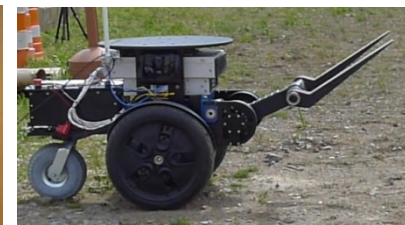


About Me

- 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 an organizing the activities required to achieve a desired goal.”*
- *Given*
 - *model (states and actions) of the agent(s) $M^a = \langle S^a, A^a \rangle$*
 - *a model of the world M^w*
 - *belief b_c^a of the agent about its current state*
 - *belief b_c^w of the agent about the current state of the world*
 - *belief of the agent over the cost function C of its actions*
 - *desired set of states for agent and world G*
- *Compute a plan π that:*
 - *maps one or more belief tuples $\langle b^a, b^w \rangle$ onto actions a in A^a*
 - *reaches one of the desired states in G*

Few Examples

- **Given**

- model (states and actions) of the agent(s) $M^a = \langle S^a, A^a \rangle$
- a model of the world M^w
- belief b_c^a of the agent about its current state
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- **Compute a plan π that:**

- maps one or more belief tuples $\langle b^a, b^w \rangle$ onto actions a in A^a
- reaches one of the desired states in G

2D path planning for omnidirectional robot:

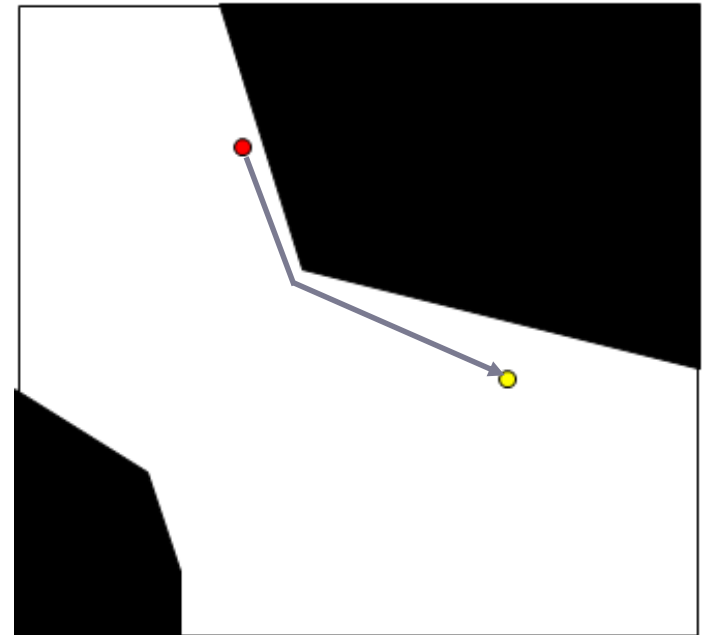
What is M^a ?

What is b_c^a ?

What is b_c^w ?

What is C ?

What is G ?



Few Examples

- **Given**

- model (states and actions) of the agent(s) $M^a = \langle S^a, A^a \rangle$
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- **Compute a plan π that:**

- maps one or more belief tuples $\langle b^a, b^w \rangle$ onto actions a in A^a
- reaches one of the desired states in G

4D (x,y,heading,velocity) path planning for autonomous navigation:

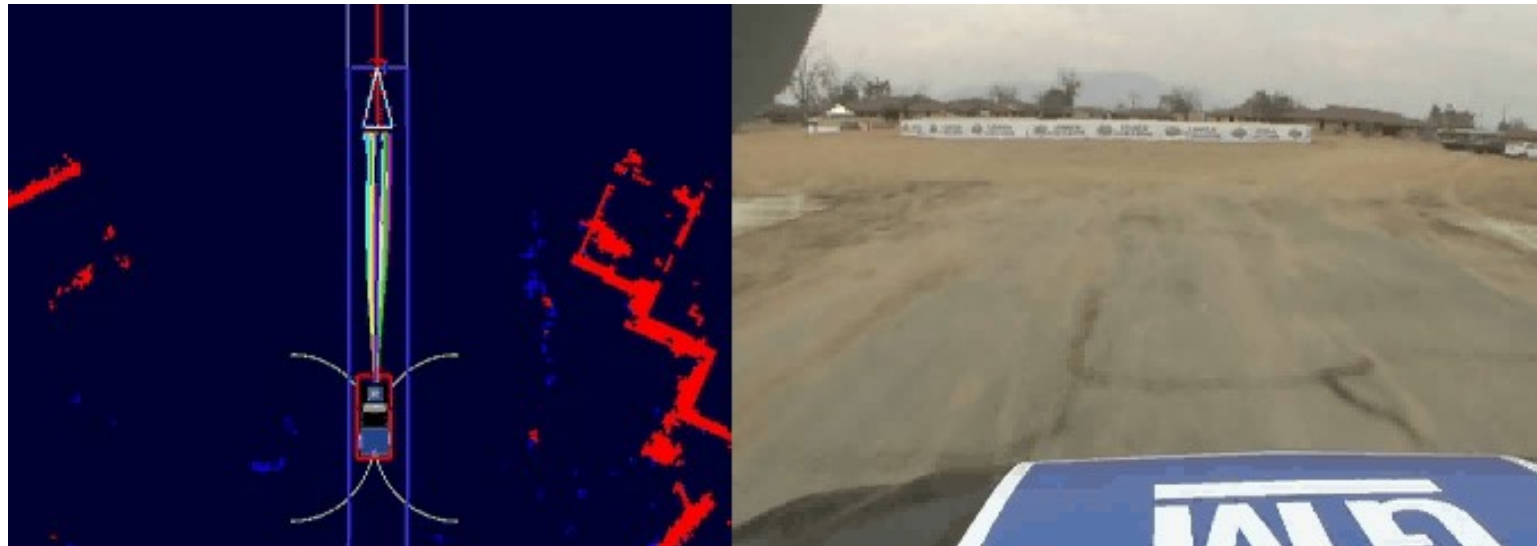
What is M^a ?

What is b_c^a ?

What is b_c^w ?

What is C ?

What is G ?



part of efforts by Tartanracing team from CMU for the Urban Challenge 2007 race

Few Examples

- **Given**

- model (states and actions) of the agent(s) $M^a = \langle S^a, A^a \rangle$
- a model of the world M^w
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- belief of the agent over the cost function C of its actions
- desired set of states for agent and world G

- **Compute a plan π that:**

- maps one or more belief tuples $\langle b^a, b^w \rangle$ onto actions a in A^a
- reaches one of the desired states in G

5D (x,y,z,heading,time) path planning for autonomous flight among people :

What is M^a ?

What is b_c^a ?

What is b_c^w ?

What is C ?

What is G ?



Few Examples

- **Given**

- model (states and actions) of the agent(s) $M^a = \langle S^a, A^a \rangle$
- a model of the world M^w
- belief b_c^a of the agent about its current state
- belief b_c^w of the agent about the current state of the world
- belief of the agent over the cost function C of its actions
- desired set of states for agent and world G

- **Compute a plan π that:**

- maps one or more belief tuples $\langle b^a, b^w \rangle$ onto actions a in A^a
- reaches one of the desired states in G

Motion planning for a mobile manipulator PR2 opening a door:

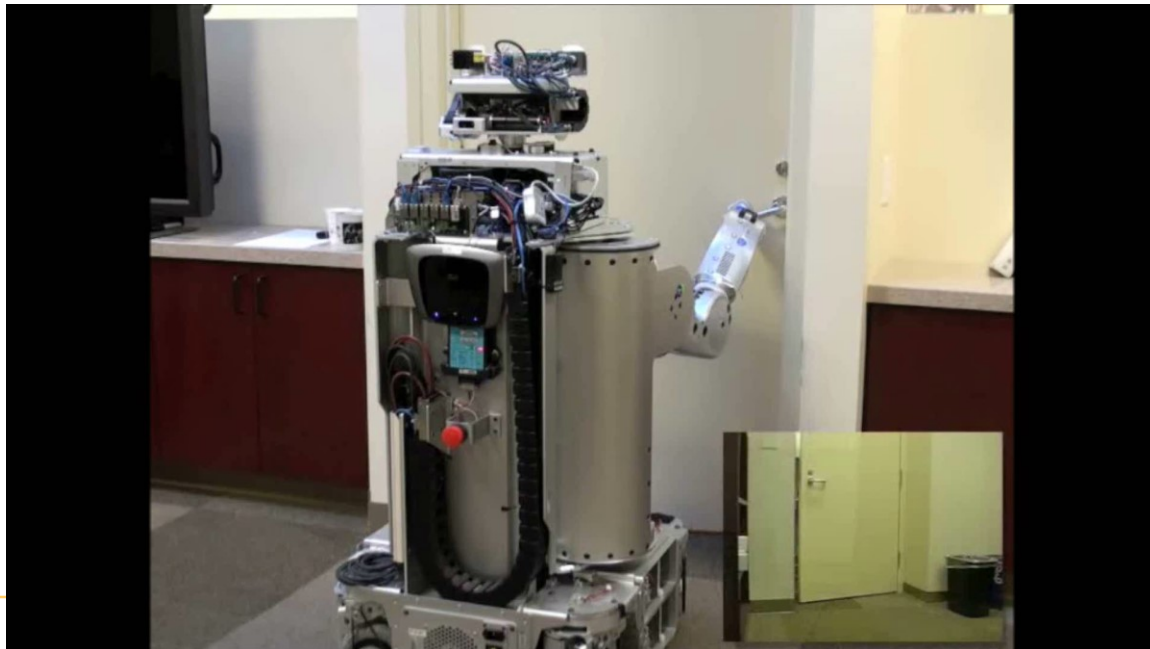
What is M^a ?

What is b_c^a ?

What is b_c^w ?

What is C ?

What is G ?



Few Examples

TRAVELWITS

Pittsburgh International Airport, PA (PIT) Florence, Italy 09/09/2016 1 Adult All Options [SEARCH](#)

CREATE PRICE ALERTS: [Sign up](#)

TRANSPORTATION OPTIONS: ☒ plane ☒ car ☒ bus ☒ train ☒ ferry

COST CALCULATION:
☒ Include parking cost into total cost
☒ Include gas cost into total cost

FILTERS:
 Maximum driving before flight
 84 miles - 322 miles
 Maximum driving after flight
 51 miles - 313 miles
 Total trip time
 11h 26min - 1 days 14h 11min
 Outbound take-off
 05:45AM - 11:05PM
 Flight stops
☒ nonstop
☒ 1 stop

RECOMMENDED TRAVEL OPTIONS (SHOWING 2 OPTIONS): SORT BY: Total Travel Time Total Cost

Cheapest option

Pittsburgh, PA (PIT) → Toronto, Canada (YYZ) → Florence, Italy (FLR)
 5h 34min
 \$51.00 gas
 \$519.53
 1 stop
 Total Cost From \$570.53
 One Way, Per Passenger
 Outbound Travel: 18h 46min
[MORE INFO](#)

Quickest option

Pittsburgh, PA (PIT) → Florence, Italy (FLR)
 11h 26min
 \$3,079.68
 1 stop
 Total Cost From \$3,079.68
 One Way, Per Passenger
 Outbound Travel: 11h 26min
[MORE INFO](#)

ALL OTHER OPTIONS (SHOWING 50 OPTIONS):

Pittsburgh, PA (PIT) → Washington, DC (DCA) → Pisa, Italy (PSA) → Florence
 4h 33min
 \$41.00 gas
 \$684.58
 1 stop
 1h 34min
 \$6.00 One Way
 Total Cost From \$731.58
 One Way, Per Passenger
 Outbound Travel: 17h 07min
[MORE INFO](#)

Pittsburgh, PA (PIT) → Washington, DC (DCA) → Pisa, Italy (PSA) → Florence S.M.N.
 4h 33min
 \$41.00 gas
 \$684.58
 1 stop
 57min
 \$6.00 One Way
 Total Cost From \$731.58
 One Way, Per Passenger
 Outbound Travel: 17h
[MORE INFO](#)

Pittsburgh, PA (PIT) → Baltimore, MD (BWI) → Pisa, Italy (PSA) → Florence
 4h 36min
 \$42.00 gas
 \$684.58
 1 stop
 1h 34min
 \$6.00 One Way
 Total Cost From \$732.58
 One Way, Per Passenger
 Outbound Travel: 21h 16min
[MORE INFO](#)

MAP VIEW:

 HOW WOULD YOU RATE YOUR EXPERIENCE?
 Great Okay Poor
[Feedback](#)

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Planning a travel from Pittsburgh, PA to Florence, Italy:

What is M^a ?

What is b_c^a ?

What is b_c^w ?

What is C ?

What is G ?

Example of Planning under Uncertainty

- **Given**

- model (states and actions) of the agent(s) $M^a = \langle S^a, A^a \rangle$
- a model of the world M^w
- belief b_c^a of the agent about its current state
- belief b_c^w of the agent about the current state of the world
- belief of the agent over the cost function C of its actions
- desired set of states for agent and world G

- **Compute a plan π that:**

- maps one or more belief tuples $\langle b^a, b^w \rangle$ onto actions a in A^a
- reaches one of the desired states in G

Planning for navigation under uncertainty in traversability:

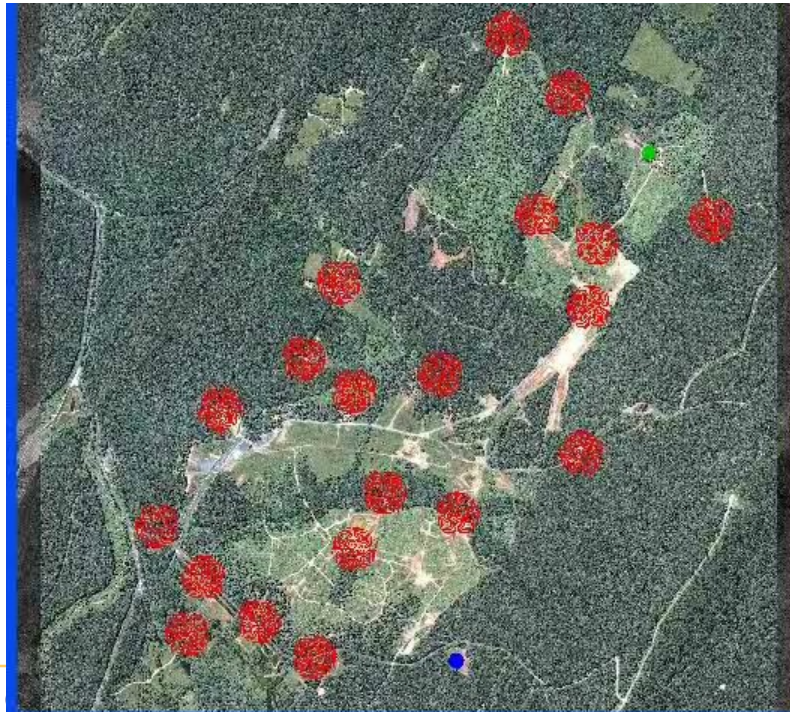
What is M^a ?

What is b_c^a ?

What is b_c^w ?

What is C ?

What is G ?



Continuous vs. Discrete vs. Hybrid Model

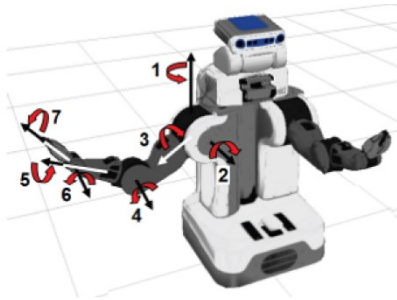
- **Given**

- model (states and actions) of the agent(s) $M^a = \langle S^a, A^a \rangle$
- a model of the world M^w
- belief b_c^a of the agent about its current state
- belief b_c^w of the agent about the current state of the world
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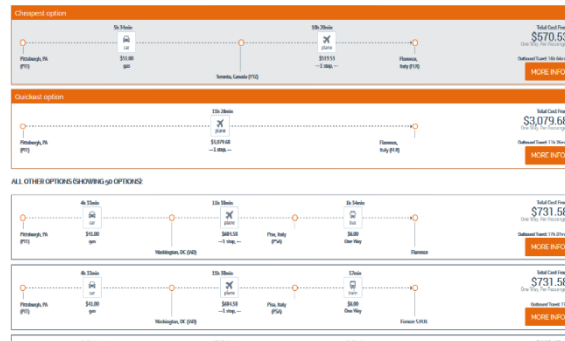
- **Compute a plan π that:**

- maps one or more belief tuples $\langle b^a, b^w \rangle$ onto actions a in A^a
- reaches one of the desired states in G

continuous



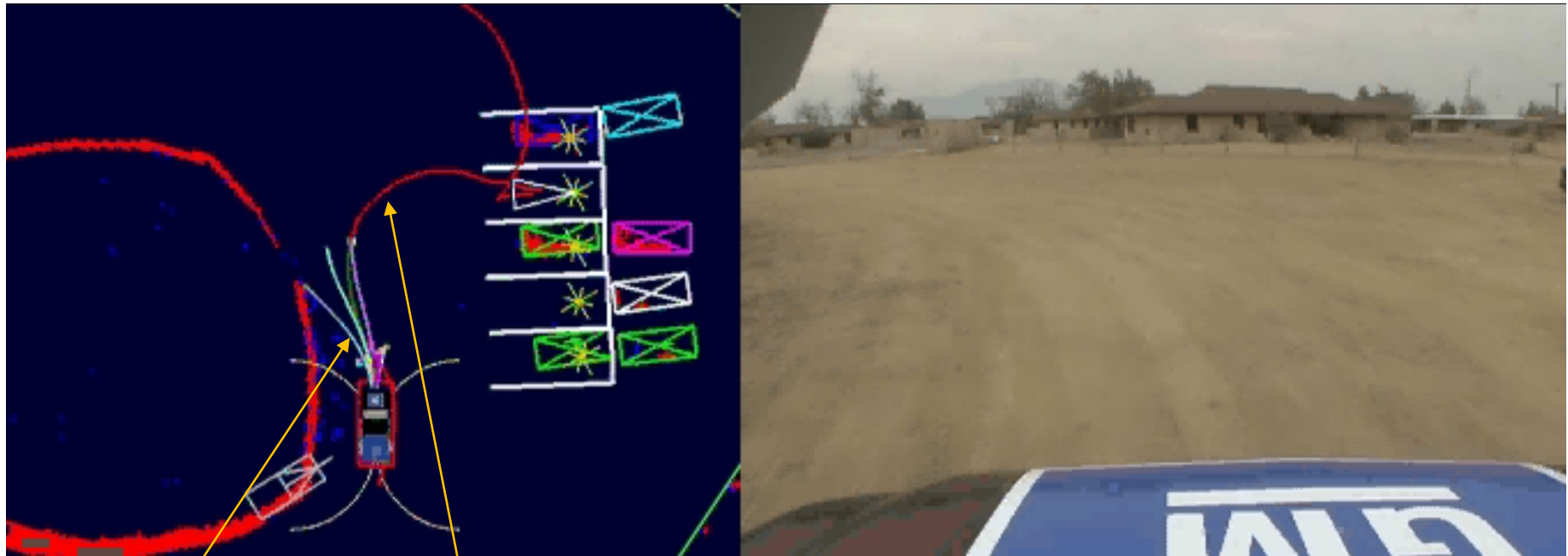
discrete



hybrid

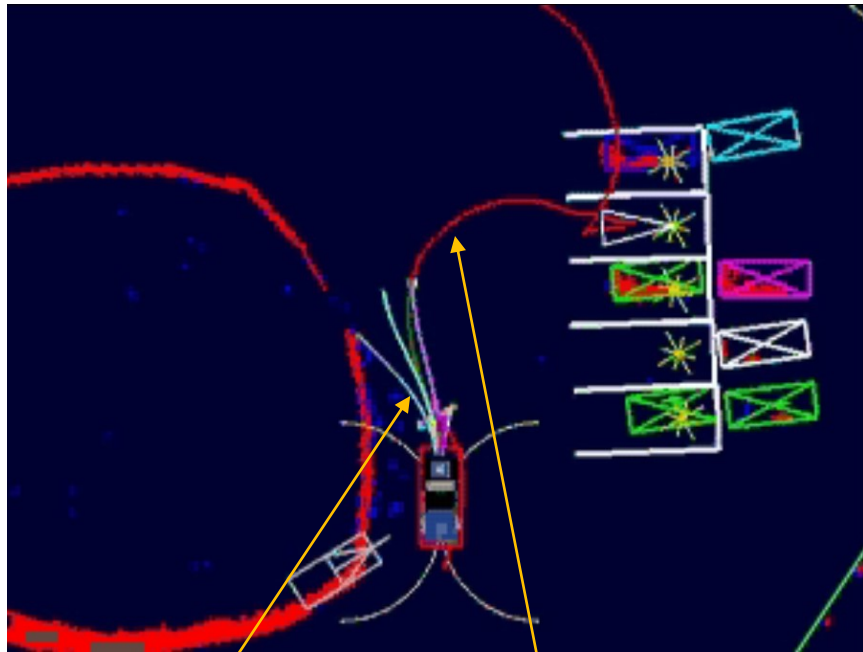


Global vs. Local Planning



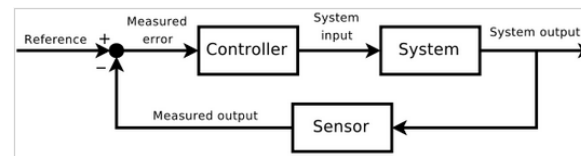
local planning *global planning*

Planning vs. Control

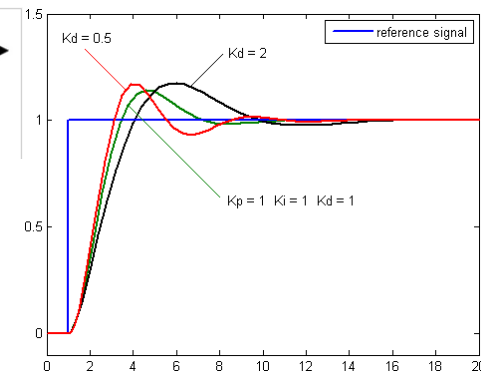


local planning

global planning



controller



Images from wikipedia

Some of the topics covered in class

- Methods for constructing models
- Methods for efficient planning on these models
- Interleaving planning and execution
- Improving planning via learning