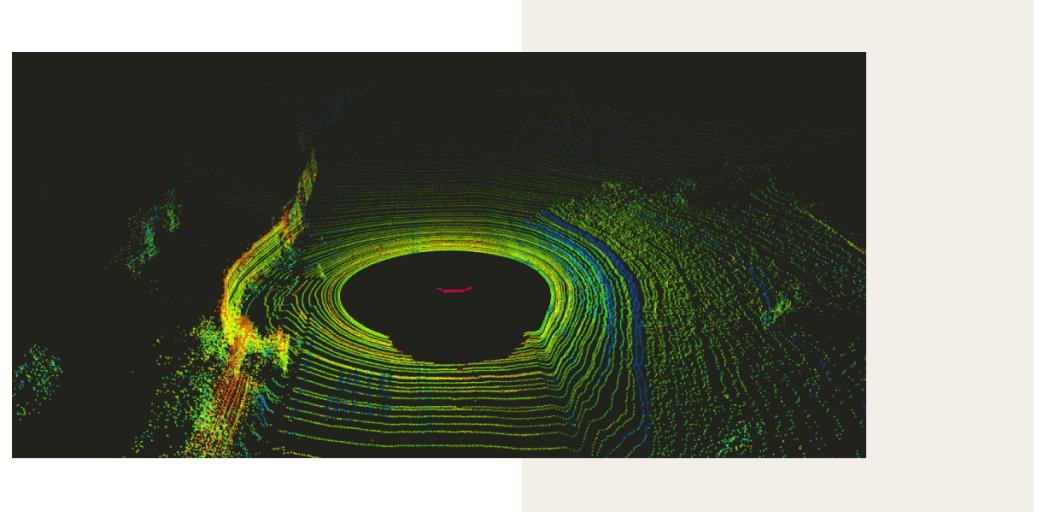
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# Recap: Sensors

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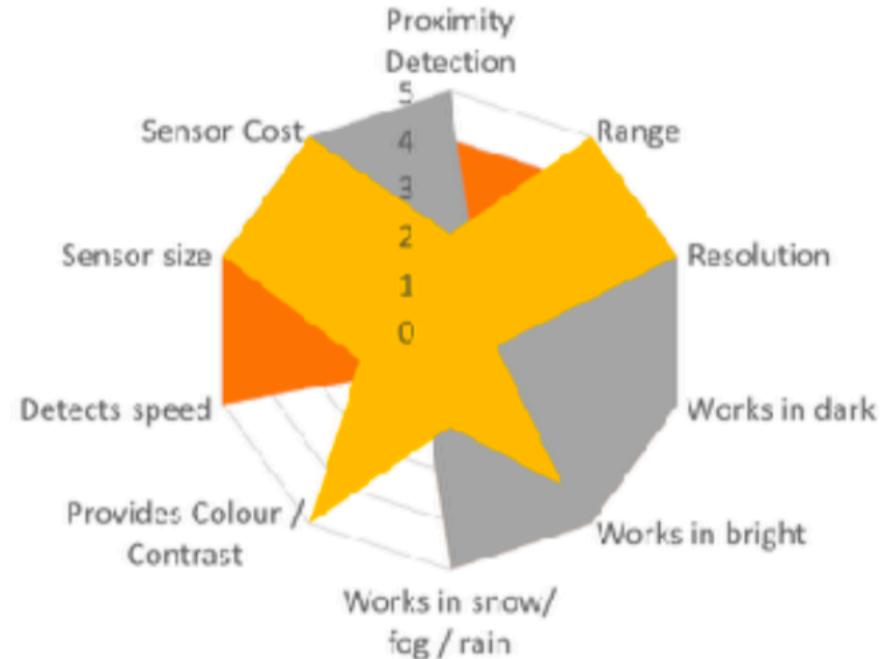
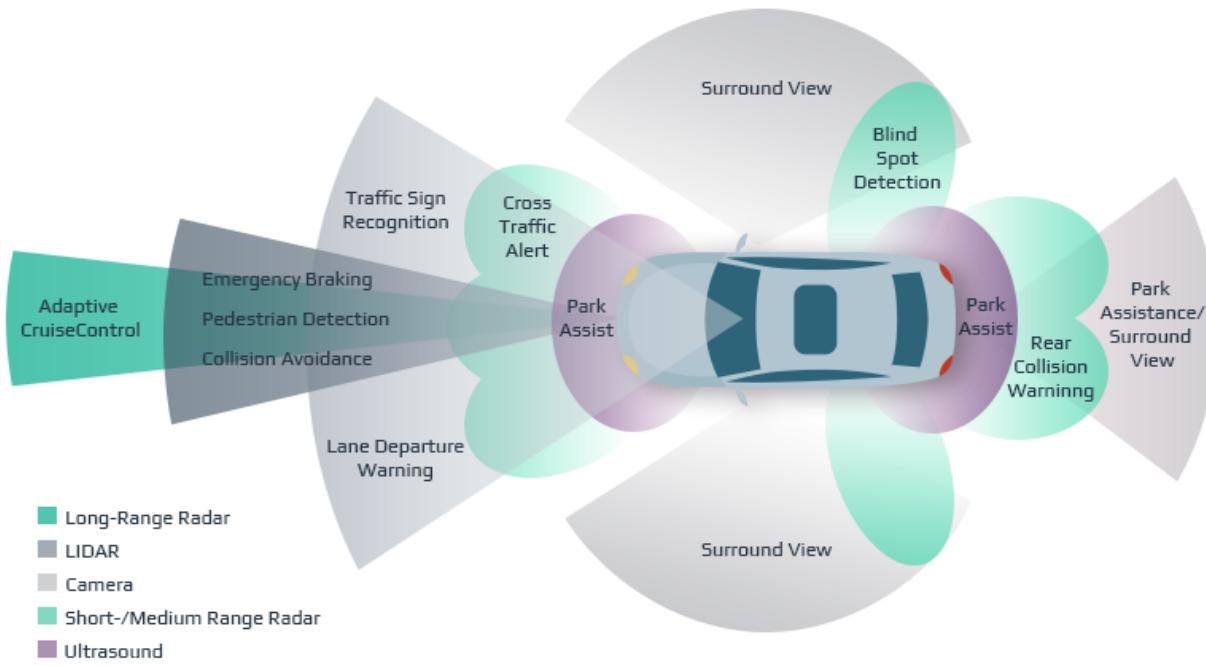
- Questions about LiDAR
- Future Directions for LiDAR
- “What’s wrong with just GPS?”
- Tradeoffs
- Camera vs LiDAR
  - Why does Elon hate LiDAR??
  - LiDAR as a “crutch”
  - Accurate vs Cheap... best of both worlds?



# Recap: Sensors

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- Sensor Fusion

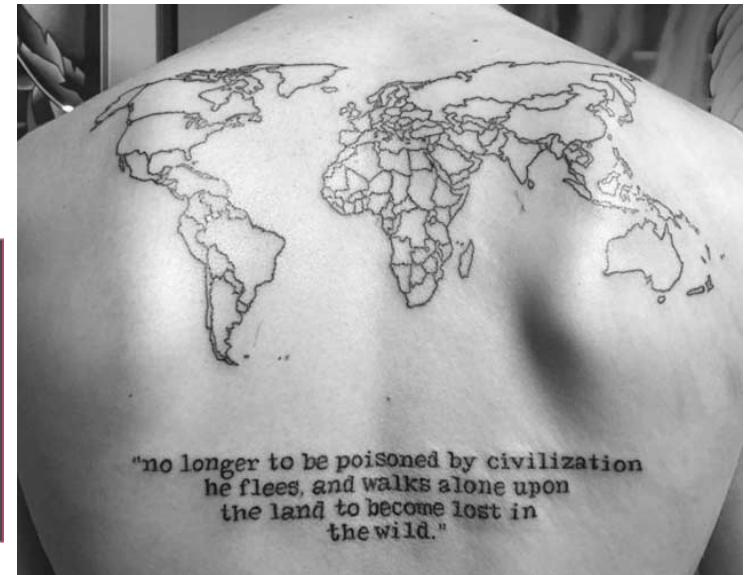
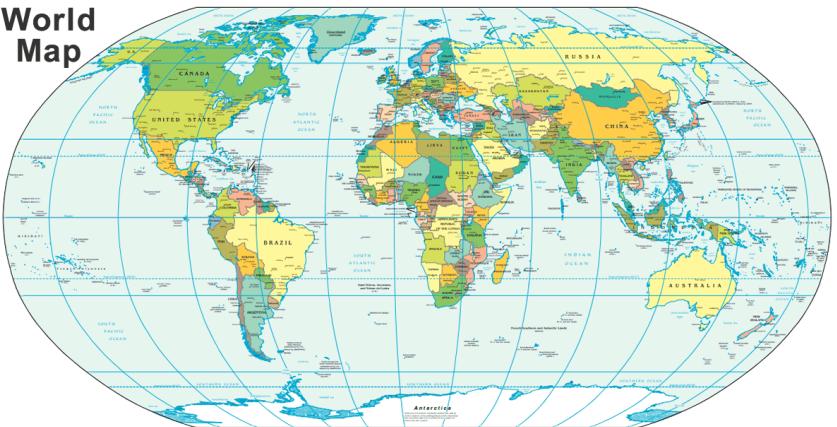


# Why Maps?

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- Model the world around us

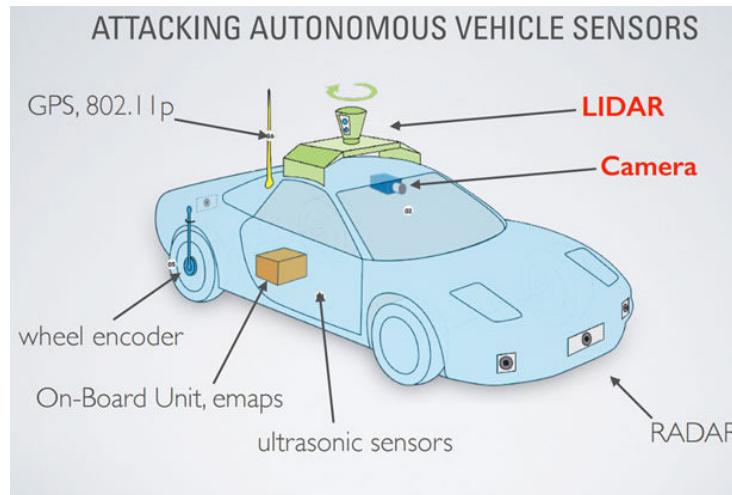
World Map



# What are Maps?

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- Map = spatial model of robot's environment
- Considerations
  - Purpose for mapping
  - Available Sensors
  - Map Representation



# Types of Maps

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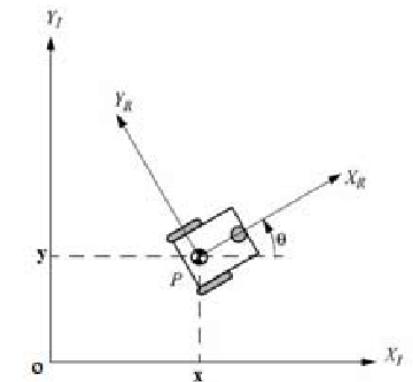
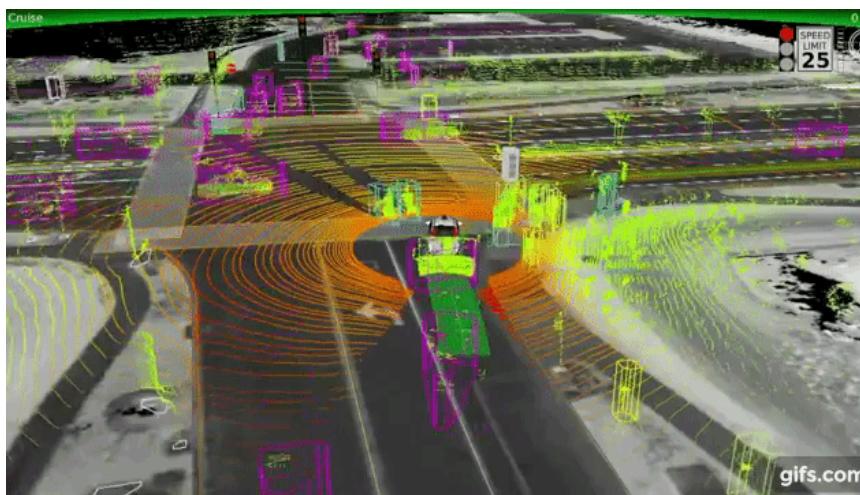
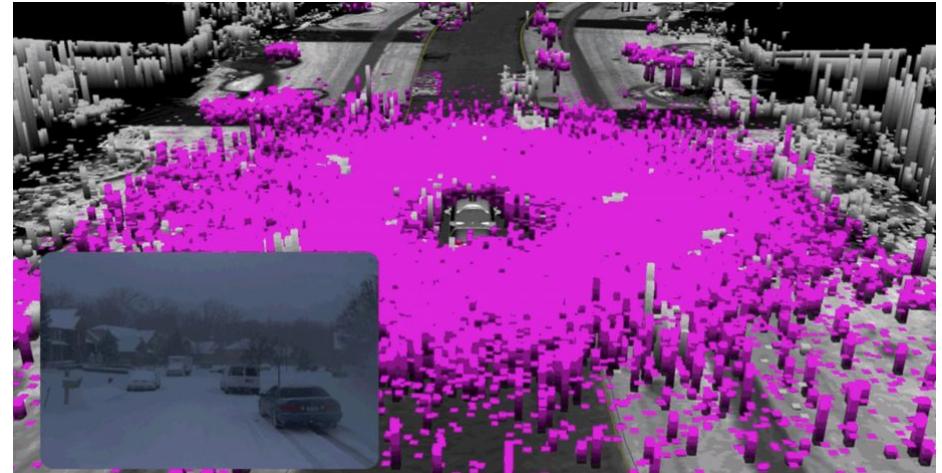
- Metric
  - Care about precise location (represented as a coordinate)
- Topological
  - Care about connections between nodes (not geometrical accuracy)
- Semantic
  - Care about information (data annotation)



# Challenges of Maps

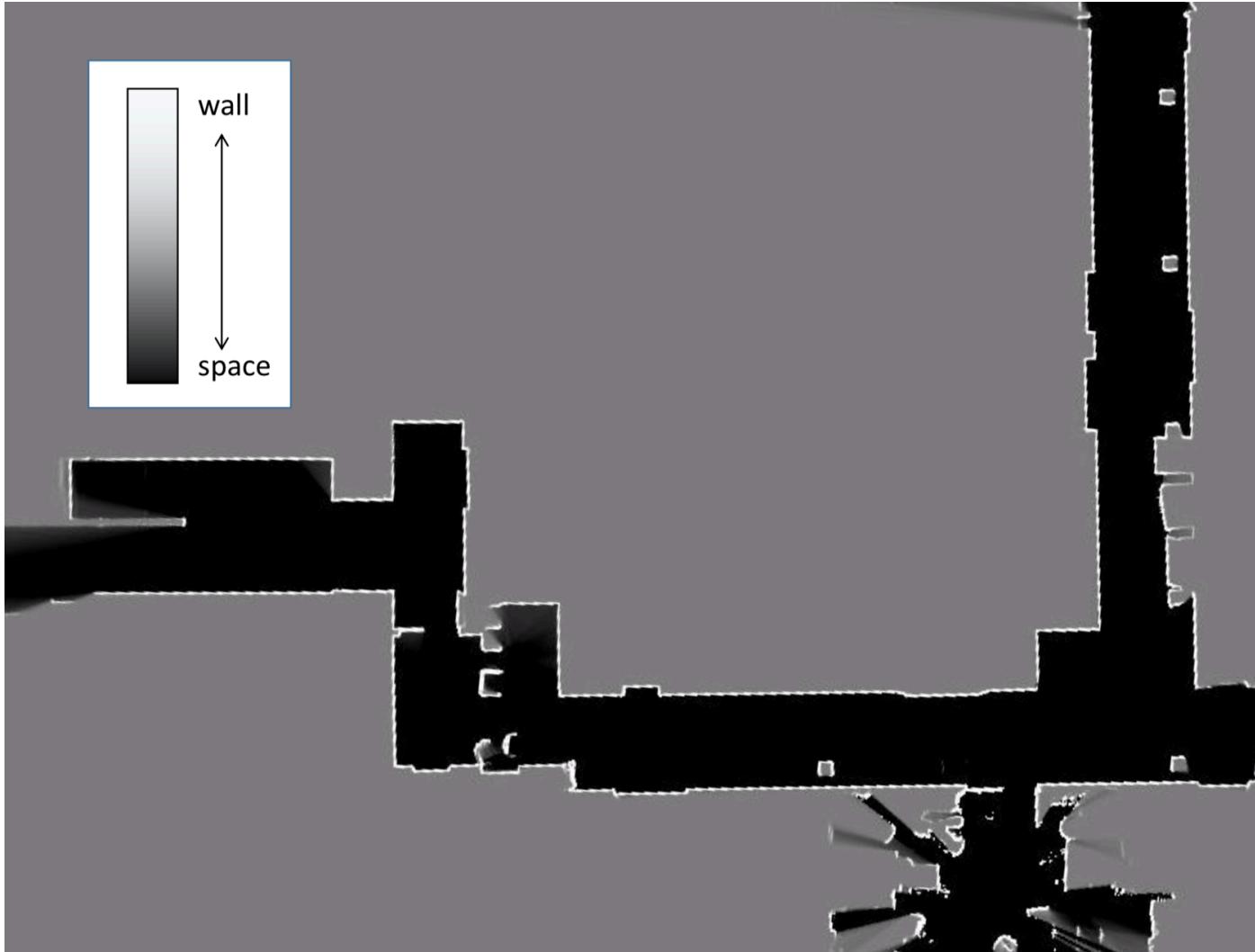
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- Sensor Issues
  - Noisy Measurements
  - Local to Global Coordinate Frames
- Motion
- Dynamic environment



# Occupied or Empty?

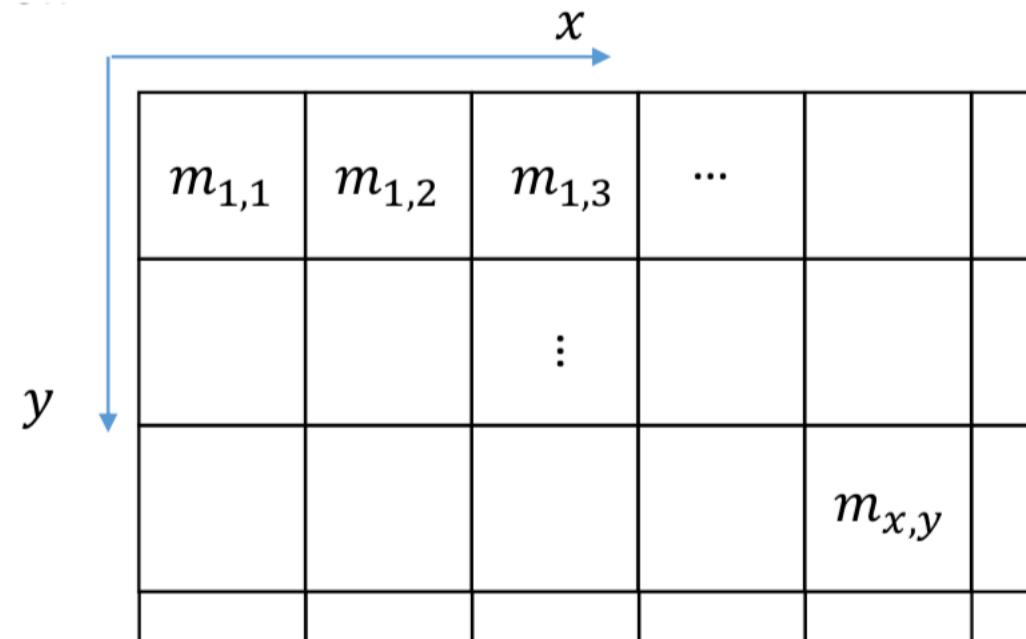
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# Occupancy Grid Mapping

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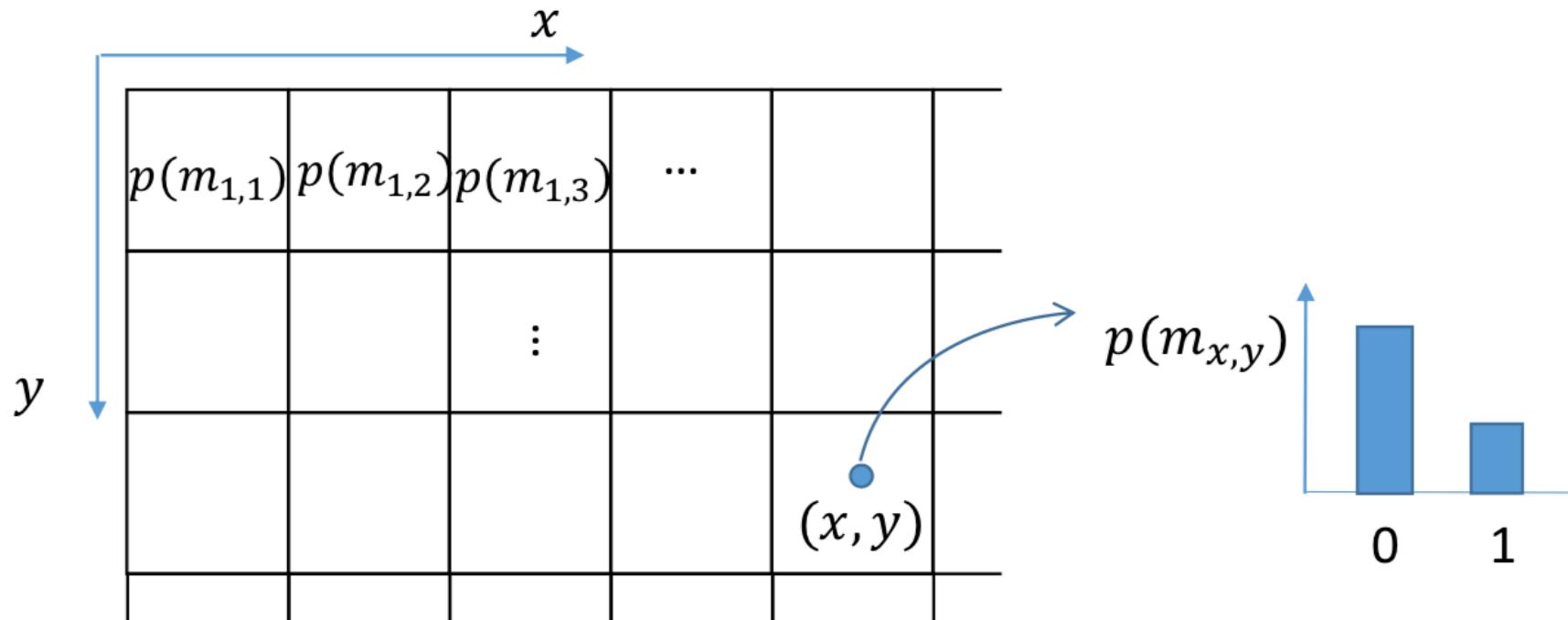
- Occupancy = 0 (free) or 1 (occupied)
- Occupancy Grid Map = grid where each cell is an occupancy



# Occupancy Grid Mapping

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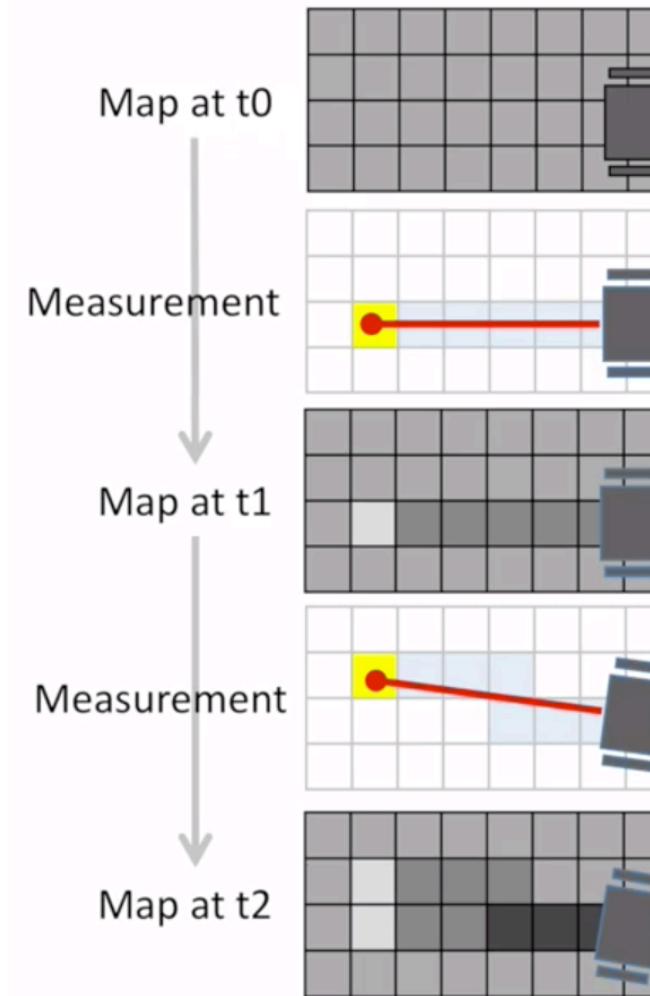
- Store **probability** of occupancy



# Occupancy Grid Mapping

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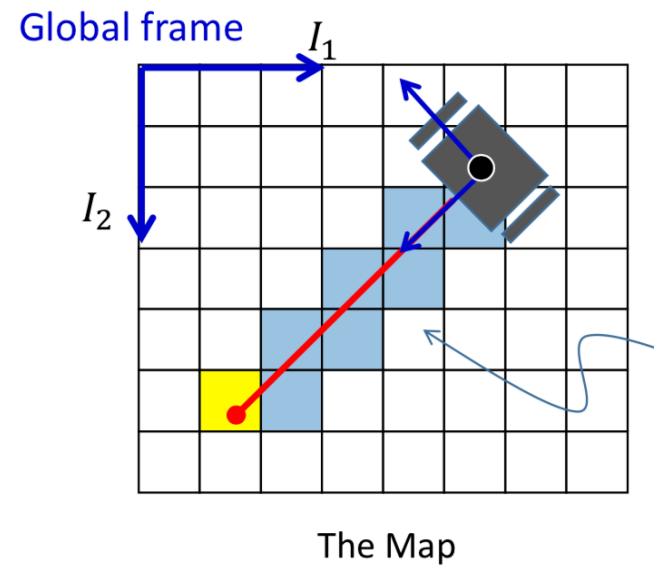
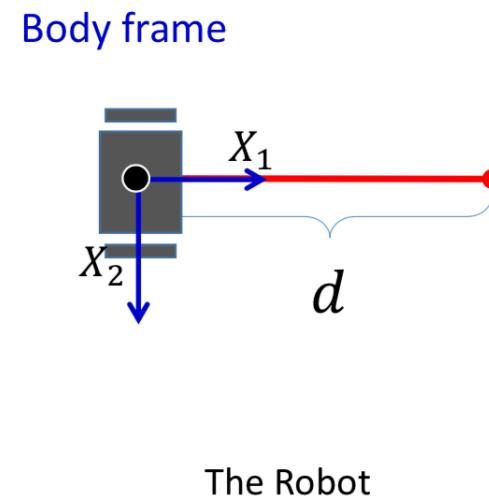
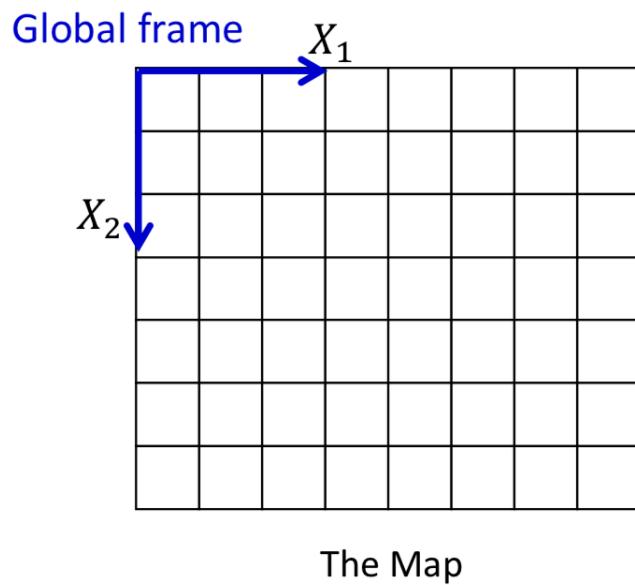
1. Prior Map
2. Measurement
3. Update (Posterior)
4. Measurement
5. Update (Posterior)



# Reference Frames

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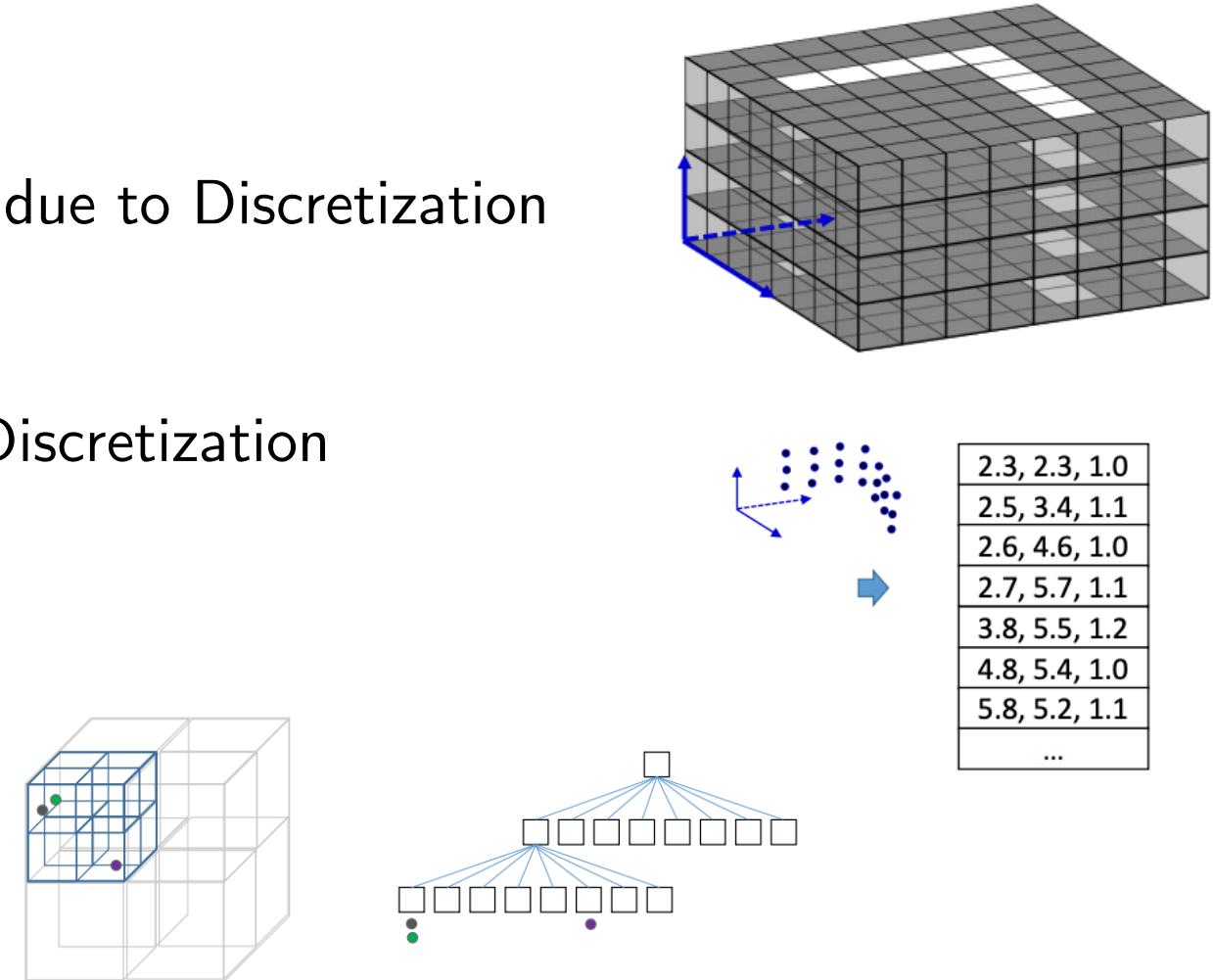
- Sensor data measured with respect to robot
- Need to transform from robot frame to global frame



# Map Representations

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- Occupancy Grid
  - **Pro:** Immediate Access to Cells
  - **Con:** Large Memory, Loss of Info due to Discretization
- List of Occupied Points
  - **Pro:** Less Memory, No Need for Discretization
  - **Con:** Long time to search!
- Tree-based Representations...



# Mapping the Real World

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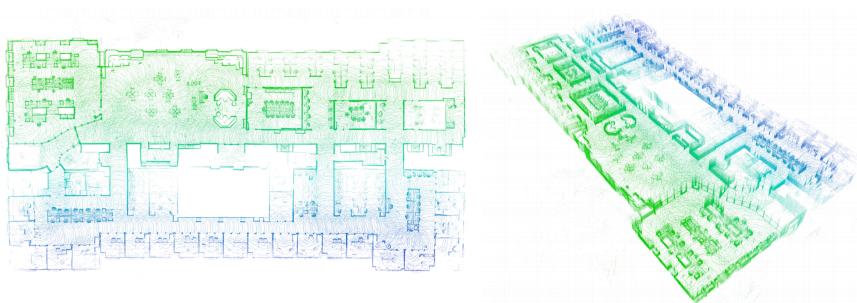
- HD (High Definition) MAPS
- Accurate, high-granularity maps
  - Lanes, crosswalks, traffic lights, stop signs...
- Offline: Build map, then use it to drive
- Online: Map the environment while driving autonomously (SLAM)
- Many self-driving car companies (Waymo, Uber, Lyft,...) rely heavily on HD Maps



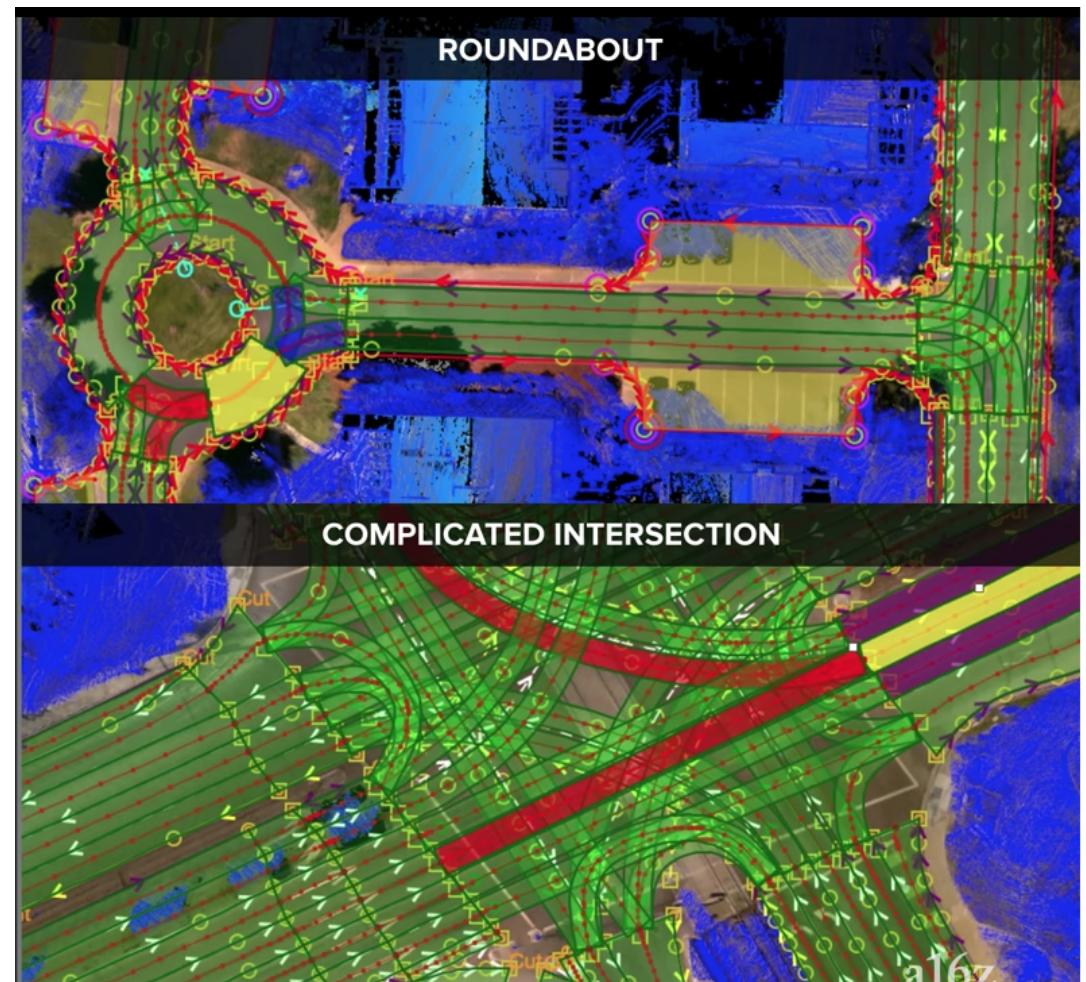
# Making an HD Map

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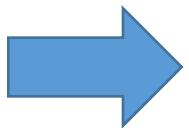
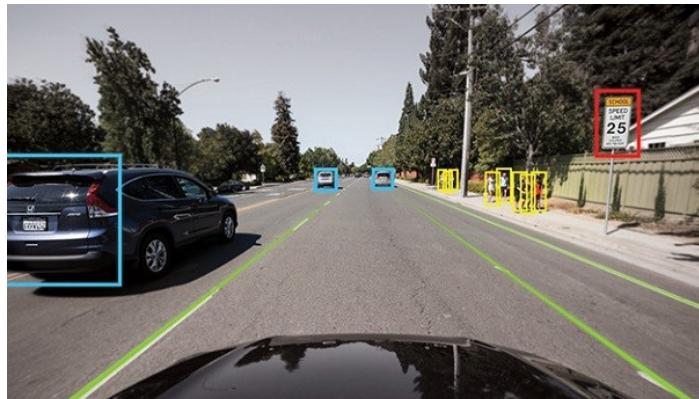
Point Clouds



HD Maps



Camera

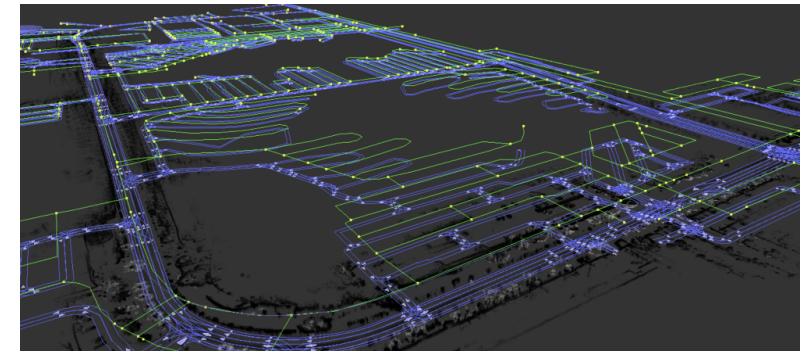




# Lyft Level 5: Mapping Principles

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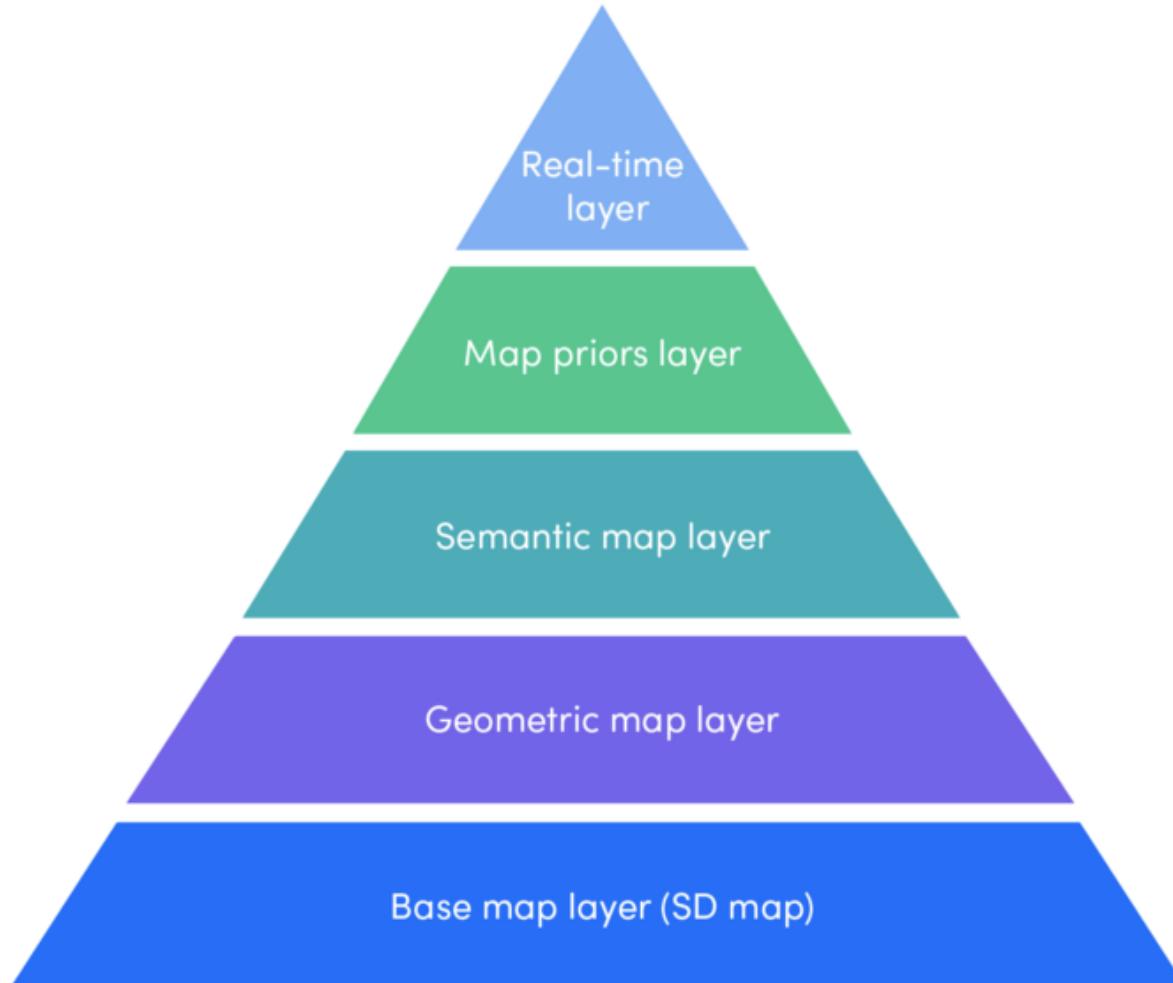
- Mapping as **pre-computation**
  - Perception and Localization of completely static objects
  - Background Subtraction
- Mapping to improve **safety**
- Maps as a unique **sensor**
  - "Immune to runtime occlusion from dynamic objects"
  - Overlay other runtime sensor data onto existing map prior
- Maps as a **global shared state**
  - Read/write across fleet → shared info





# Lyft Level 5: Layered Map

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# Lyft Level 5: Layered Map

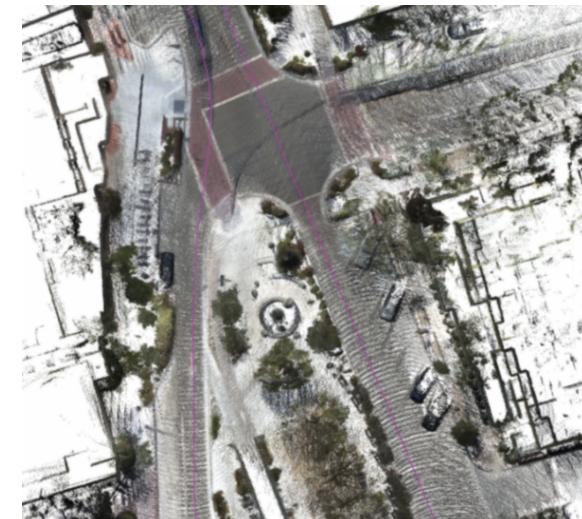
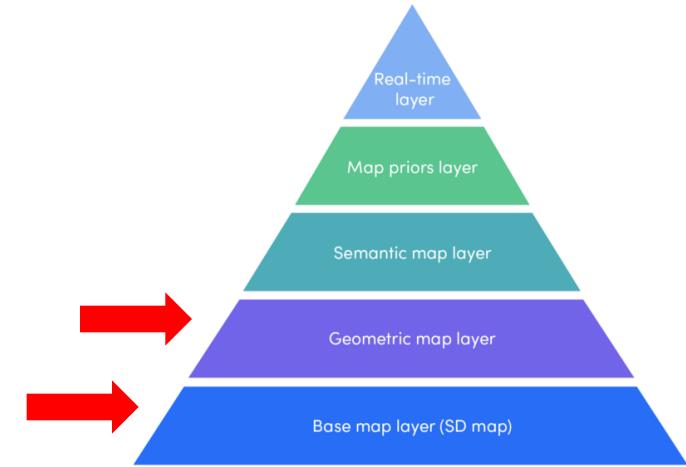
- **Base Layer (SD Map)**

- Connectivity data
- Template
- E.g. Google Maps



- **Geometric Map Layer**

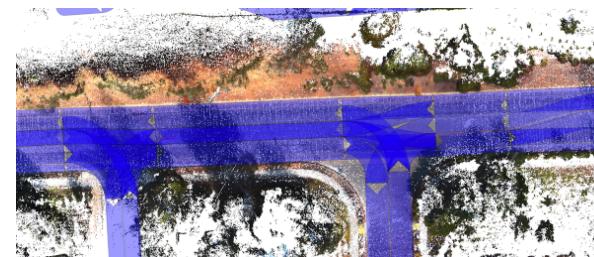
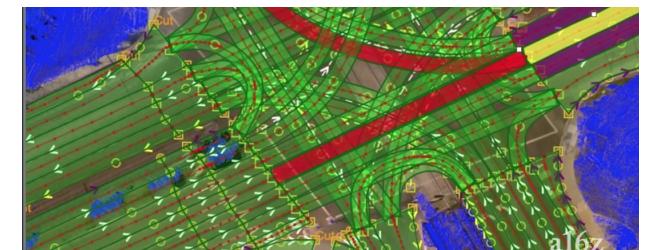
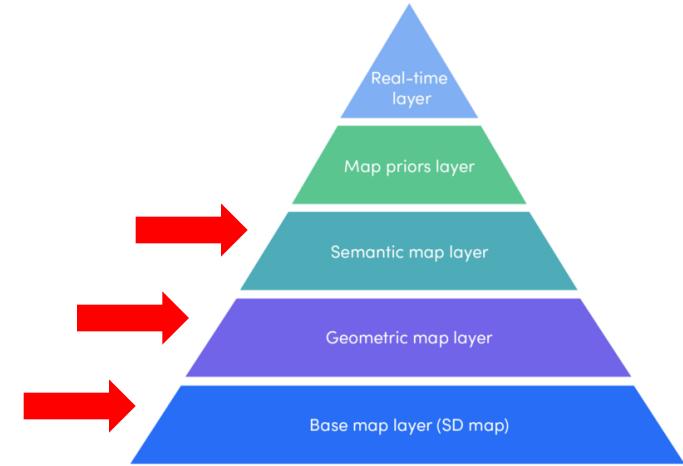
- 3D information of the world
- Raw sensor data → aligned point cloud  
→ post-processed → “map objects”
- “Ground map” and drivable surface
- Human Technicians





# Lyft Level 5: Layered Map

- **Semantic Map Layer**
  - Adds “semantic objects”
    - Lane boundaries, intersections, crosswalks, parking spots, traffic lights, etc.
  - Rich Metadata associated with objects
    - e.g. speed limits associated with lane segments, bounding boxes, etc.
  - Lots of annotation by human technicians (and computer vision)
  - Connectivity graphs and structural/representational solutions

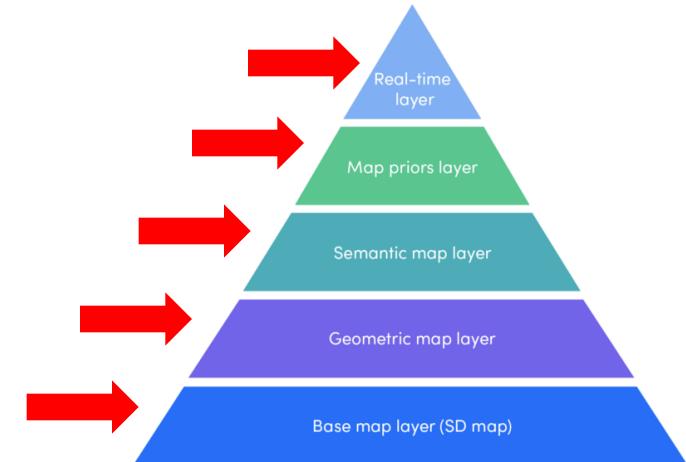




# Lyft Level 5: Layered Map

- **Map Priors Layer**
  - Heuristics and hints for real-time
  - Derived information about dynamic elements and human driving behavior

- **Real-time Layer**
  - Read/write capable
  - Real-time traffic info
  - Support of sharing across fleet

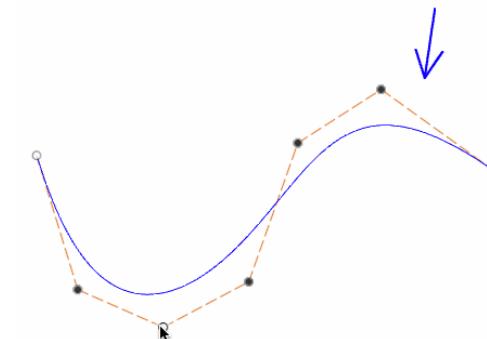
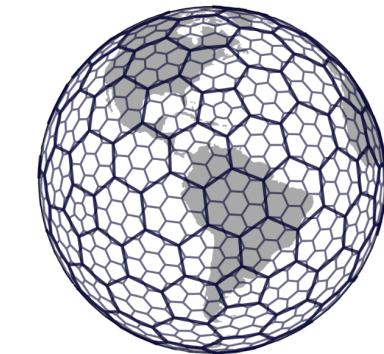
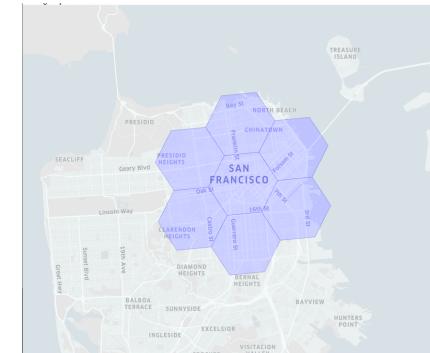
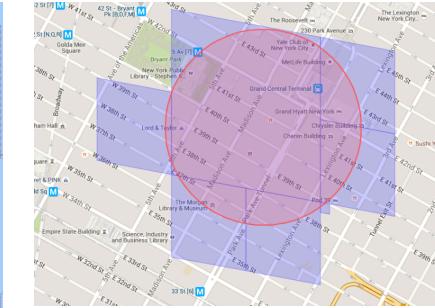
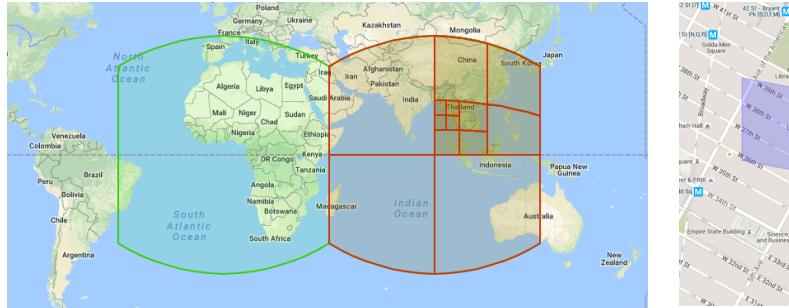


- All layers built **independently** and **aligned**
- Data transmitted across layers

# Storage and Retrieval

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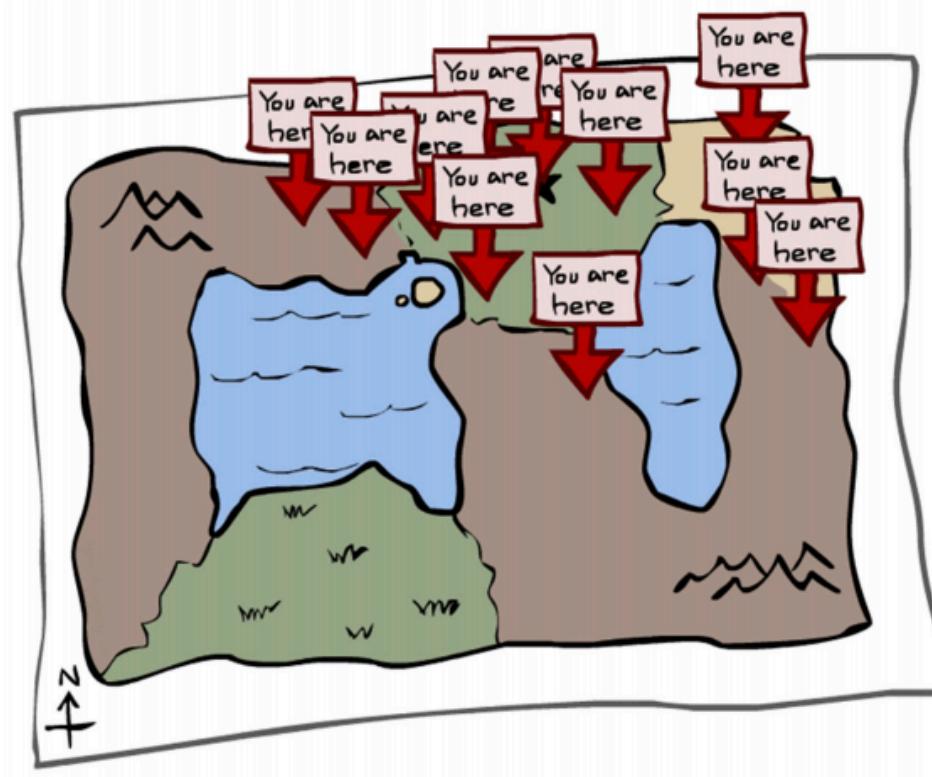
- Indexing small chunks
  - S2/H3/others
  - Operations
  - Querying
  - Distributed
- Geometric Representations
  - E.g. Road/Lane Splines
  - Polygons and related problems
  - Video Games



# Localization

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- I have a map... now what?
- Where am I?



# Localization

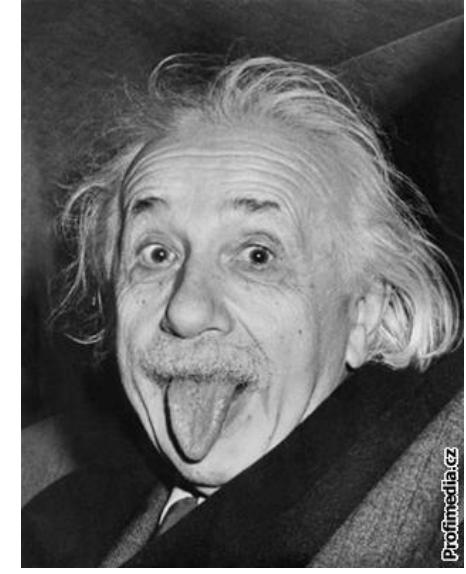
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- Sherlock Holmes

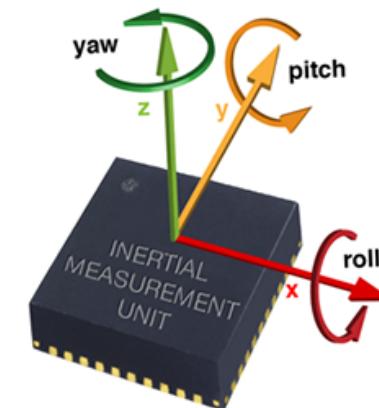
# Pose

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- Reference Frames
  - Robot reference frame
  - Global reference frame
- **Pose = translation and rotation**
- Representations of Pose
  - Euler Angles, Quaternions, Homogeneous Transforms, etc....
- 6 Degrees of Freedom (DoF)
  - X, Y, Z, Roll, Pitch, Yaw



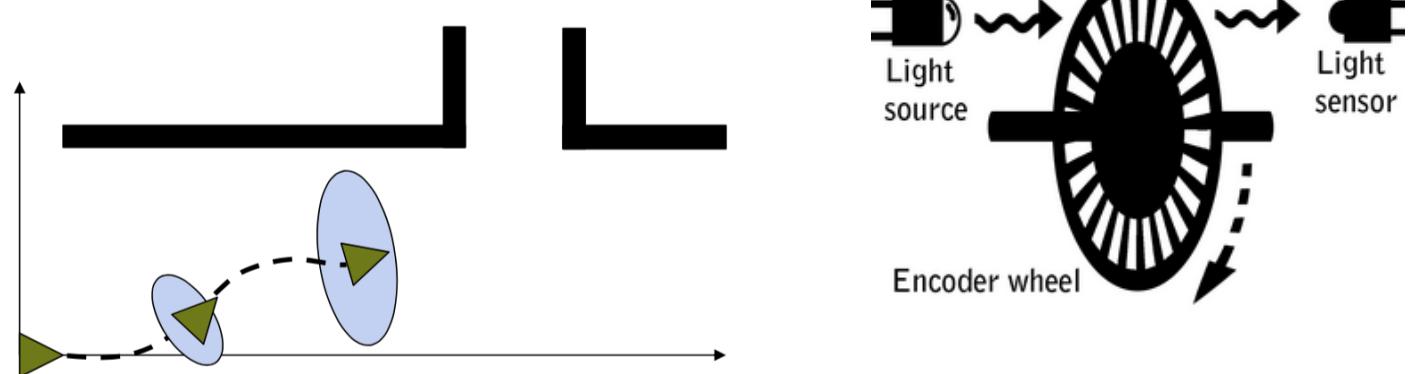
Profimedia.cz



# Localization Attempt 1: Dead Reckoning

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- Want to find pose
- But don't know how!
- Maybe know starting location?
- Wheel encoders? → Odometry
- Problems?
  - Drift, skid, wind, etc.
  - **Errors compound!**



# Make Localization Great Again

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How? PROBABILITY



# Make Localization Great Again

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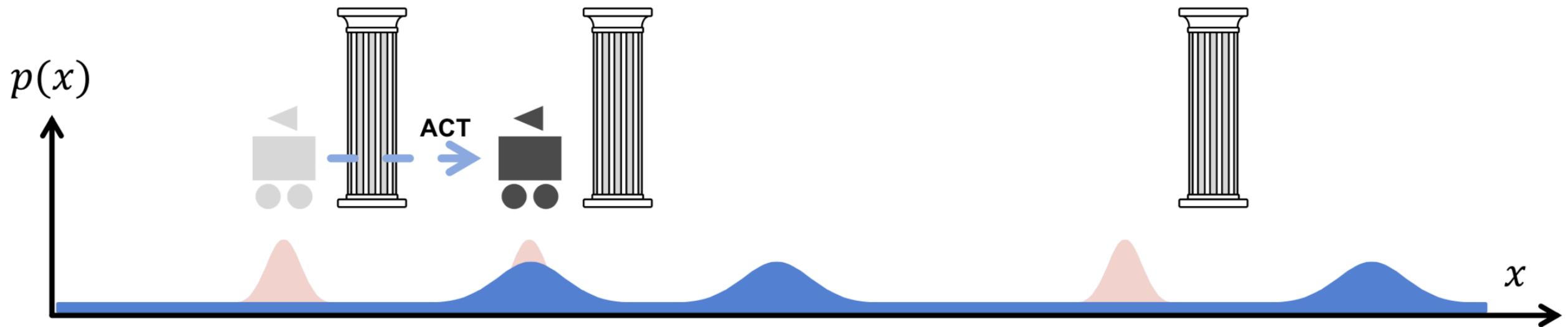
# Make Localization Great Again

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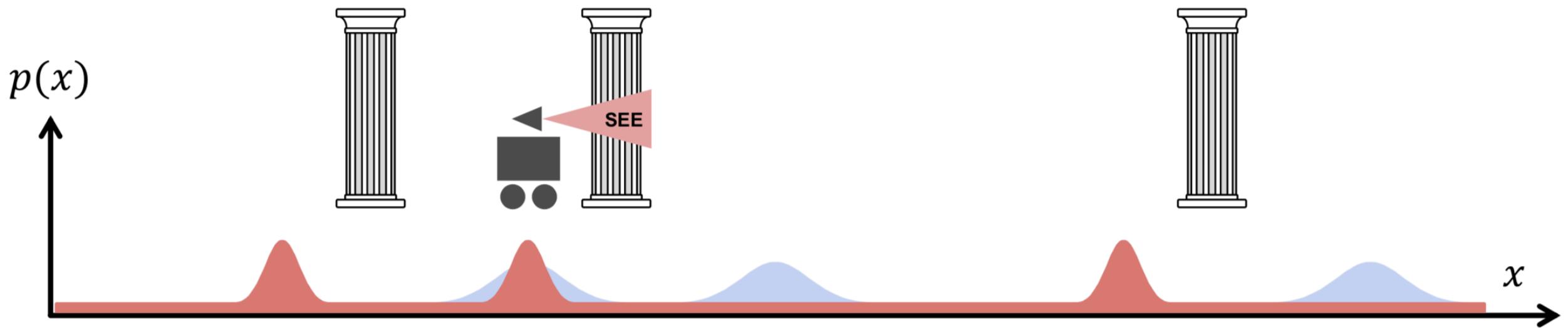
# Make Localization Great Again

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# Make Localization Great Again

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# Make Localization Great Again

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