

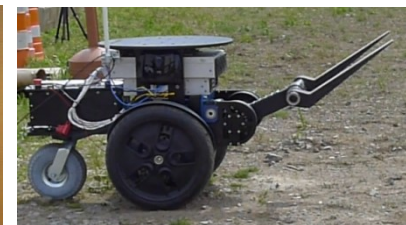
16-350 Spring'19
Planning Techniques for Robotics

Introduction;
What is Planning for Robotics?

Maxim Likhachev
Robotics Institute
Carnegie Mellon University

About Me

- My Research Interests:
 - Planning, Decision-making, Learning
 - Applications: planning for complex robotic systems including aerial and ground robots, manipulation platforms, small teams of heterogeneous robots
- More info: <http://www.cs.cmu.edu/~maxim>
- Search-based Planning Lab: <http://www.sbpl.net>



What is Planning?

- According to Wikipedia: “*Planning is the process of thinking about and organizing the activities required to achieve a desired goal.*”

What is Planning for Robotics?

- According to Wikipedia: *“Planning is the process of thinking about an organizing the activities required to achieve a desired goal.”*
- **Given**
 - model (states and actions) of the robot(s) $M^R = \langle S^R, A^R \rangle$
 - a model of the world M^W
 - current state of the robot $s_{current}^R$
 - current state of the world $s_{current}^W$
 - cost function C of robot actions
 - desired set of states for robot and world G
- **Compute a plan π that**
 - prescribes a set of actions a_1, \dots, a_K in A^R the robot should execute
 - reaches one of the desired states in G
 - (preferably) minimizes the cumulative cost of executing actions a_1, \dots, a_K

Few Examples

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Planning for omnidirectional robot:

What is M^R ?

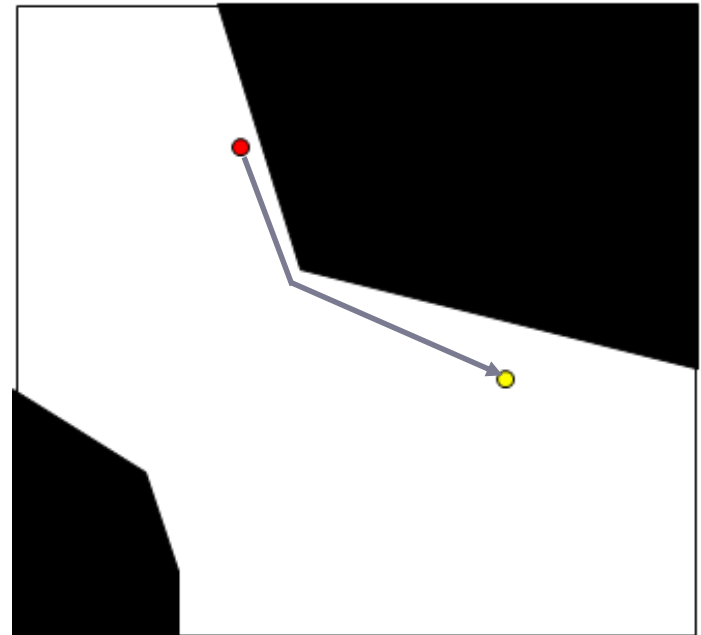
What is M^W ?

What is $s_{current}^R$?

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What is C ?

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Planning for omnidirectional drone:

What is M^R ?

What is M^W ?

What is $s_{current}^R$?

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MacAllister et al., 2013

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Planning for autonomous navigation:

What is M^R ?

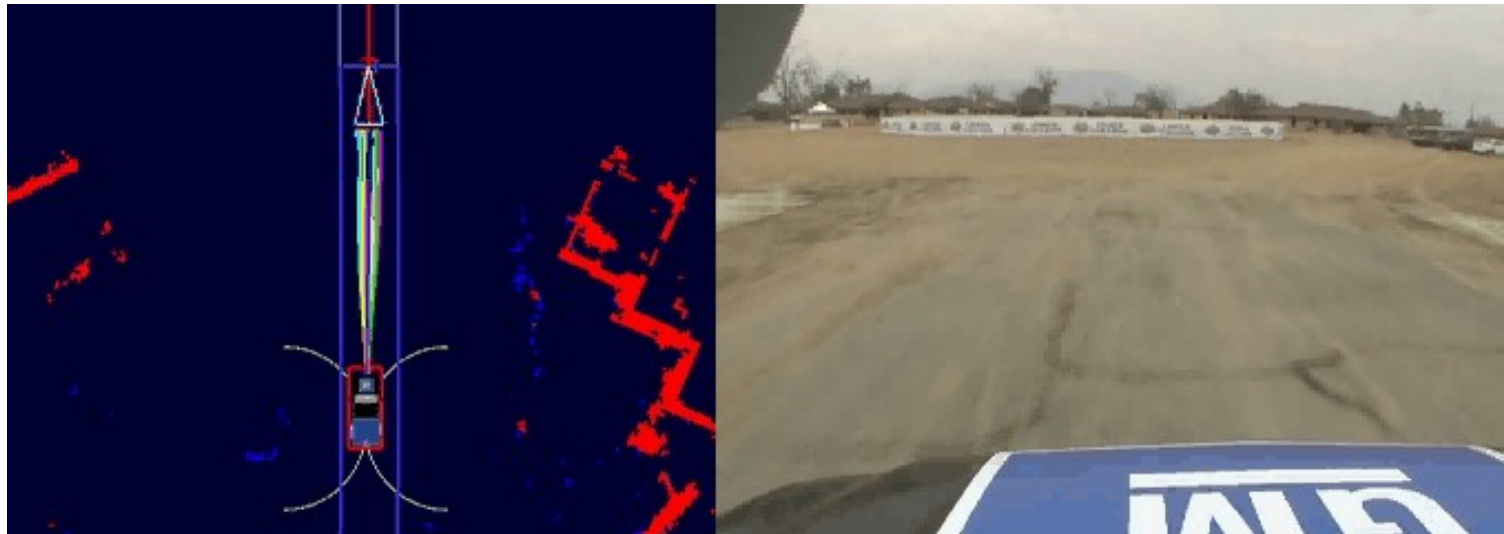
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Likhachev & Ferguson, '09; part of Tartanracing team from CMU for the Urban Challenge 2007 race

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Planning for autonomous flight among people :

Narayanan et al., 2012

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Planning for a mobile manipulator robot opening a door: Gray et al., 2013

What is M^R ?

What is M^W ?

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Planning for a mobile manipulator robot assembling a birdcage: Cohen et al., 2015

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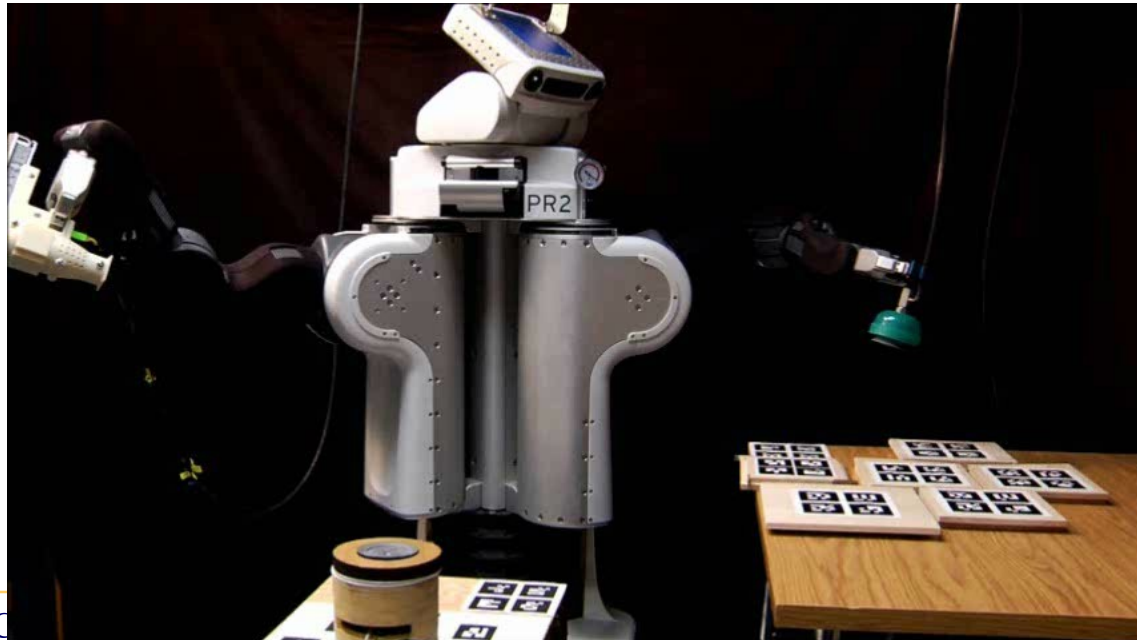
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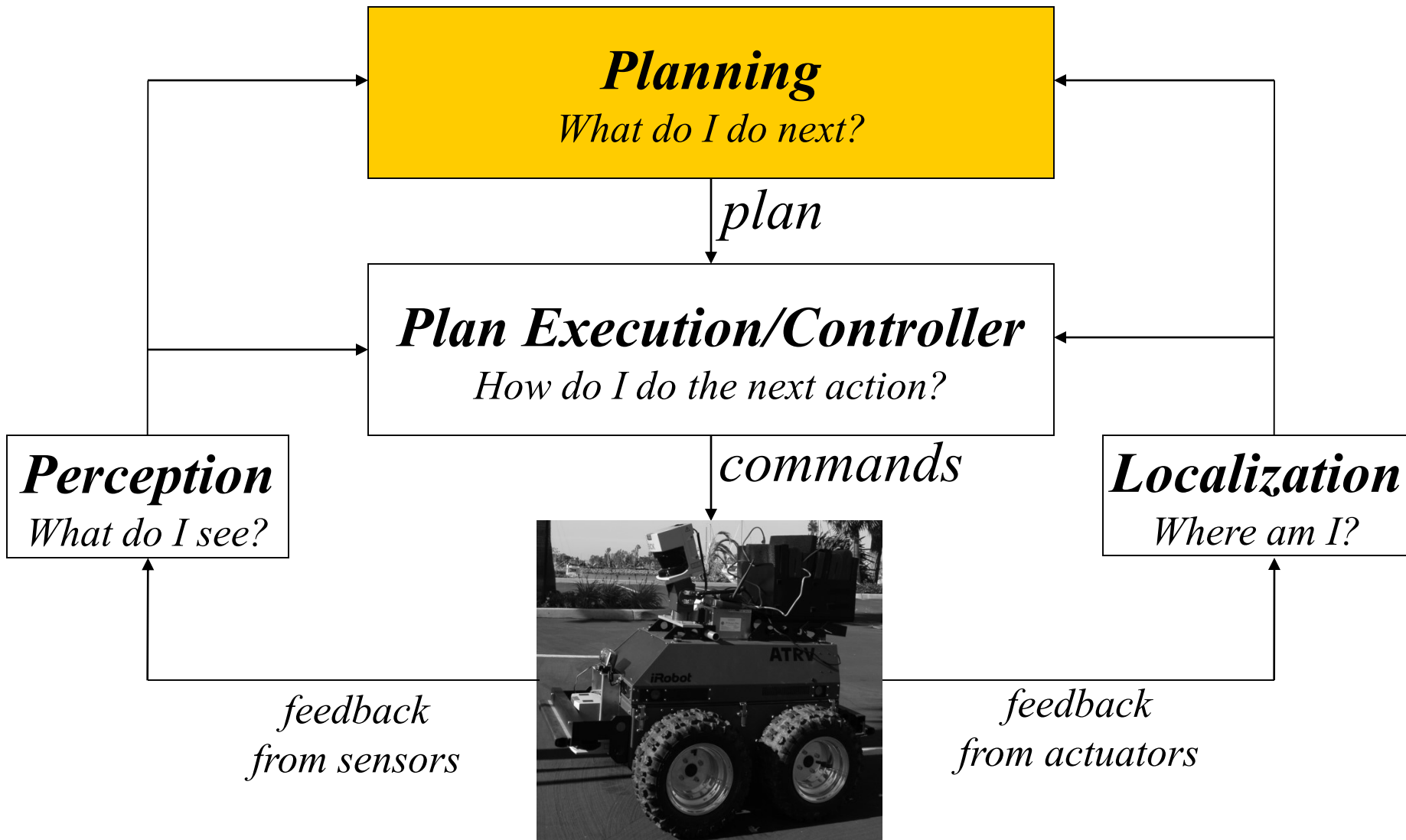
What is $s_{current}^W$?

What is C ?

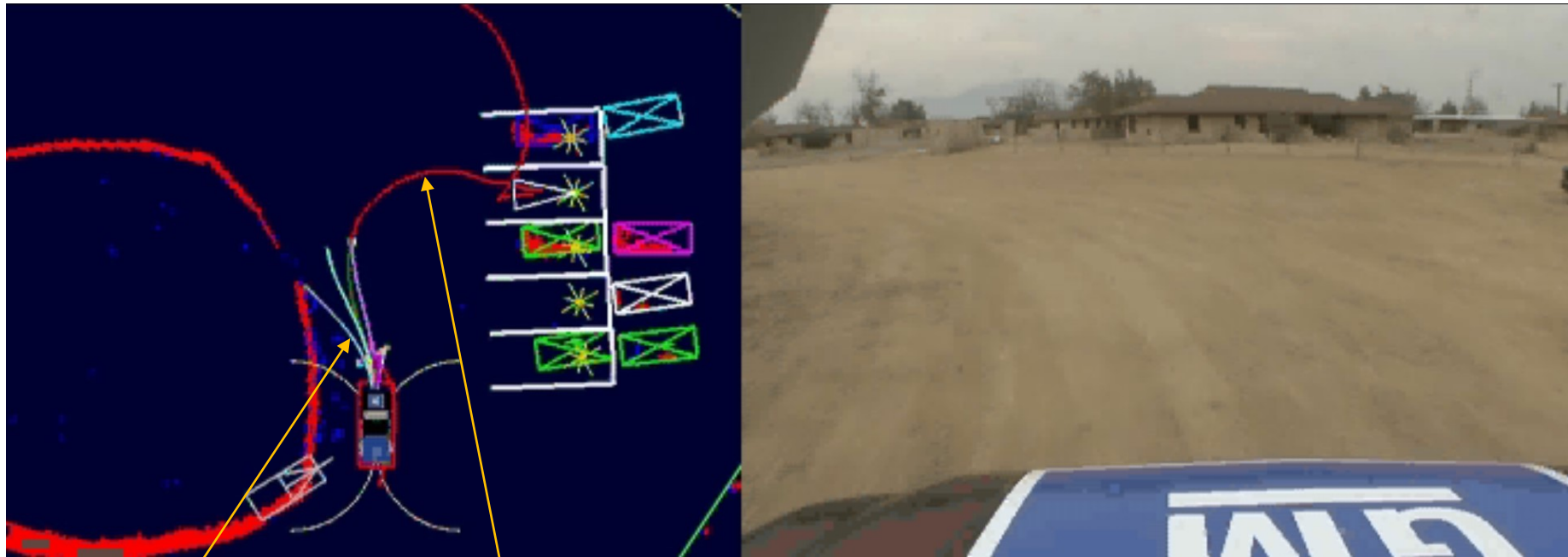
What is G ?



Planning within a Typical Autonomy Architecture

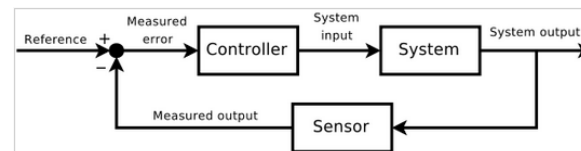


Planning vs. Trajectory Following vs. Control

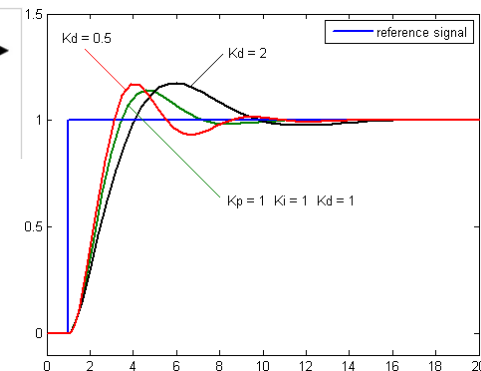


*local planning
(trajectory following)*

global planning



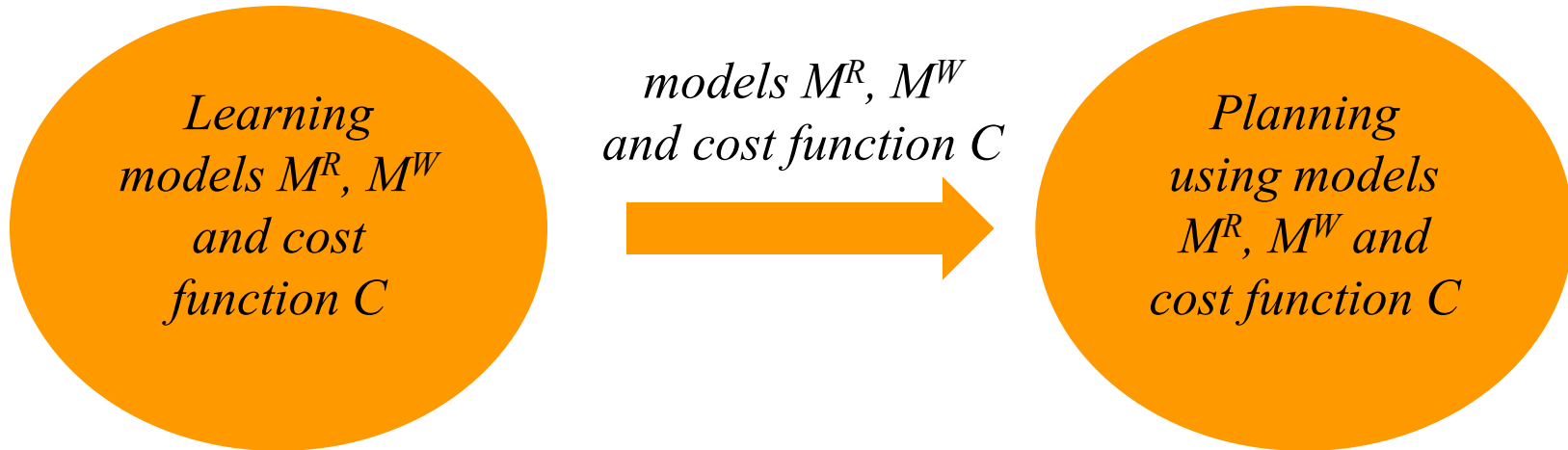
controller



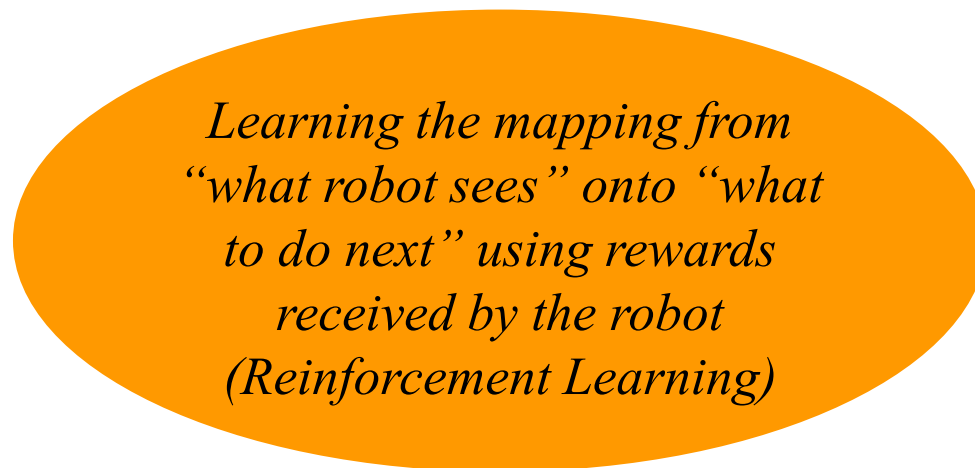
Images from wikipedia

Planning vs. Learning

Model-based approach



Model-free approach



Class Logistics

- Instructor:

Maxim Likhachev – maxim@cs.cmu.edu

- TA:

Shohin Mukherjee – shohinm@andrew.cmu.edu

- Website:

<http://www.cs.cmu.edu/~maxim/classes/robotplanning>

- Mailing List for Announcements and Questions:

Will be set it up shortly

Class Logistics

- Books (optional):
 - Planning Algorithms *by Steven M. LaValle*
 - Heuristic Search, Theory and Applications *by Stefan Edelkamp and Stefan Schroedl*
 - Principles of Robot Motion, Theory, Algorithms, and Implementations *by Howie Choset, Kevin M. Lynch, Seth Hutchinson, George A. Kantor, Wolfram Burgard, Lydia E. Kavraki and Sebastian Thrun*
 - Artificial Intelligence: A Modern Approach *by Stuart Russell and Peter Norvig*

Class Prerequisites

- Knowledge of programming (e.g., C, C++)
- Knowledge of data structures
- Some prior exposure to robotics (e.g., Intro to Robotics class) is preferred

Class Objectives

- Understand and learn how to implement most popular planning algorithms in robotics including heuristic search-based planning algorithms, sampling-based planning algorithms, task planning, planning under uncertainty and multi-robot planning
- Learn basic principles behind the design of planning representations
- Understand core theoretical principles that many planning algorithms rely on and learn how to analyze theoretical properties of the algorithms
- Understand the challenges and basic approaches to interleaving planning and execution in robotic systems
- Learn common uses of planning in robotics

Tentative Class Schedule

Date	Day	Topic	HW out	HW due
14-Jan	Mon	Introduction; What is Planning?		
16-Jan	Wed	planning representations: grid-based graphs		
21-Jan	Mon	MLK DAY - NO CLASS		
23-Jan	Wed	search algorithms: Uninformed A*		
28-Jan	Mon	search algorithms: A*	HW1	
30-Jan	Wed	heuristics, weighted A*, Backward A*		
4-Feb	Mon	interleaving planning and execution: Anytime heuristic search		
6-Feb	Wed	interleaving planning and execution: Freespace assumption, Incremental heuristic search		
11-Feb	Mon	interleaving planning and execution: Limited Horizon search, LRTA*		
13-Feb	Wed	planning representations: lattice-based graphs, explicit vs. implicit graphs		HW1
18-Feb	Mon	case study: planning for autonomous driving	HW2	
20-Feb	Wed	planning representations: PRM for continuous spaces		
25-Feb	Mon	planning representations/search algorithms: RRT, RRT-Connect		
27-Feb	Wed	case study: planning for mobile manipulation and articulated robots		
4-Mar	Mon	search algorithms: IDA*, Beam Search, Multi-goal A*		
6-Mar	Wed	case study: planning for exploration and surveillance tasks		HW2
11-Mar	Mon	SPRING BREAK - NO CLASS		
13-Mar	Wed	SPRING BREAK - NO CLASS		
18-Mar	Mon	search algorithms: Markov Property, dependent vs. independent variables, Dominant Relationship		
20-Mar	Wed	planning representations: state-space vs. symbolic representation for task planning	HW3	
25-Mar	Mon	search algorithms: symbolic task planning algorithms		
27-Mar	Wed	final project proposal presentations		
1-Apr	Mon	planning under uncertainty: Minimax formulation		
3-Apr	Wed	planning under uncertainty: Expected Cost Minimization formulation		HW3
8-Apr	Mon	planning under uncertainty: Solving Markov Decision Processes		
10-Apr	Wed	planning under uncertainty: Solving Markov Decision Processes (cont'd)		
15-Apr	Mon	TBD		
17-Apr	Wed	exam review		
22-Apr	Mon	exam		
24-Apr	Wed	multi-robot planning: centralized planning		
29-Apr	Mon	multi-robot planning: decentralized planning		
1-May	Wed	final project presentations		

Three Homeworks + Final Project

- All homeworks and the final project are individual (no groups)
- Homeworks are programming assignments
- Final project is a research-like project. For example:
 - to develop and implement a planner for a robot planning problem of your choice
 - to extend a particular planning algorithm to improve its running time or to handle additional conditions
 - to prove novel properties of a planning algorithm
 - Get a feel for doing research: Individual meetings, Two class presentations (initial idea and final)

Class Structure

- Grading

Three homeworks	33%
Exam	20%
In-class pop quizzes	10%
Final project	32%
Participation	5%

- Exam is tentatively scheduled for April 22 (no final exam)
- Late Policy
 - 3 free late days
 - No late days may be used for the final project!
 - Each additional late day will incur a 10% penalty

Questions about the class?