Planning for Symbiotic Robot Autonomy

Manuela M. Veloso

Carnegie Mellon University

Computer Science Department

(and Robotics Institute, Machine Learning, ECE, and MechE Departments)

www.cs.cmu.edu/~mmv

NSF Workshop on Robot Planning in the Real World

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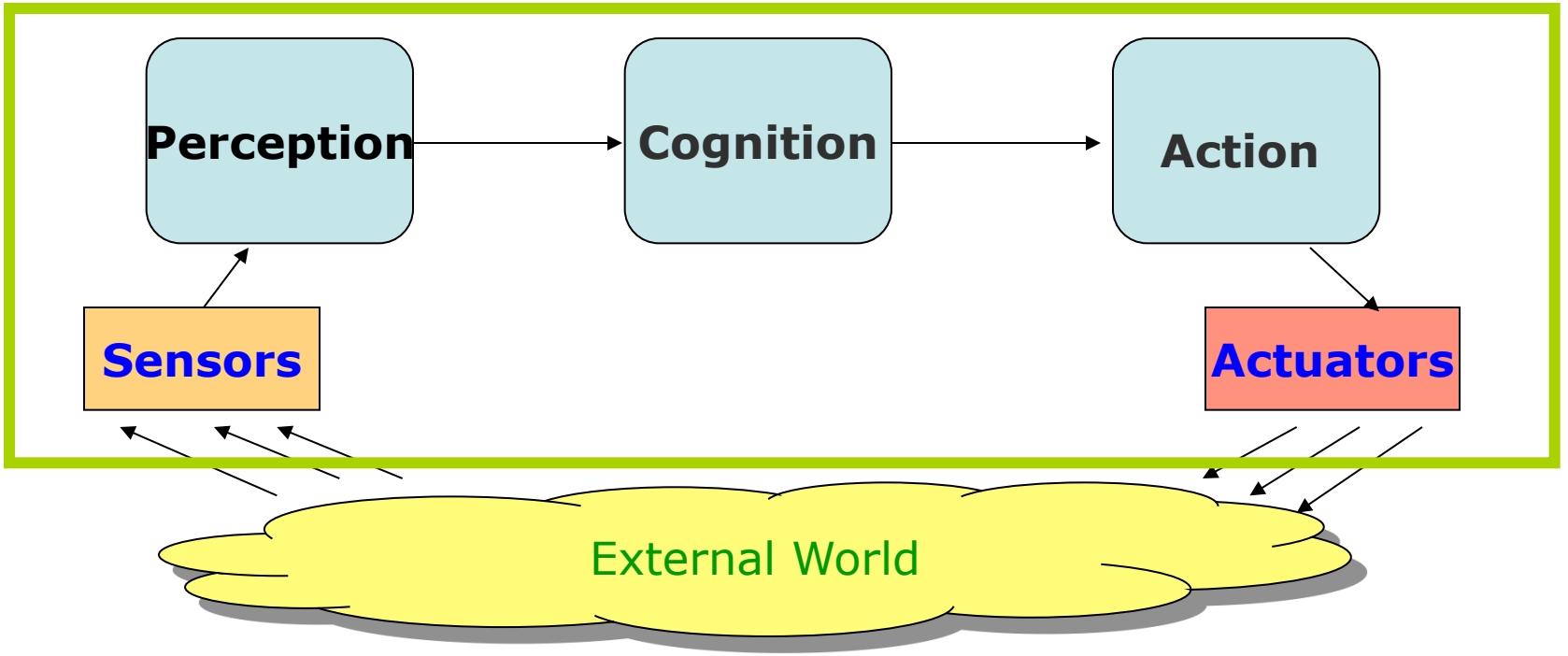
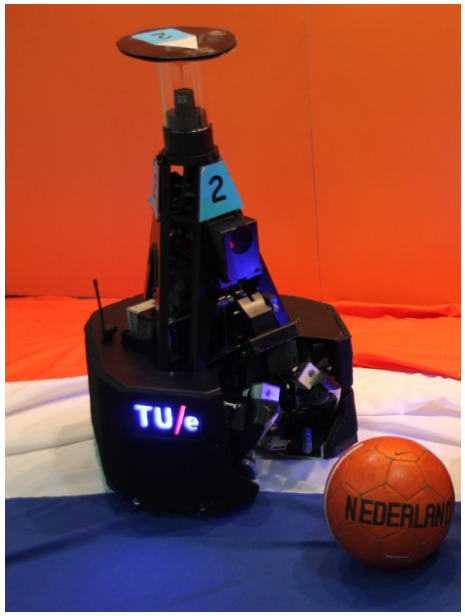
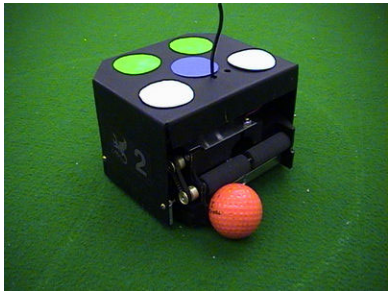
Artificial Intelligence and Robotics
The Quest for Autonomous Intelligent Robots

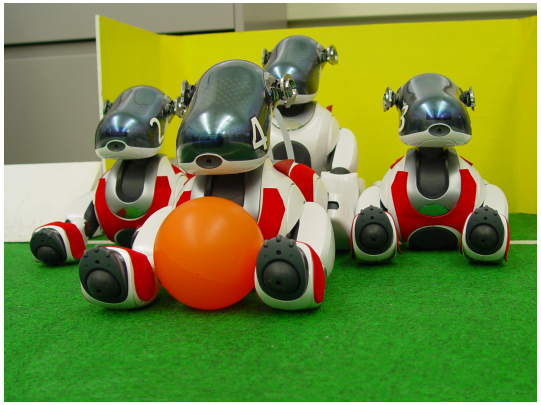


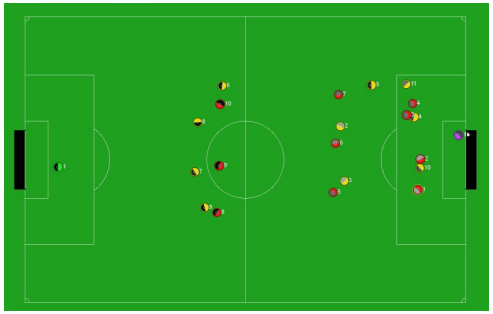
- Perception: Processing, understanding of sensory data
- Cognition: Knowledge representation, planning, learning
- Action: Motion, manipulation, speech

RoboCup Soccer: "*By 2050, a team of robots will beat the World Cup human champions*"





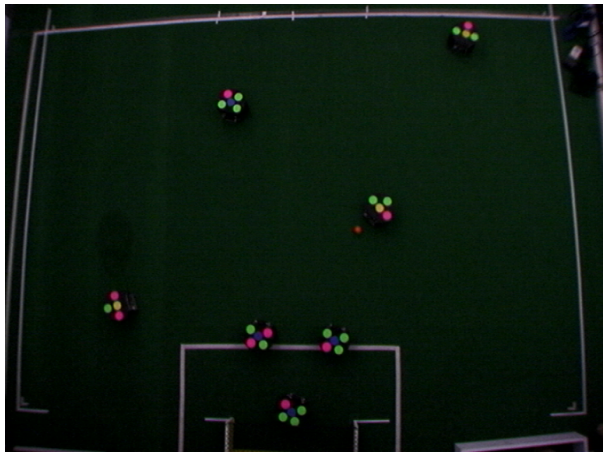


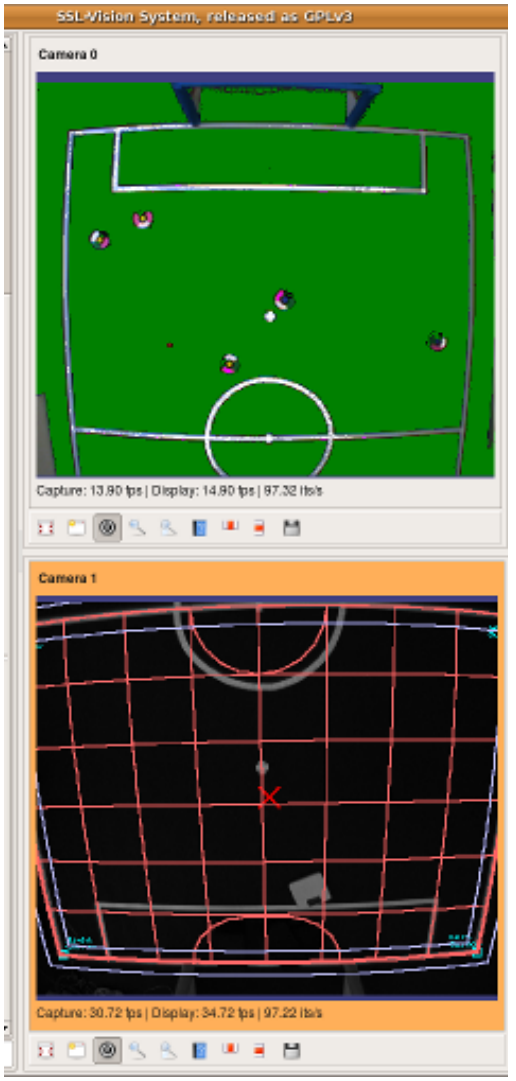


And RoboCup@Home, Rescue, and Junior www.robocup.org
Every year, the roadmap and competitions are updated.
Different leagues challenge and advance different aspects of the goal.

RoboCup “Small-Size” Soccer

Centralized Perception, Cognition, and Distributed Action





CMDragons’13 – thanks to Joydeep Biswas, et al.

Many Real-World Challenges

- Noisy vision at 60Hz
- Perception
  - Position, id, orientation
- Real-time planning
  - Individual, team
- Uncertainty in models of own actions
  - Calibration, physical interference
- Poor models of opponents
  - Prediction

State Assessment, Planning, and Replanning

Autonomous Robot Soccer Teams

James Bruce, Stefan Zickler, Joydeep Biswas, Sonia Chernova, Colin McMillen, Scott Lenser, Michael Bowling, Peter Stone

- Planning under uncertainty and adversaries
  - Physics-based planning
  - Probabilistic motion planning with safety guarantees
  - Adapting and learning to the opponent
  - Short-sighted probabilistic planning
- World modeling
  - Real-time perception
  - Multi-observation sensor resetting localization
- Teamwork
  - Communication, thrust, conflict resolution
  - Role assignment
- Task with goals: the opportunity “to close the loop”
  - Purposeful perception, reasoning, and action

Videos: www.cs.cmu.edu/~coral

References: Perception, Behavior Architecture, Teamwork

- CMDragons: Dynamic Passing and Strategy on a Champion Robot Soccer Team,
James Bruce, Manuela Veloso, and Stefan Zickler.
In *Proceedings of ICRA'08.*
- Fast and inexpensive color image segmentation for interactive robots,
James Bruce, Tucker Balch, and Manuela Veloso. In Proceedings of IROS'00.
- SSL-Vision: The Shared Vision System for the RoboCup Small Size League,
S. Zickler, T. Laue, O. Birbach, M. Wongphati, and M. Veloso.
In *Proceedings of the RoboCup Symposium*, Graz, Austria, 2009.
- STP: Skills, tactics and plays for multi-robot control in adversarial environments,
Brett Browning, James Bruce, Michael Bowling, and Manuela Veloso.
IEEE Journal of Control and Systems Engineering, 219:33--52, 2005.
- Real-time randomized path planning for robot navigation,
James Bruce and Manuela Veloso.
In *Proceedings of IROS'02.*
- Safe Multi-Robot Navigation within Dynamics Constraints,
James Bruce and Manuela Veloso.
Proceedings of the IEEE, Special Issue on Multi-Robot Systems, 2006.

Videos: www.cs.cmu.edu/~coral

References: Physics-Based Planning, Short-Sighted Probabilistic Planning

- Efficient Physics-Based Planning: Sampling Search via Non-Deterministic Tactics and Skills,
  Stefan Zickler and Manuela Veloso.
  In *Proceedings of AAMAS'09*.
- Tactics-Based Behavioral Planning for Goal-Driven Rigid Body Control,
  Stefan Zickler and Manuela Veloso.
  Computer Graphics Forum, 2009.
- Variable Level-of-Detail Motion Planning in Environments with Poorly Predictable Bodies,
  Stefan Zickler and Manuela Veloso.
  In *Proceedings of ECAI'1*
- Short-Sighted Stochastic Shortest Path Problems,
  Felipe Trevizan and Manuela Veloso.
  In *Proceedings of ICAPS'12.*

CoBot(s) – Collaborative Robot(s)
www.cs.cmu.edu/~coral/cobot

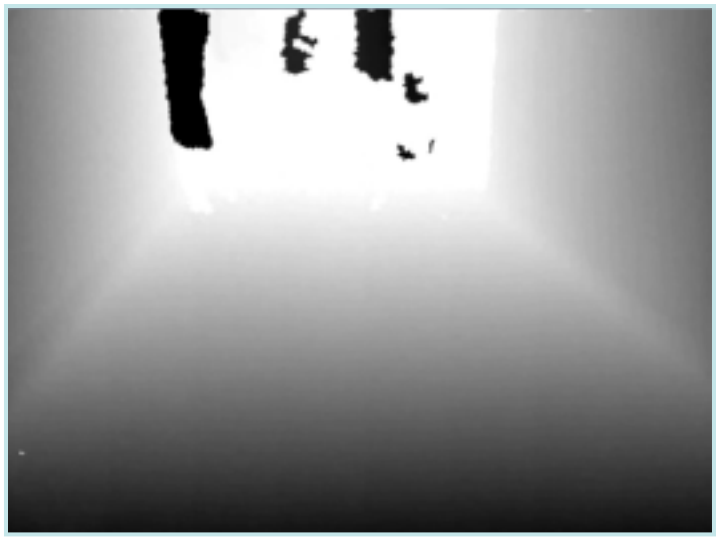
Joydeep Biswas, Brian Coltin, Stephanie Rosenthal, Mehdi Samadi, Thomas Kollar, Cetin Mericli, Juan Pablo Mendoza, Yichao Sun, Vittorio Perera

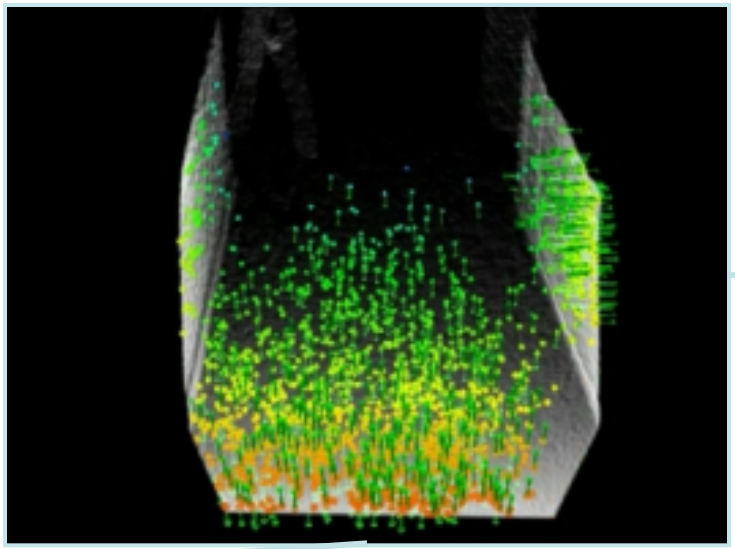
- Tasks
  - Go to a location
  - Deliver a message
  - Escort a visitor
  - Transport object between locations
  - Semi-autonomous telepresence
  - Visitor companion

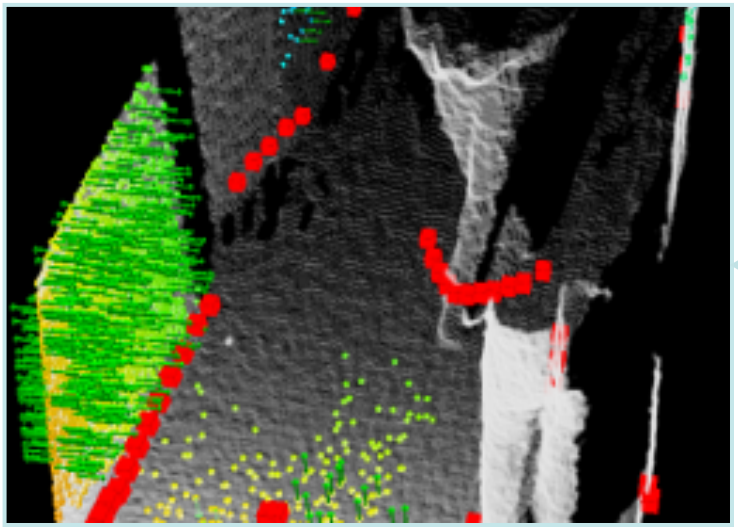
Robots designed and built by Michael Licitra

Effective Depth-Based Localization and Navigation

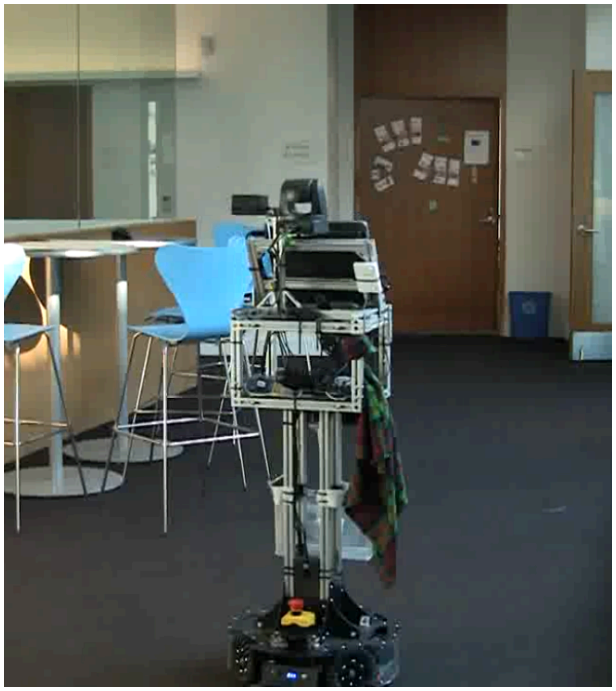
Joydeep Biswas

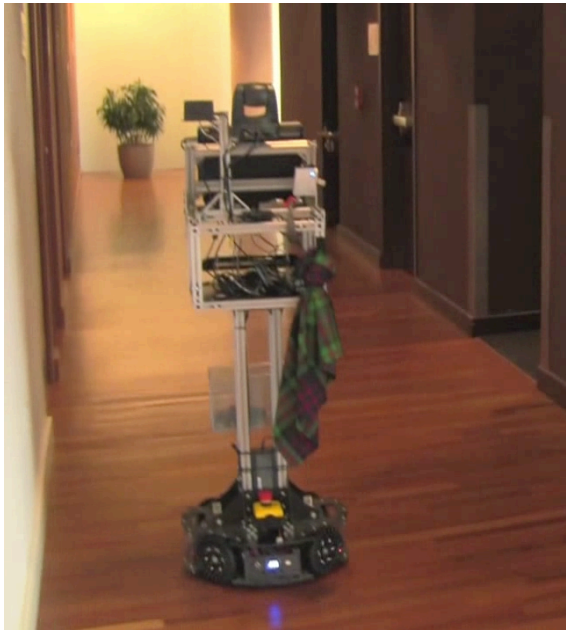






Robust real-world localization and navigation:
Wide range of environments

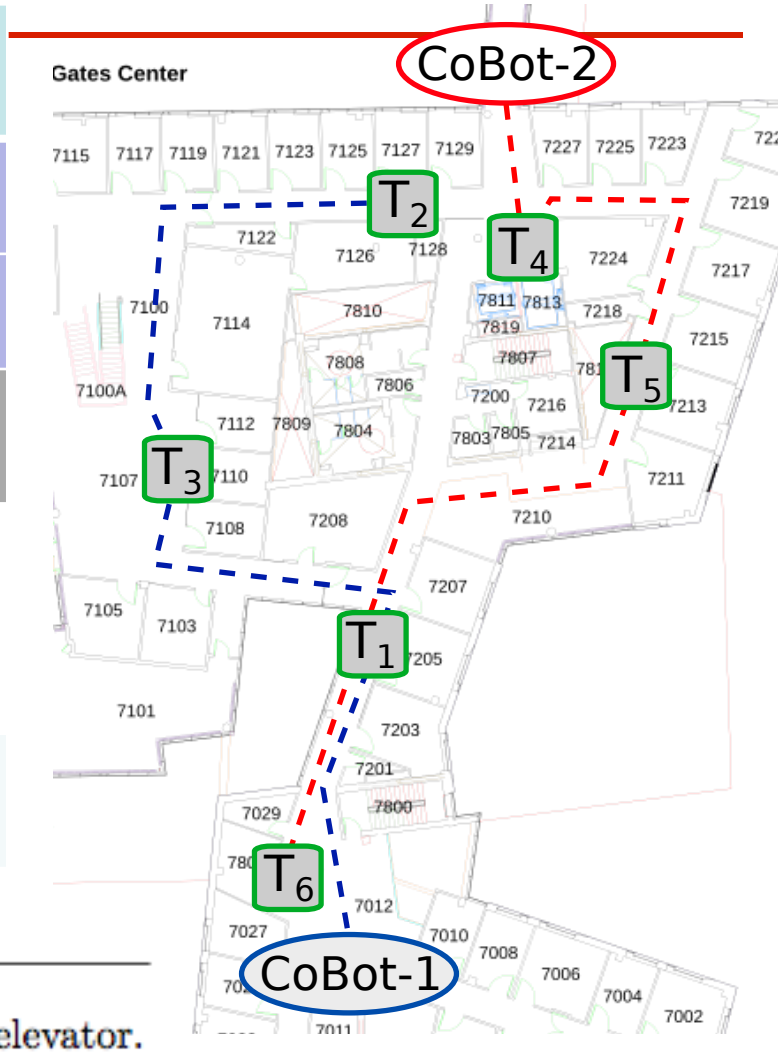




Multi-Robot Online Task Scheduling

Brian Coltin

Sub-Task	Description	Location	Start	End
T_1	Pick up paper.	7205	3:00	3:30
T_2	Deliver paper.	7127	3:00	3:30
T_3	Deliver message.	7110	3:10	3:20
T_4	Meet visitor.	Elevator	3:00	3:10
T_5	Deliver visitor.	7213	3:00	3:10
T_6	Deliver message.	7801	3:10	3:15



CoBot-1		CoBot-2	
Time	Task	Time	Task
3:00 PM	T_1 : Pick up paper.	3:00 PM	T_4: Meet visitor at elevator.
3:10 PM	T_3 : Deliver message.	3:07 PM	T_5: Deliver visitor.
3:15 PM	T_2 : Deliver paper.	3:12 PM	T_6: Deliver message.

Symbiotic Autonomy
to Handle "Inevitable" Robot Limitations

Robots

Proactively and Autonomously

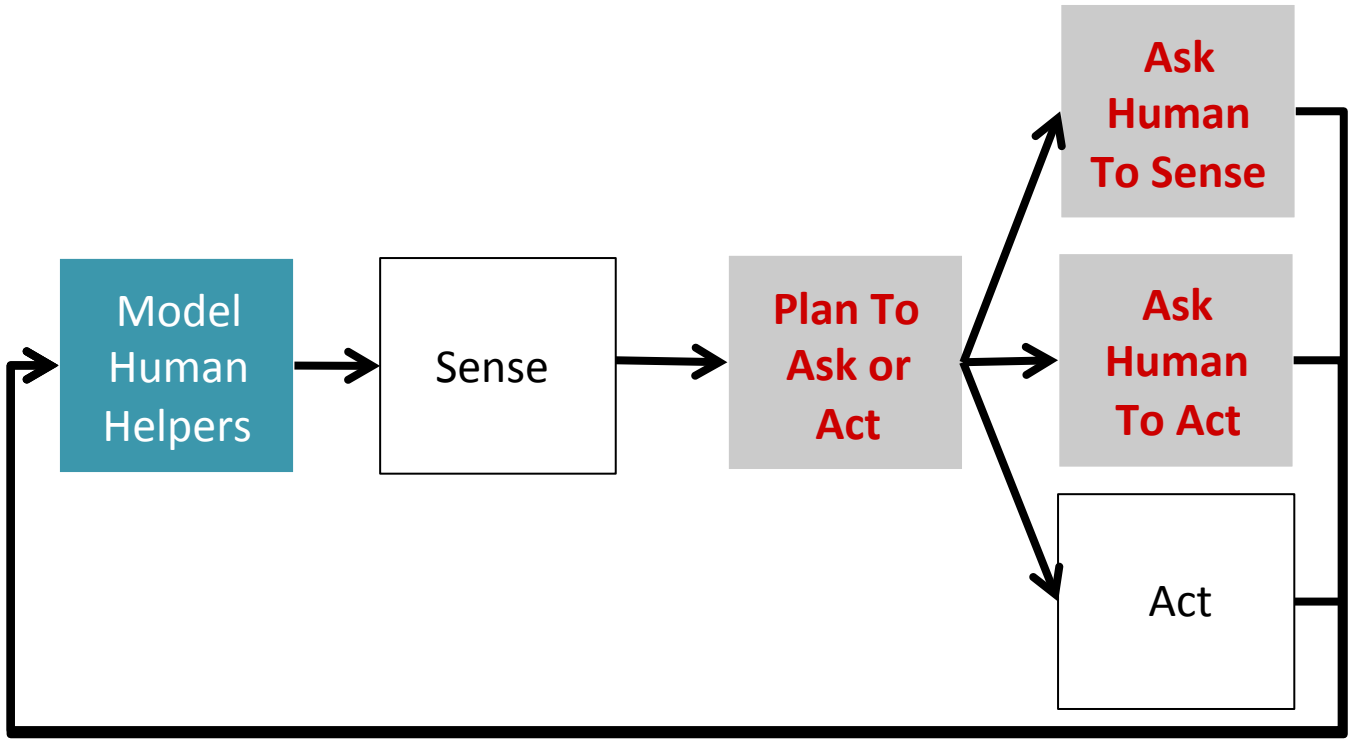
Ask for Help for:

what they cannot do (*actuation*)

what they do not know (*cognition*)

what they do not find (*perception*)

Effective Task Autonomy: Human-Centered Planning



Functionality: Enable Complex Tasks

Usability: Ask Available, Accurate, Willing Helpers

Stephanie Rosenthal, PhD thesis 2012

Actuation and localization limitations
Stephanie Rosenthal, PhD 2012

Models of Environment Helpers

Availability

Interruptibility

Expertise

Accuracy

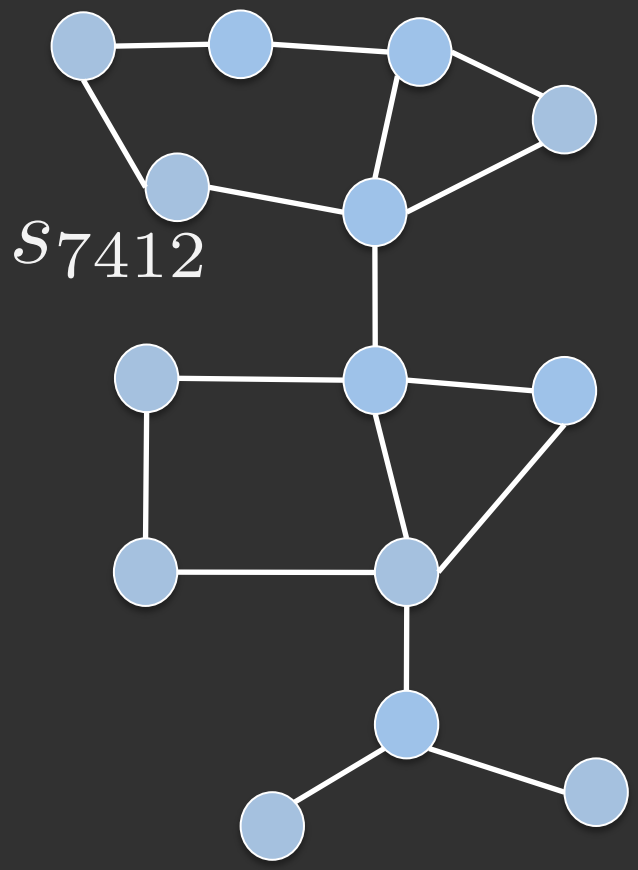
Location

Interaction History

Willingness to Help

Incentive to Help

HOP-POMDP $\{S, \alpha, \eta, \lambda, A, O, T, \Omega, R\}$



Humans located in robot states

Ask Action: a_{ask}

No Response Observation o_{null}

Ask Observations:

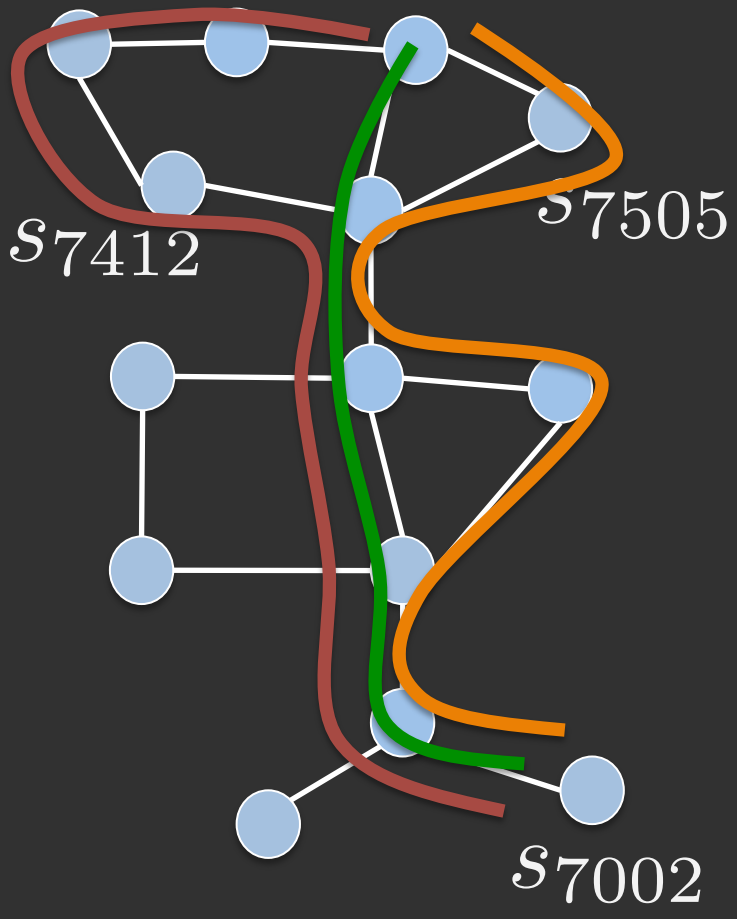
Availability: $\alpha_s = \sum_{o \neq o_{null}} p(o|s, a_{ask})$

Accuracy: $\eta_s = \frac{p(o_s|s, a_{ask})}{\alpha_s}$

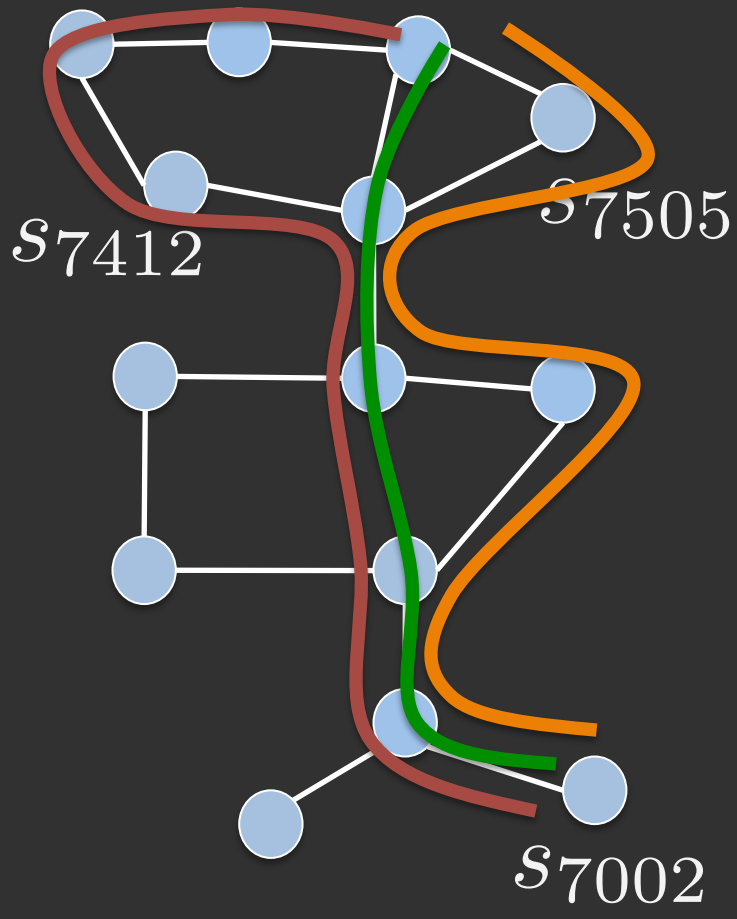
Ask Transition: $T(s, a_{ask}, s) = 1$

Ask Cost: cost of help λ_s

Route Planning



Best in distance



Best in distance and potential human helpers

Plan to Send Email if No Progress in Task

Subject:	CoBot needs help
From:	"CoBot robots" <cmu.cobot@gmail.com>
Date:	Fri, October 18, 2013 9:31 am
To:	coral-group@cs.cmu.edu
Priority:	Normal
Mailing List:	Unsubscribe | Help | Subscribe
Options:	View Full Header | View Printable Version | Download this as a file

I have waited for more than 5 minutes for a response to the question 'Hello, I am here to guide you to room 7412. Please press Done when you are ready to go.'. Can someone please come to Gates elevator on floor GHC7 to answer the question so that I can complete my task?

Learning from Spoken Interaction and Web Access

Learning Environmental Knowledge from Task-Based Human-Robot Dialog,
Thomas Kollar, Vittorio Perera, Daniele Nardi, and Manuela Veloso. In *ICRA'13.*
Using the Web to Interactively Learn to Find Objects,
Mehdi Samadi, Thomas Kollar, and Manuela Veloso. In *AAAI'12.*

CoBot References and Videos:

www.cs.cmu.edu/~coral/cobot

References: Perception, Localization, Navigation

- Localization and navigation of the CoBots over long-te:rm deployments, Joydeep Biswas and Manuela Veloso.
International Journal of Robotics Research, 2013, to appear.

- Depth Camera Based Indoor Mobile Robot Localization and Navigation,
  Joydeep Biswas and Manuela Veloso.
  In *Proceedings of ICRA'12.*

- Planar Polygon Extraction and Merging from Depth Images,
  Joydeep Biswas and Manuela Veloso.
  In *Proceedings of IROS'12.*

- Corrective Gradient Refinement for Mobile Robot Localization,
  Joydeep Biswas, Brian Coltin, and Manuela Veloso.
  In *Proceedings of IROS'11.*

- Fast Human Detection for Indoor Mobile Robots Using Depth Images,
  Benjamin Choi, Cetin Mericli, Joydeep Biswas, and Manuela Veloso.
  In *Proceedings of ICRA'13.*

CoBot References and Videos:

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Task Scheduling, Symbiotic Autonomy

- CoBots: Collaborative Robots Servicing Multi-Floor Buildings, Video and Extended abstract Manuela Veloso, Joydeep Biswas, Brian Coltin, Stephanie Rosenthal, Tom Kollar, Cetin Mericli, Mehdi Samadi, Susana Brandao, and Rodrigo Ventura. In *Proceedings of IROS'12.*

- Dynamic User Task Scheduling for Mobile Robots, Brian Coltin and Manuela Veloso. In Proceedings of the AAAI'11 Workshop on "Automated Action Planning for Autonomous Mobile Robots."

- An Effective Personal Mobile Robot Agent Through Symbiotic Human-Robot Interaction, Stephanie Rosenthal, Joydeep Biswas, and Manuela Veloso. In Proceedings of AAMAS'10.

Summary: Robot Planning in the Real World

- **Real-time perception**
- **Replanning** also due to inevitably other poorly modeled actuators
- **Symbiotic autonomy**
  - cover for inevitable limitations, intrinsic or learnable
- **Coordinate with other robots, interact with humans, access the web**
- **Learn** models and data
  - from human demonstration, correction, general interaction with the environment, humans, web, others,…