Introduction to robot algorithms
CSE 410/510

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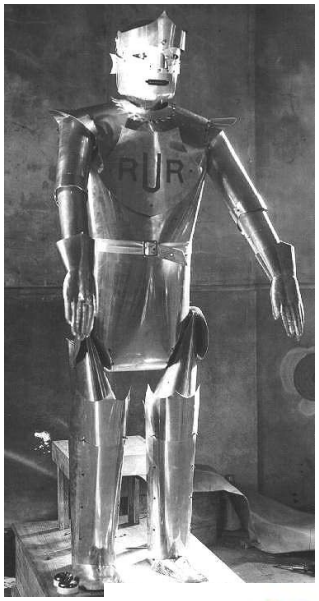
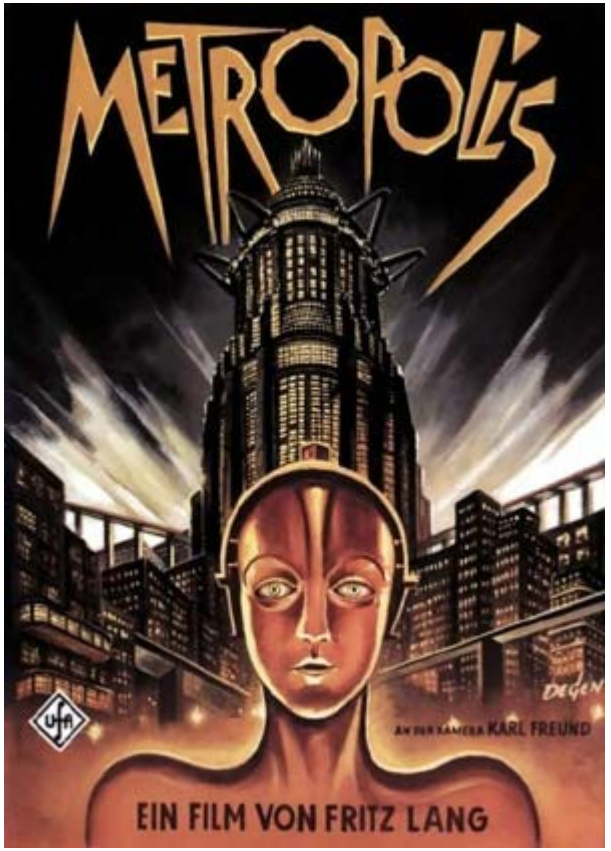
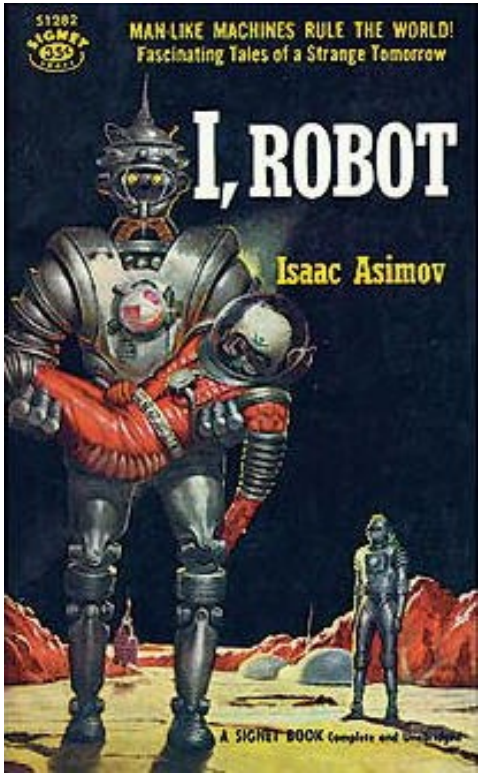
Times: MWF, 10-10:50
Location: Clemens 322
Course web page:
http://people.csail.mit.edu/rplatt/cse510.html
Office Hours: 11-12 MW, 330 Davis Hall
TA:

What is robotics?

Answer from science fiction: a mechanical person

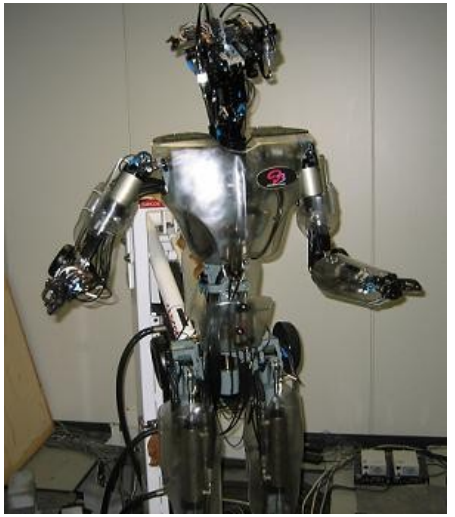




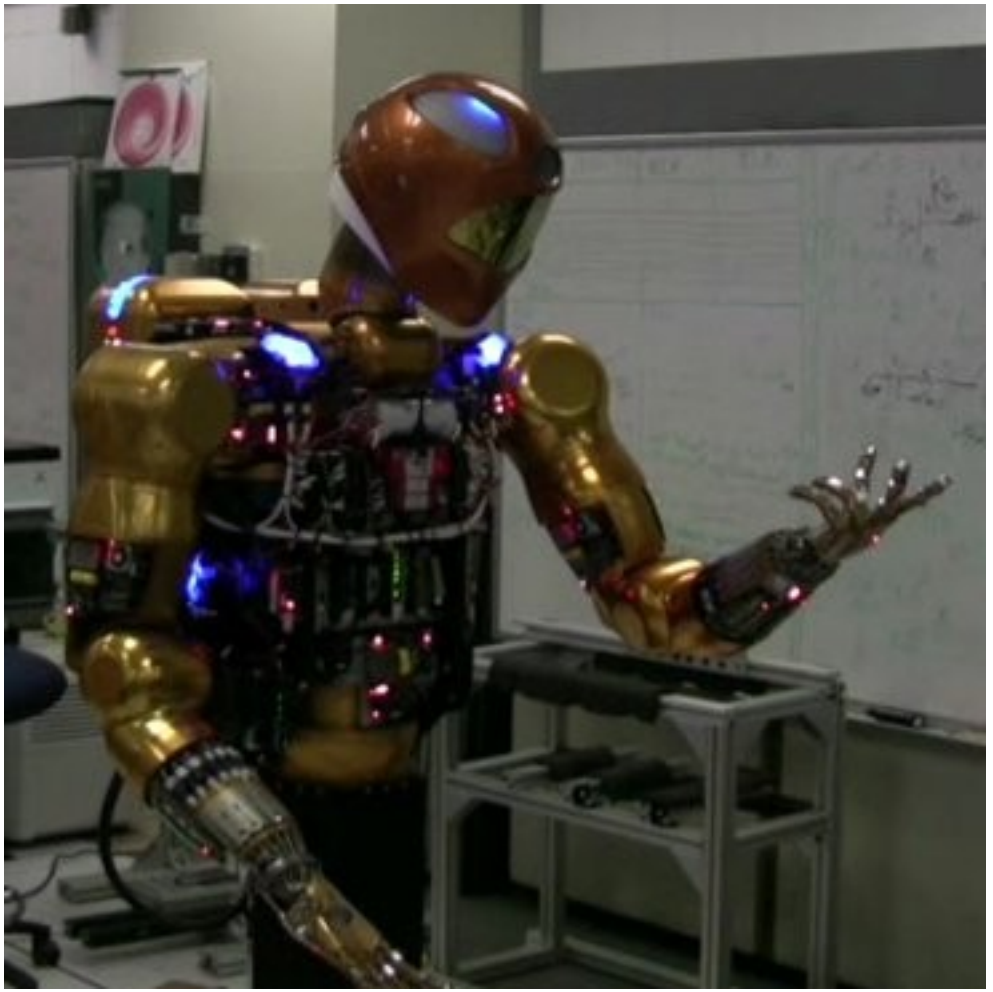


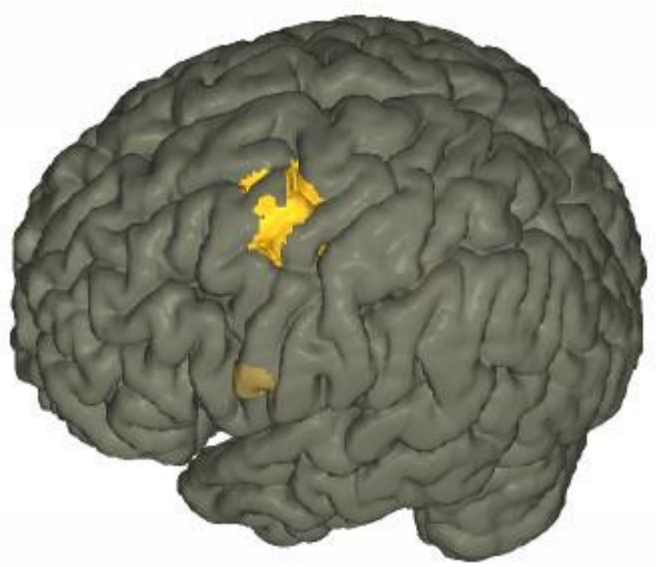
What do robotics researchers do?

...try to build mechanical people



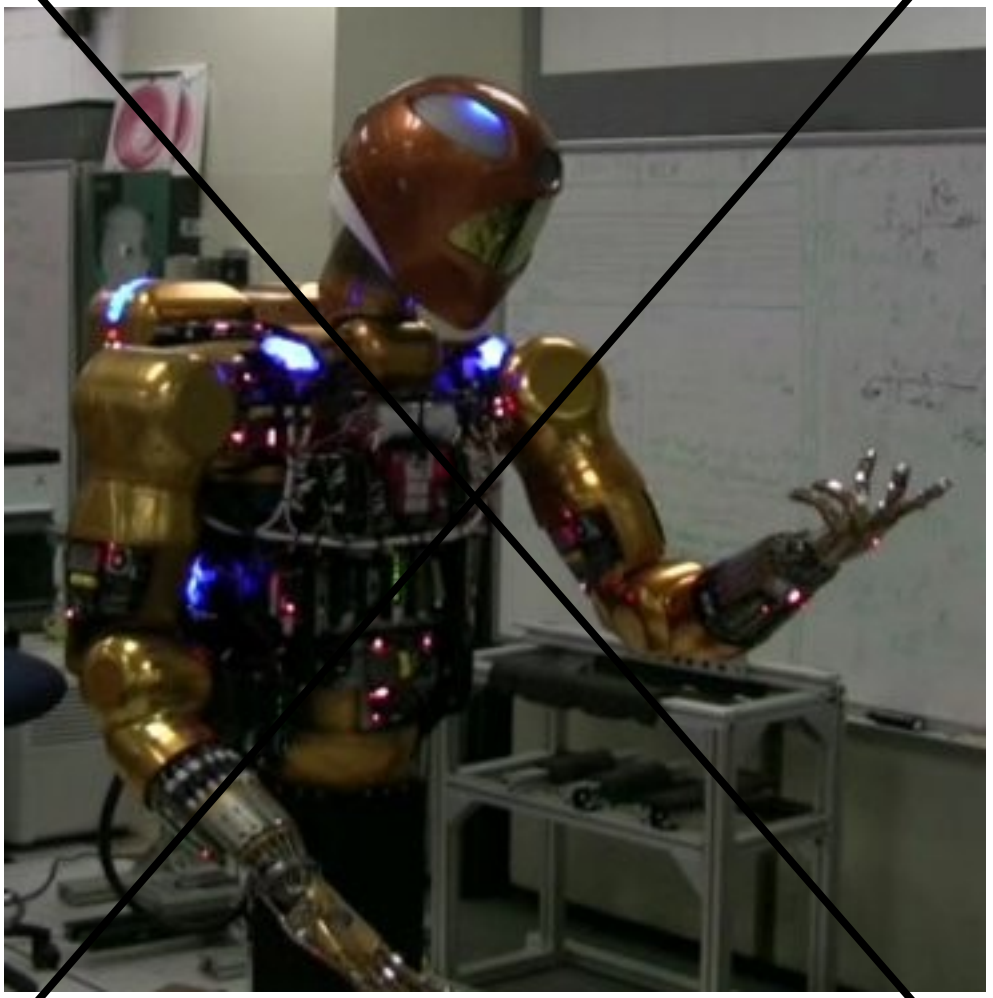
The hard part?

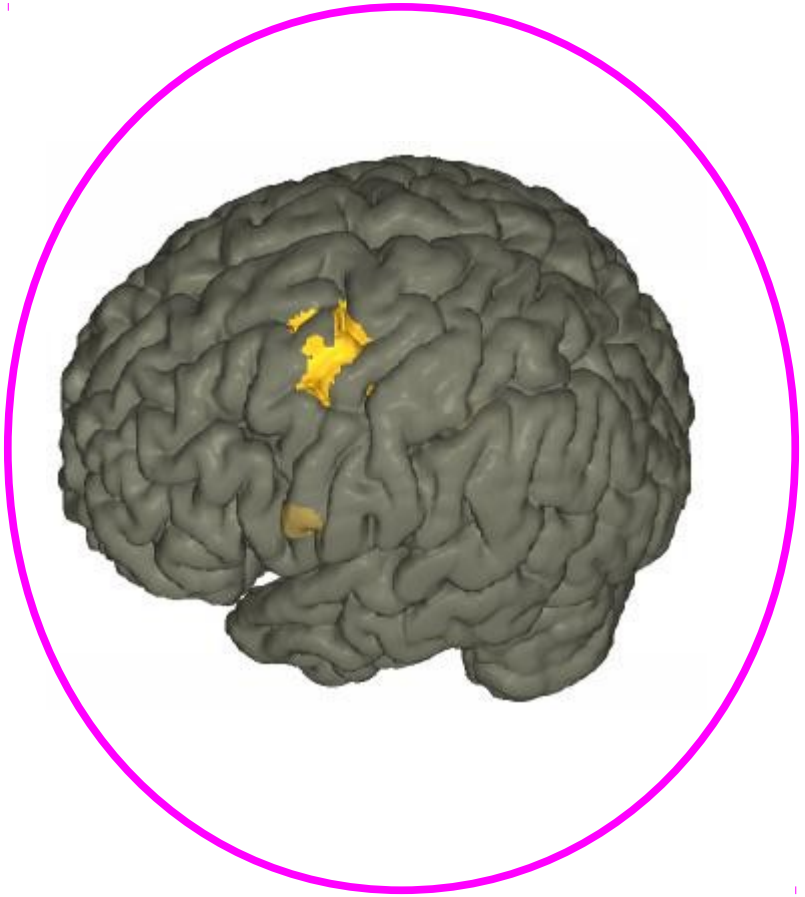




Hardware? or Smarts?

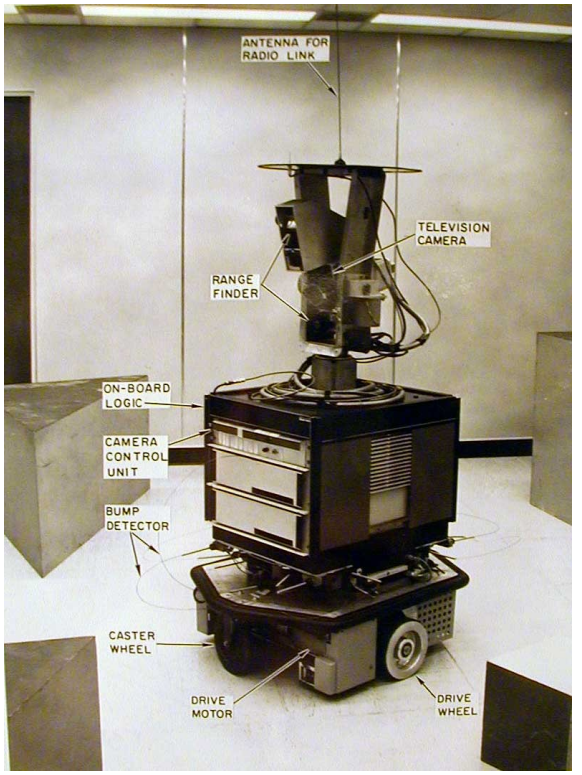
The hard part?





Hardware? or Smarts!

An enduring approach to robotics



- SRI, 1967
- Sense-think-act paradigm
  1. Sense the world using vision, sonar range finder
  2. Plan a sequence of actions that achieves specified goal (STRIPS)
  3. Execute plan
- Tasks: navigation around blocks and over bridges, rearranging blocks by pushing them

Charles Rosen, Nils Nilsson

This course: objectives

1. Understand “the” basic problems in robotics
2. Understand a few key algorithms in detail
3. Learn mathematical/algorithmic tools that you can use elsewhere

Topics

1. Planning
2. Control
3. Localization and mapping
4. Planning/Control as Optimization

Topics

1. Planning

    - configuration space, topology, rotation
    - dynamic programming
    - sample-based methods
    - cell methods
    - A^* and its variants
    - kinodynamic planning

Motion Planning

Problem statement:

Given: model of state space

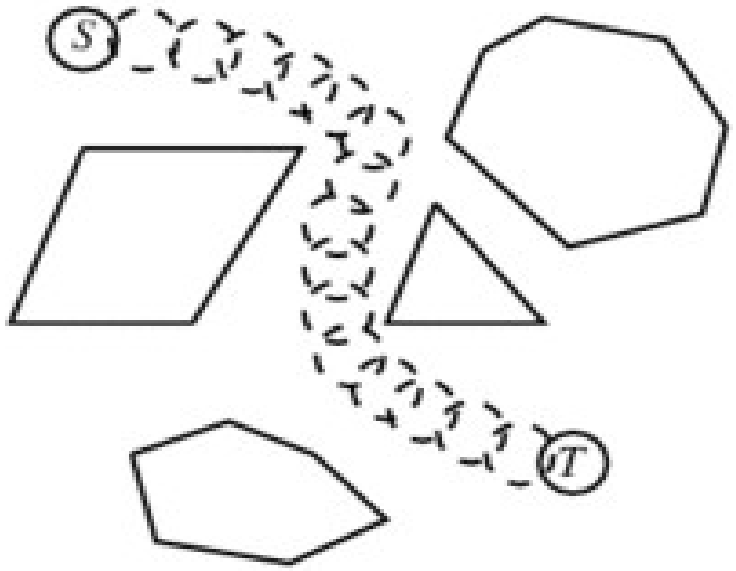
Given: a model obstacles in state space

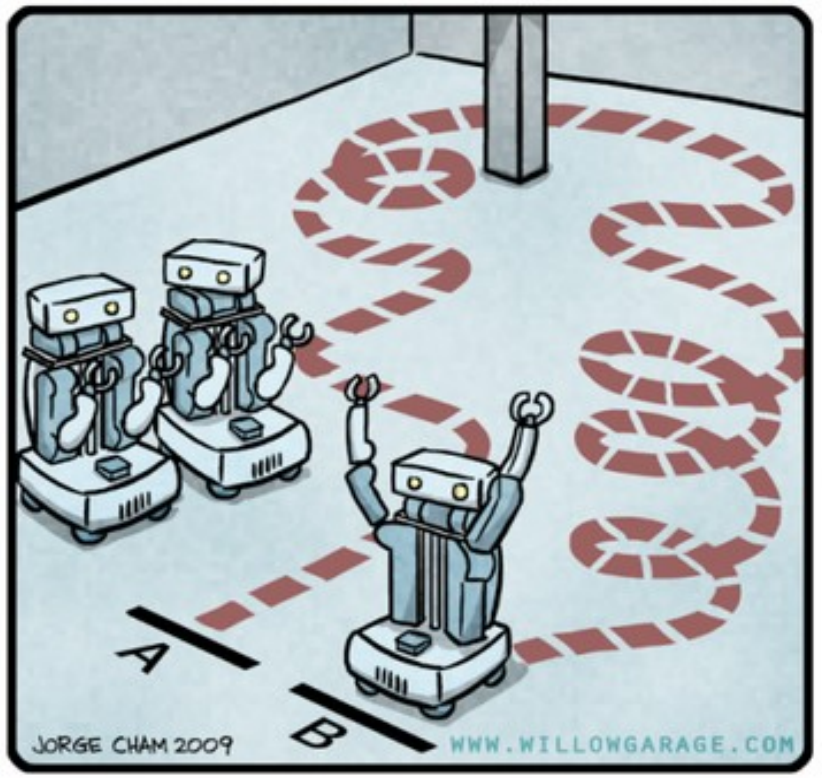
Problem: find a path from start to goal

Motion Planning

Applications:

1. mobile robot path planning



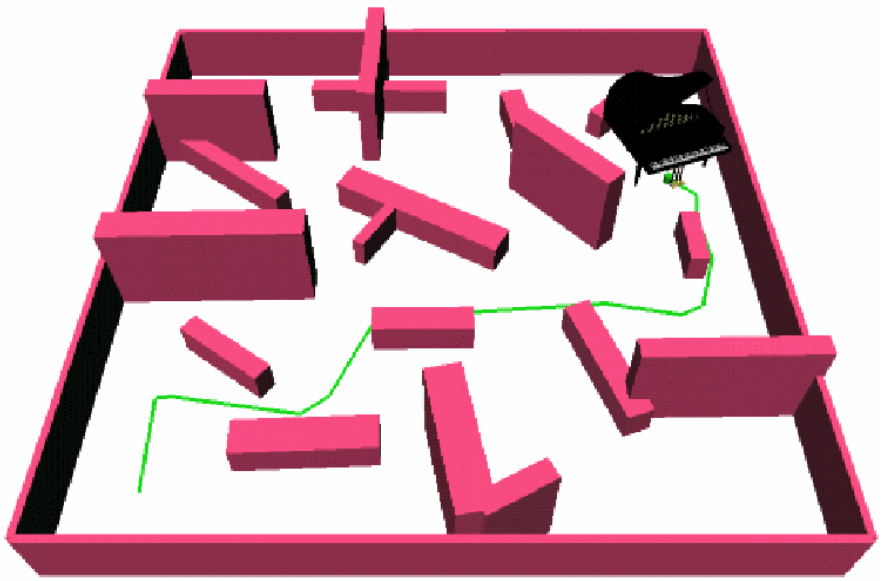


"HIS PATH-PLANNING MAY BE SUB-OPTIMAL, BUT IT'S GOT FLAIR."

Motion Planning

Applications:

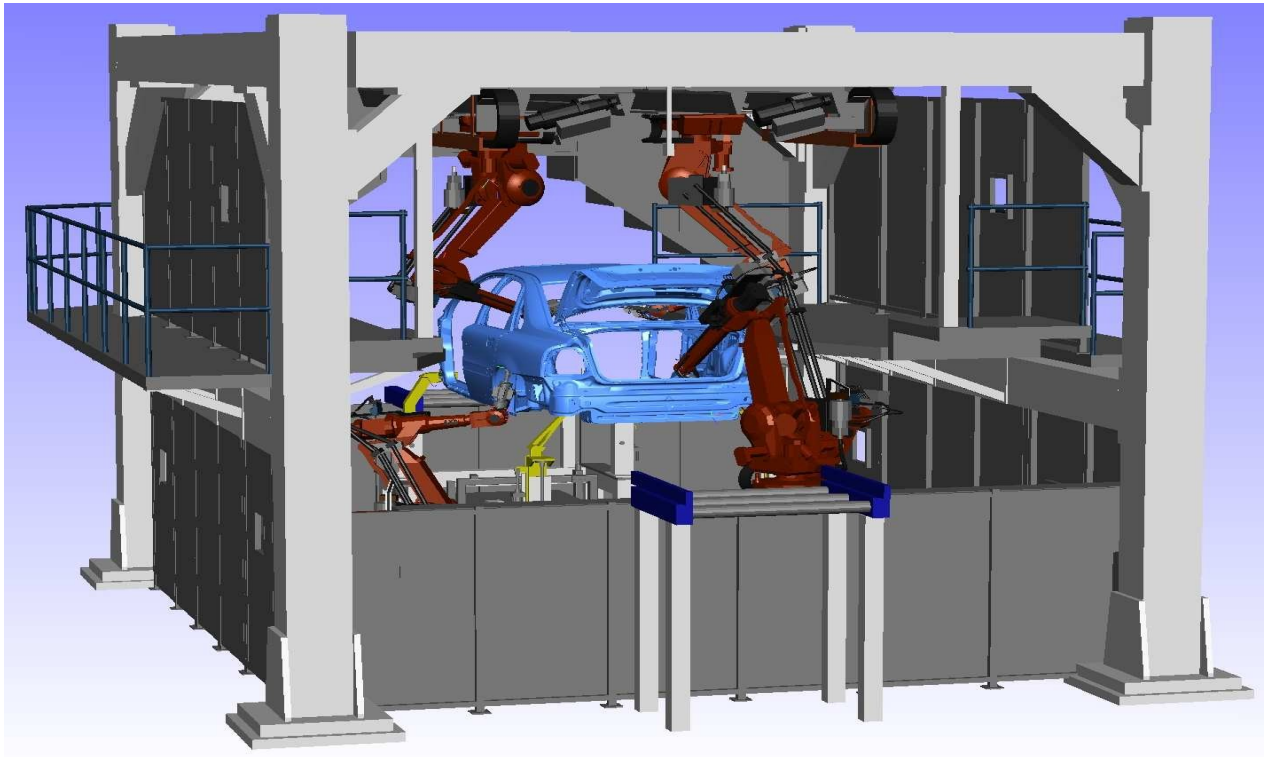
2. “Piano movers problem”



Motion Planning

Applications:

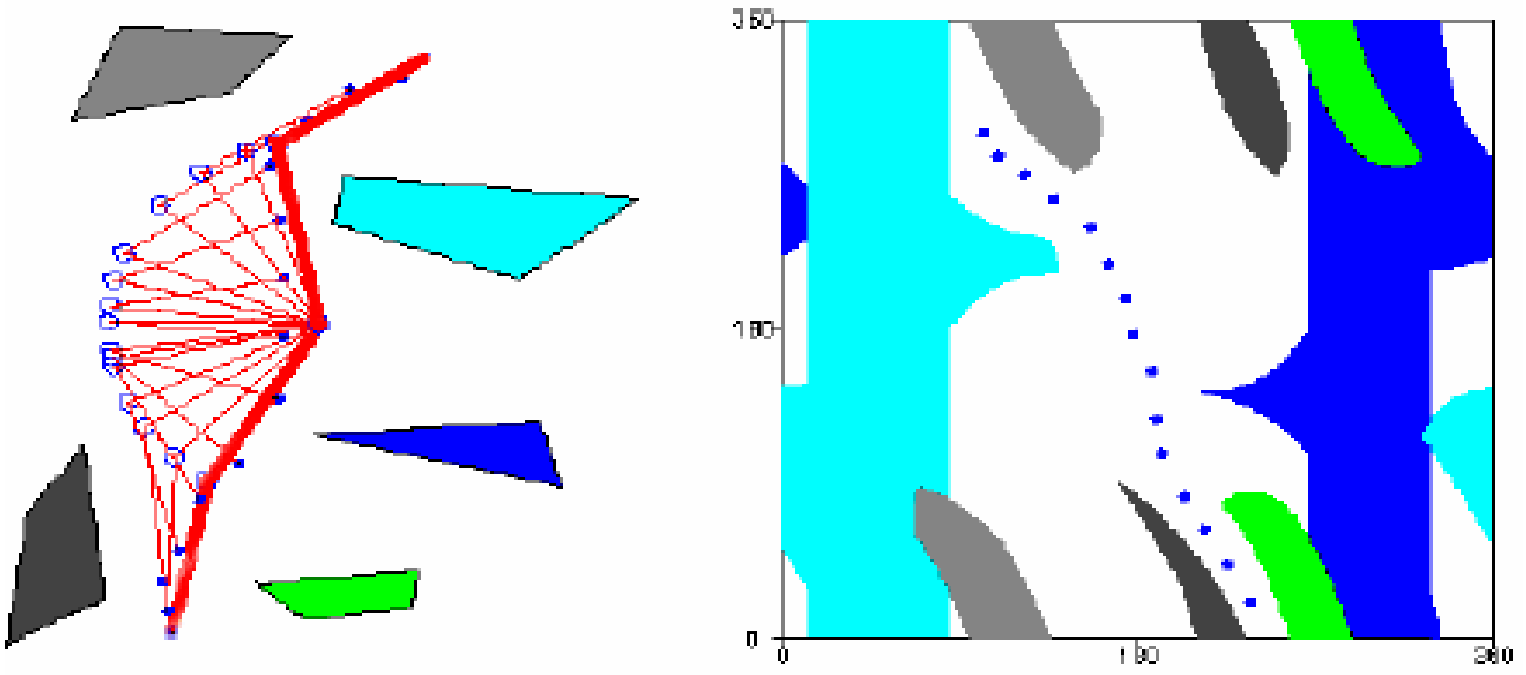
3. articulated arm motion planning



Motion Planning

Applications:

3. articulated arm motion planning

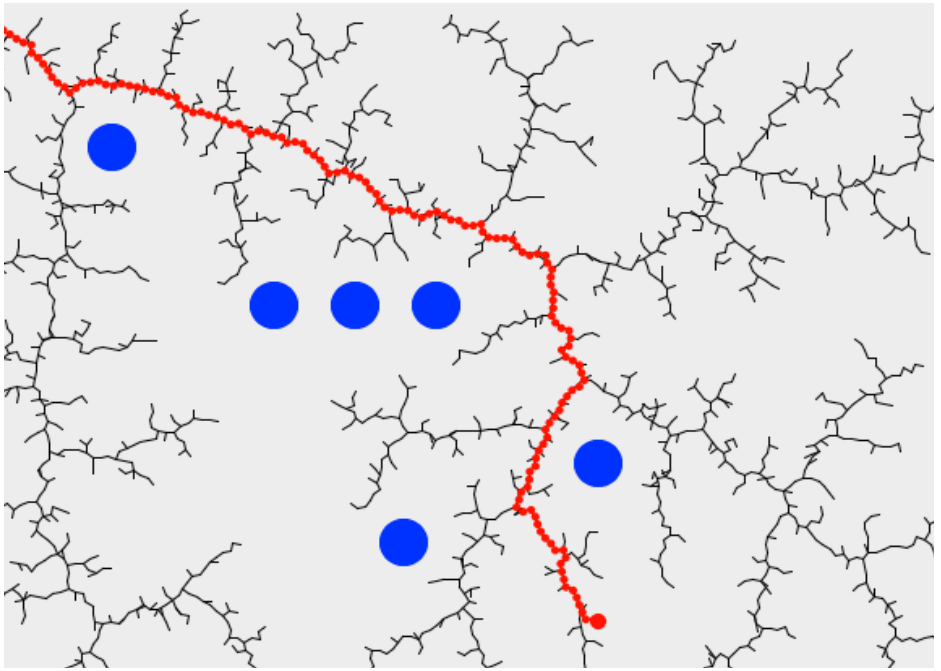


Motion Planning

Two main algorithms:

1. Probabilistic Road Maps (PRM)

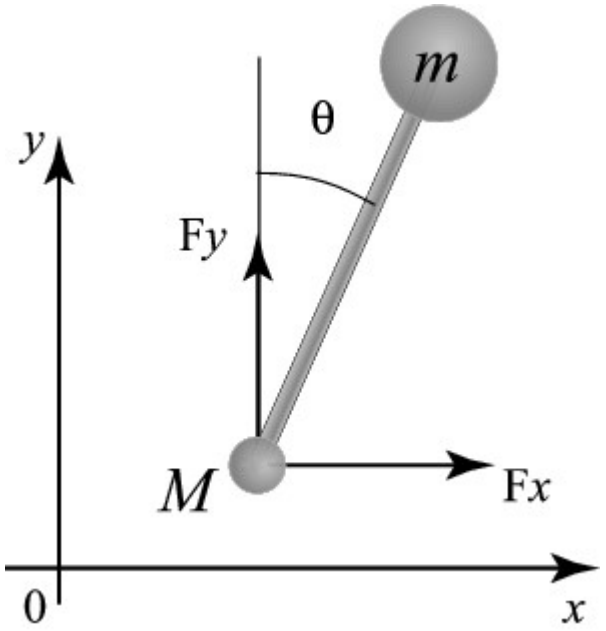
2. Rapidly Exploring Random Tree (RRT)

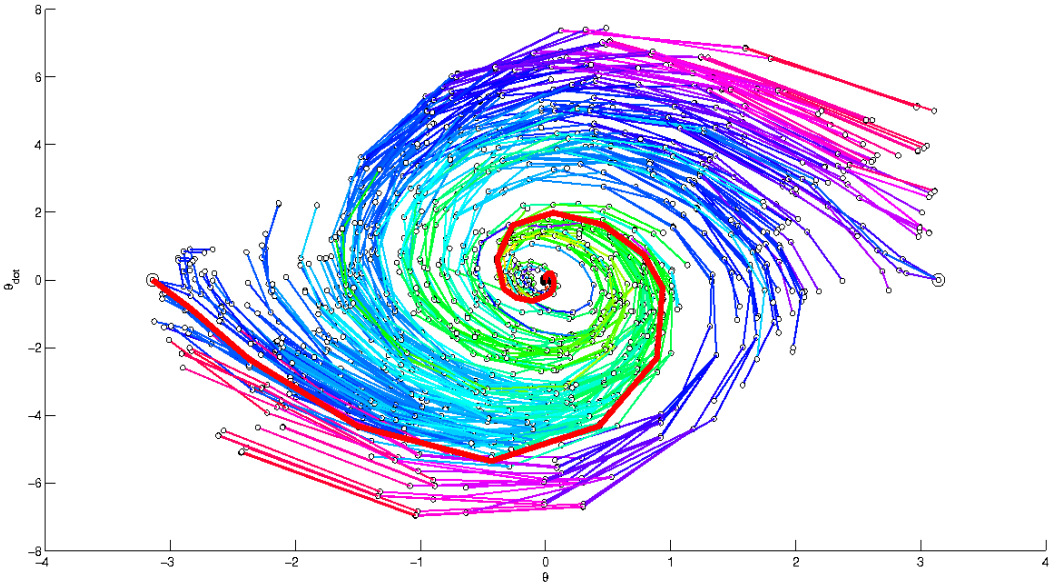


Motion Planning

Also kinodynamic applications:

- inverted pendulum

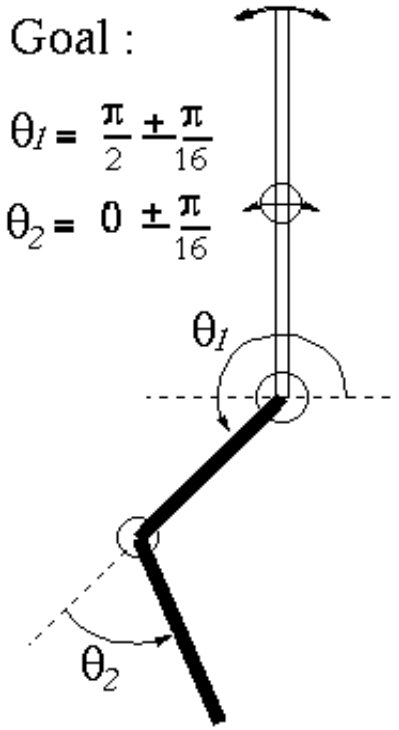




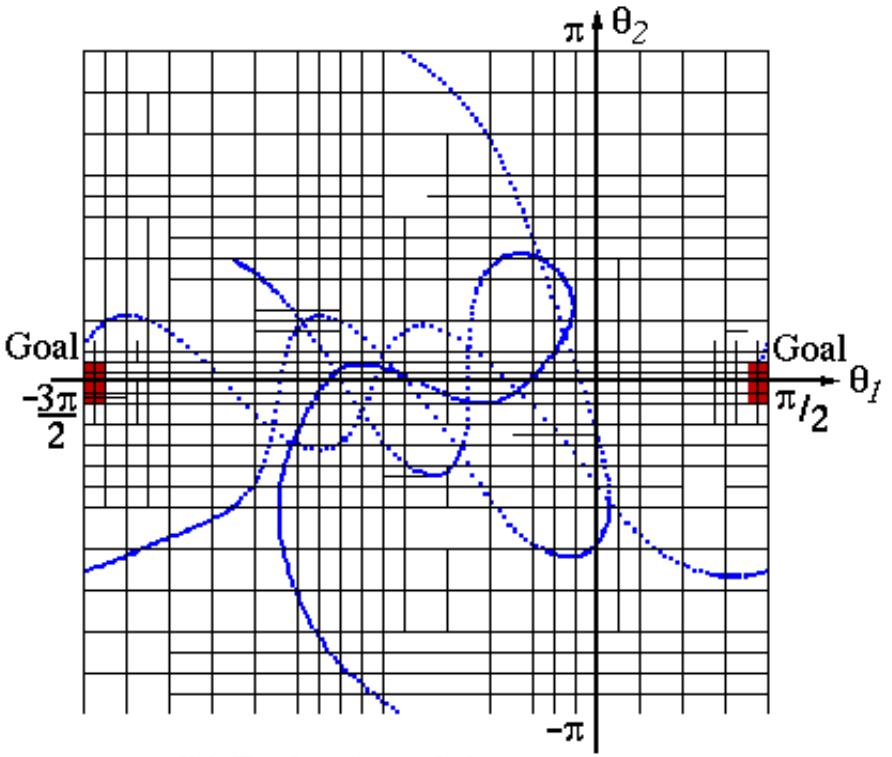
Motion Planning

Also kinodynamic applications:

- “Acrobot”



(a) The Acrobot



(b) Projection of the state space

Topics

2. Control

- Markov Decision Processes
- Value iteration, policy iteration
- continuous state spaces
- function approximation
- linear optimal control
- differential dynamic programming

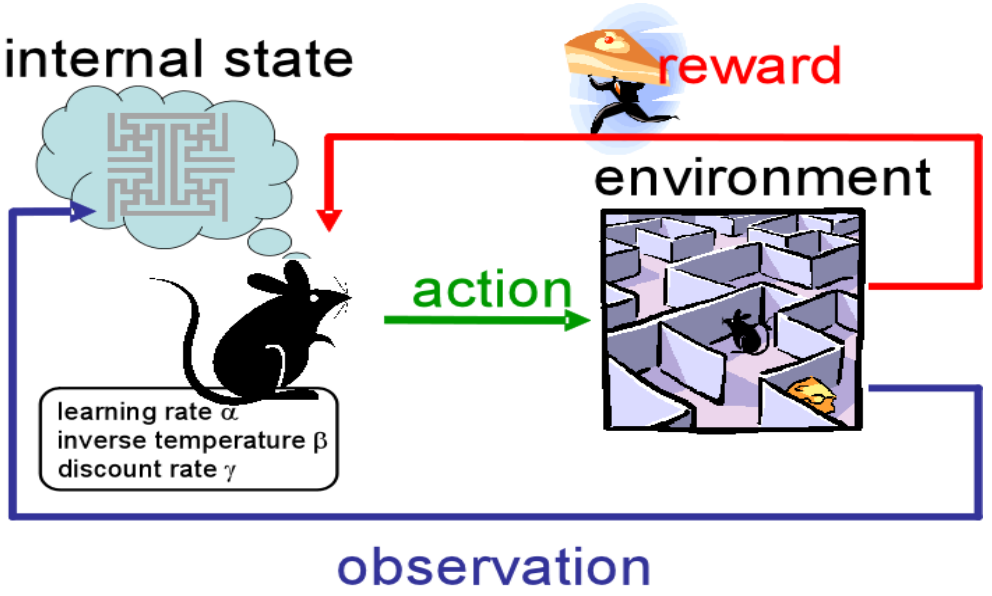
Reinforcement learning

Given: the ability to take actions

Given: the ability to perceive state exactly

Given: “rewards”

Objective: gradually calculate a policy for acting optimally with respect to the reward function.



Topics

3. Localization and mapping

- Bayes filtering
- particle filtering
- EKF, UKF, etc.
- Rao-blackwellization
- scan matching
- gMapping, EKF-SLAM, FastSLAM, etc.

Estimation: localization

Problem statement:

Given: noisy sensors that measure partial information

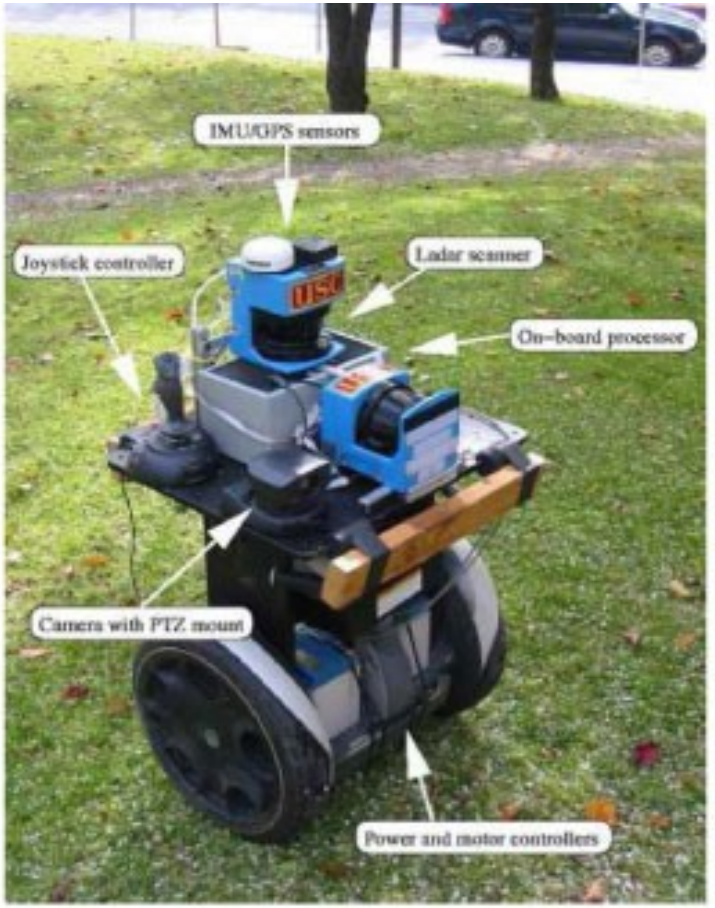
Given: a model of the system

Problem: estimate state

Estimation: localization

For example:

<u>Given:</u> mobile robot with laser scanners moving in an office building



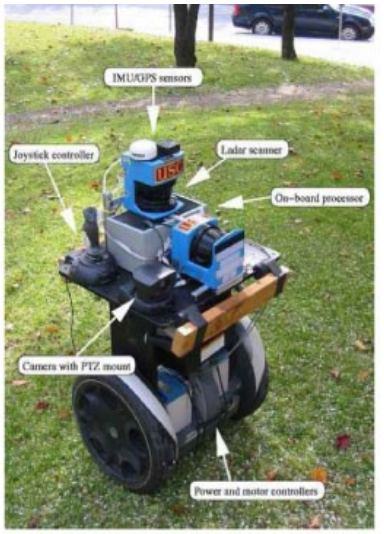
A Segway RMP equipped with laser range finders IMU.

Estimation: localization

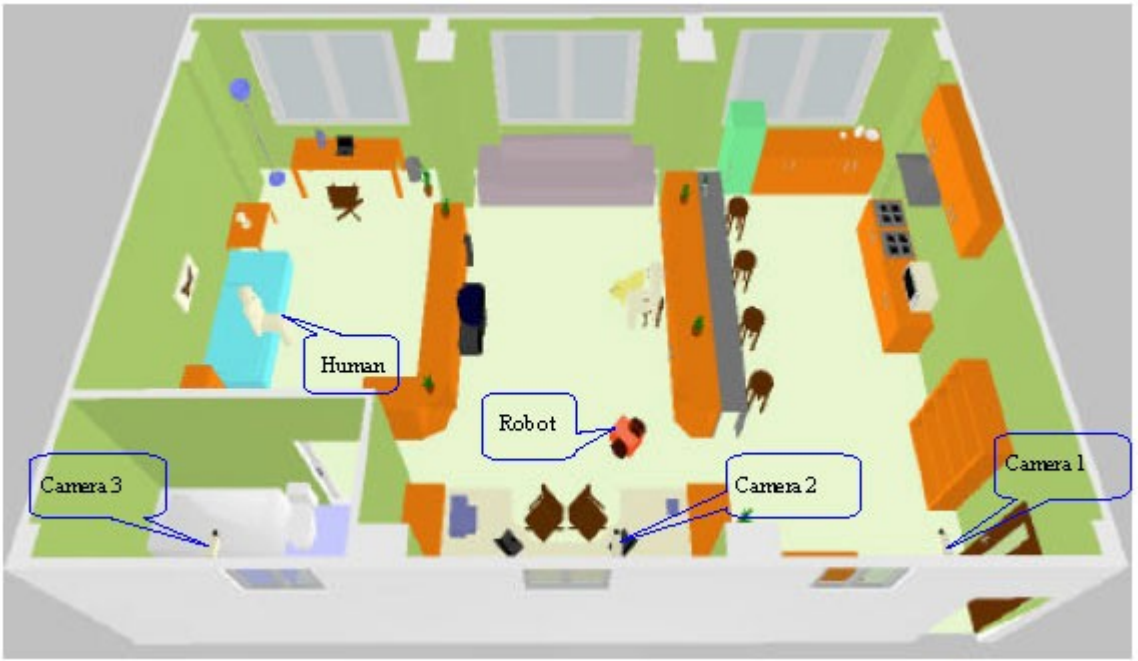
For example:

<u>Given:</u> mobile robot with laser scanners moving in an office building

<u>Given:</u> a map of the building, model of how wheels move



\ Segway RMP equipped with laser range finders IMU.



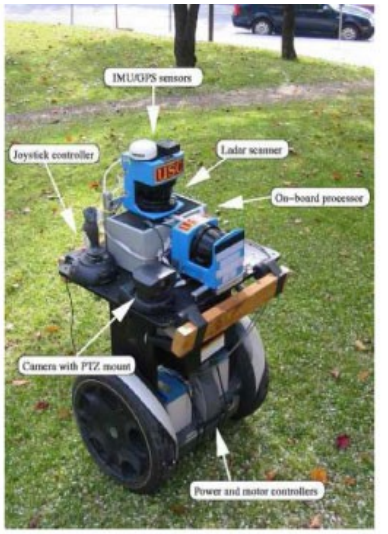
Estimation: localization

For example:

<u>Given:</u> mobile robot with laser scanners moving in an office building

<u>Given:</u> a map of the building, model of how wheels move

<u>Objective</u>: localize robot



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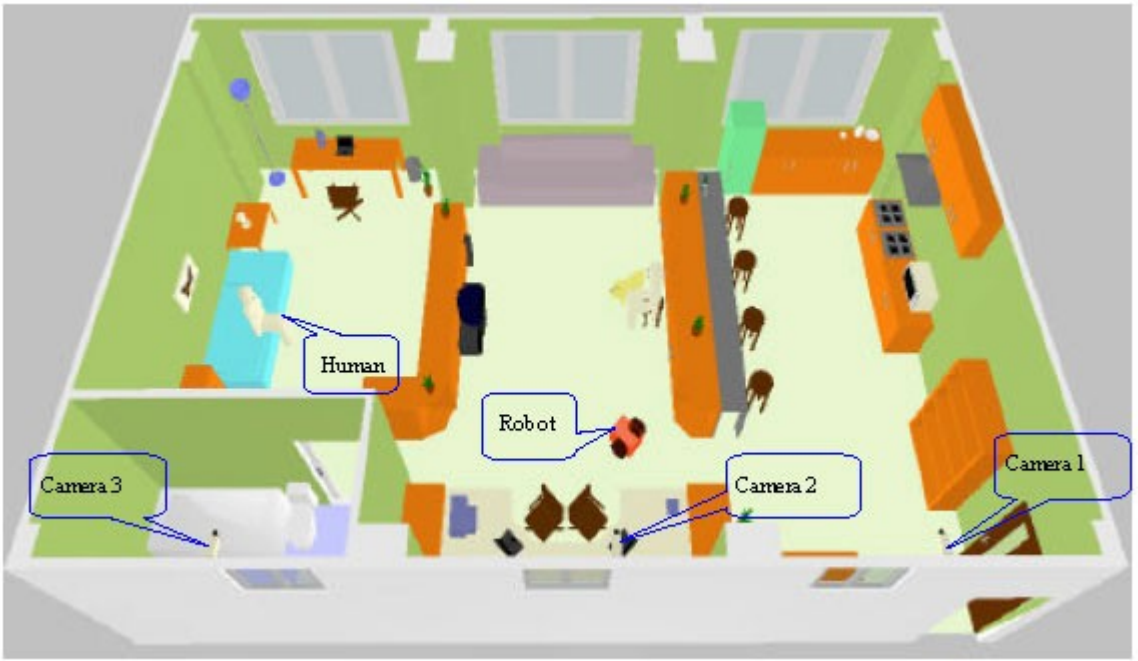


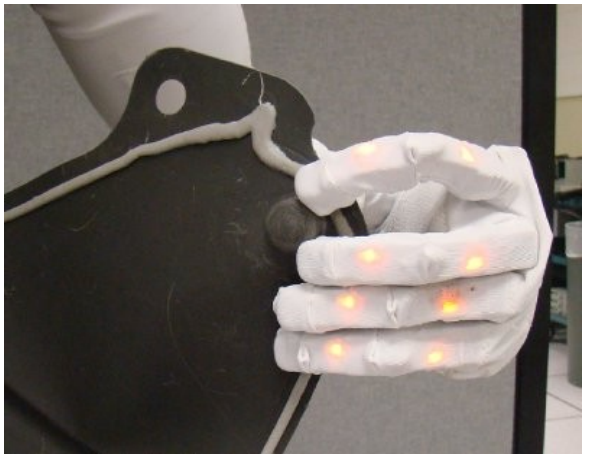
Estimation: localization

Potential algorithms: variants of Bayesian filtering:

1. Extended Kalman filter (EKF)
2. Unscented Kalman filter (UKF)
3. Ensemble Kalman filter
4. Histogram (Markov) filter
5. Particle filter
6. Others?

Potential applications:

1. mobile robot localization
2. localization of object held in hand
3. ?



Estimation: localization

Estimation: localization

Mapping

In principle, same as localization:

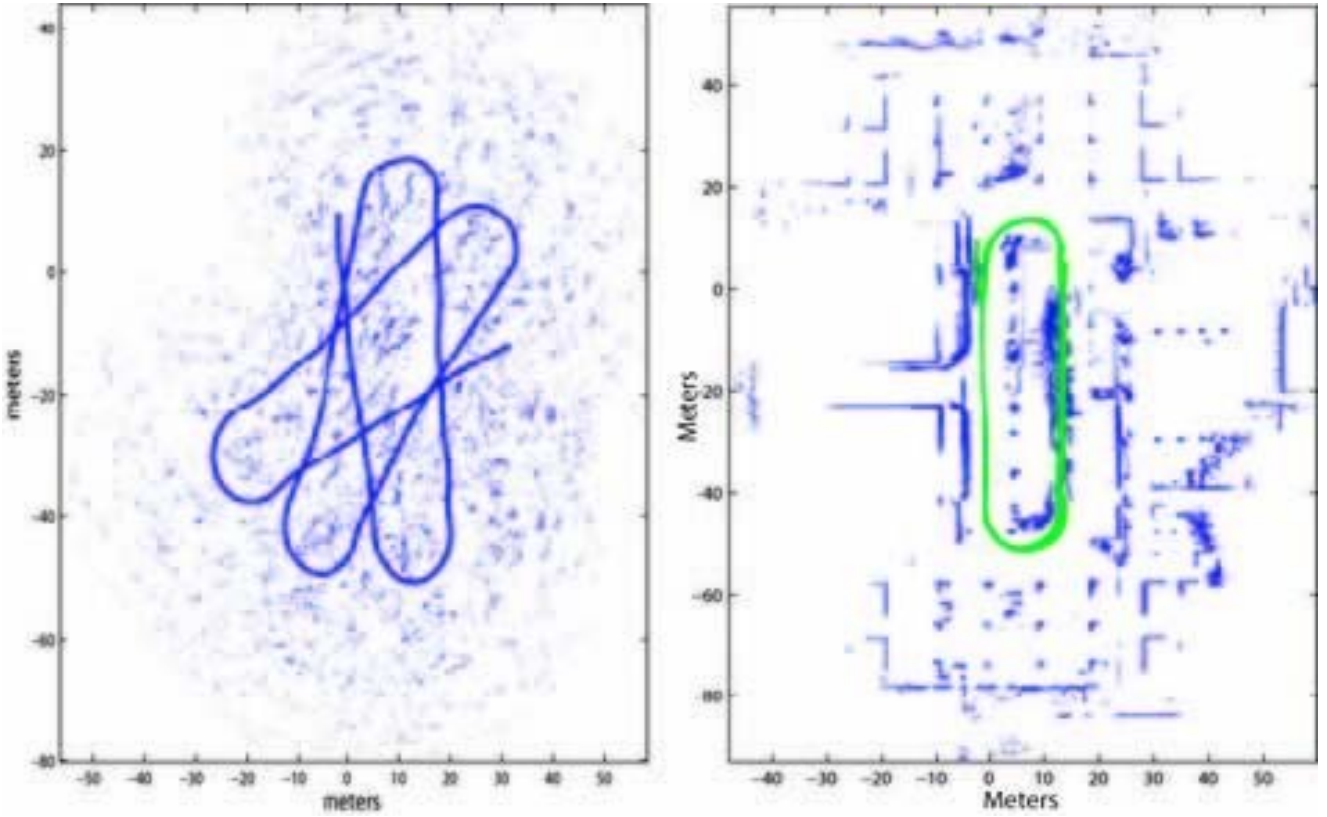
Given: mobile robot with laser scanners moving in an office building

Given: no map!

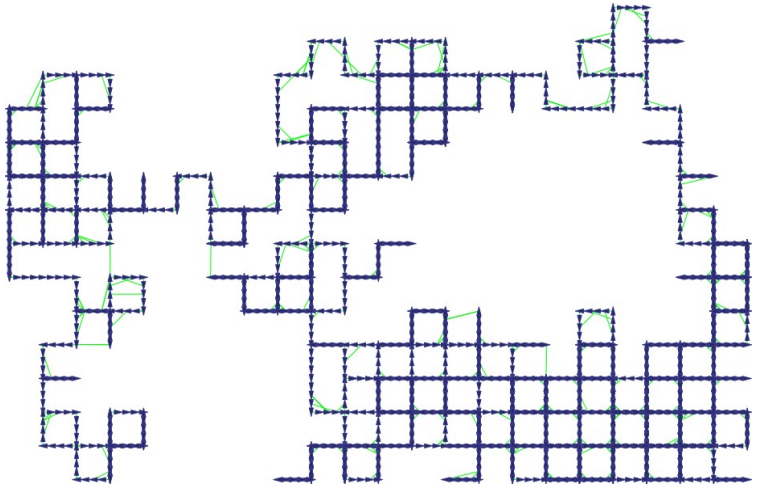
Objective: localize robot, estimate map

Algorithms:
- same as for localization
- new problem: high dimensionality of estimation problem
- other problems too...
- solutions: various tricks to deal w/ high dimensionality

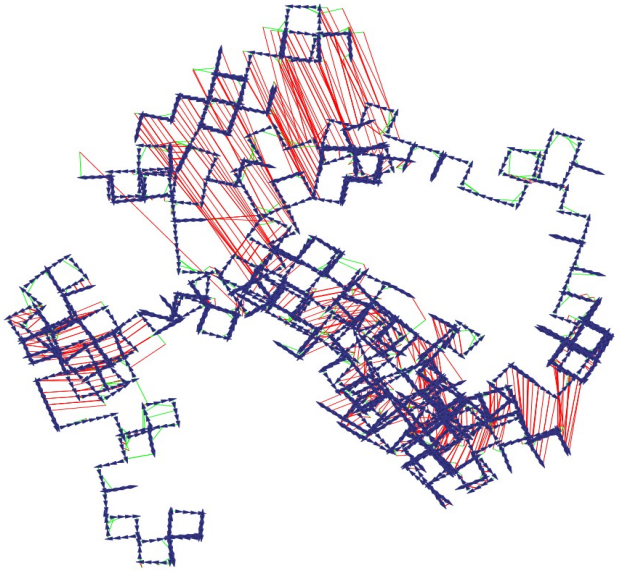
Mapping



Mapping

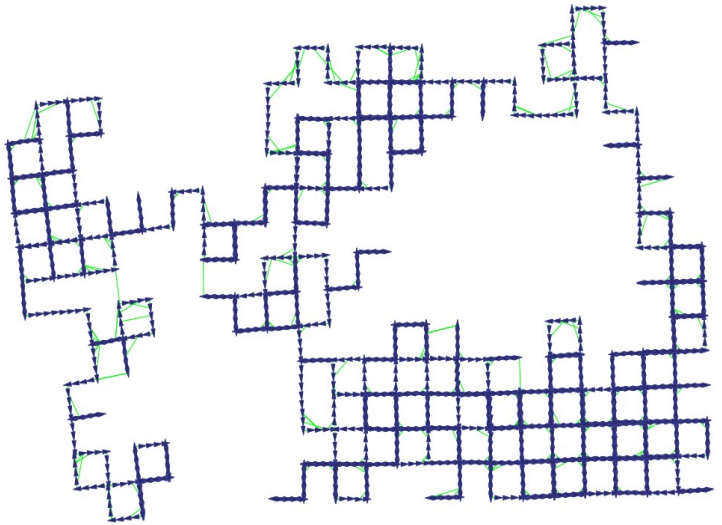


Ground truth



Odometry

Reconstructed



Topics

4. optimization in planning and control

- standard convex optimization problems
- model predictive control
- sequential quadratic programming
- semi-definite relaxations
- polynomial optimization, controller stability

Convex optimization

Model predictive control

1. Parameterize trajectory by a sequence of via points.
2. define cost function and dynamics constraints
3. solve the following optimization problem:

Minimize: cost function
Subject to: dynamics constraints

Under certain circumstances, this problem is convex...

Course Prerequisites

1. Ability to program in Matlab (of the ability to learn to do this)

2. Comfortable with linear algebra.

Reading material, notes

1. There is no single assigned text. I will assign papers and chapters as we go. This will be posted to my webpage.

2. I'll try to have my notes posted the day prior to lecture.

Course Requirements

1. Approximately four homework/lab assignments

2. Final exam
    - you can be tested on things that I say in class as well as what's in the notes and reading.