A Practical Approach to Human/Multi-Robot Teams

Elizabeth Sklar[1], **Simon Parsons**[1],
A. Tuna Özgelen[2], **M. Q. Azhar**[2], **Todd Flyr**[2],
Eric Schneider[1] and **Jeffery Raphael**[1]

[1]Dept of Computer Science
University of Liverpool

[2]Dept of Computer Science
The Graduate Center
City University of New York

contact author: *e.i.sklar@liverpool.ac.uk*

motivation

- to address issues that are well-studied in *virtual* or *simulated* multiagent systems, but present challenges in *physical* multi-robot systems
- with a focus on **coordination**, **task allocation**, **human-robot interaction**:
  - robot-robot context ⇒ multi-robot routing
  - human-robot context ⇒ shared decision making
- example domains (*environments that are risky for or inaccessible to humans...*):
  - search and rescue
  - humanitarian de-mining
  - hazardous waste clean-up
  - disaster recovery
  - test environment: variant of the *Treasure Hunt Game*
- **projected impact:**
  - **to improve human/multi-robot team coordination in dynamic environments**

talk outline

1. research environment
2. coordinated task allocation
3. cooperative decision making

research environment

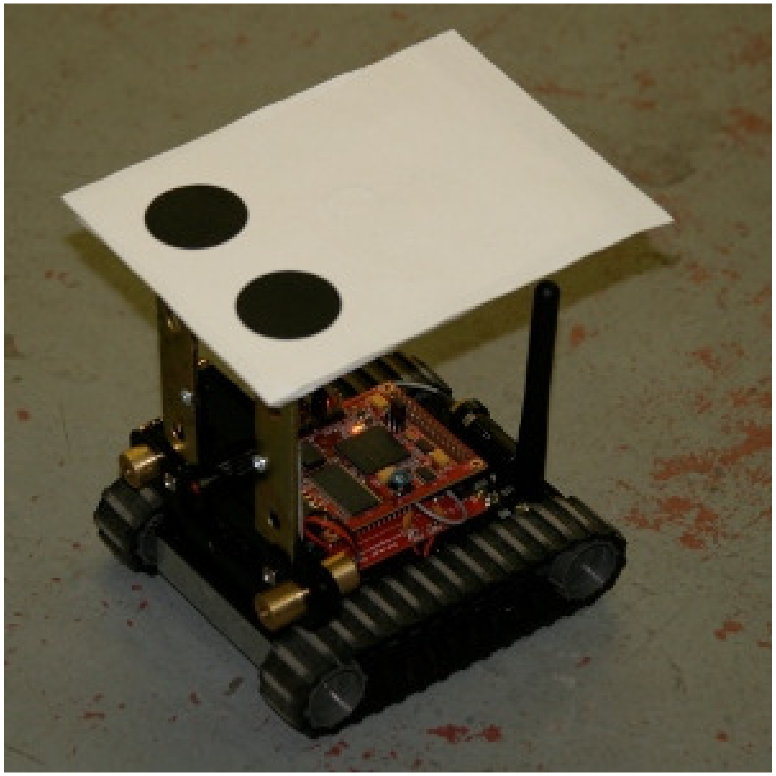
- "rough-and-ready" approach
- deploy heterogeneous team of low-end (i.e., inexpensive) robots (although work presented here only tests homogeneous team)
- distribute tasks (e.g., exploration) amongst team members
- replace lost robot(s) as needed
- practical constraints present difficulties (e.g., image processing, computational resources, network connectivity, power management, environmental noise, etc.)

$\Rightarrow$ **research opportunities !!**

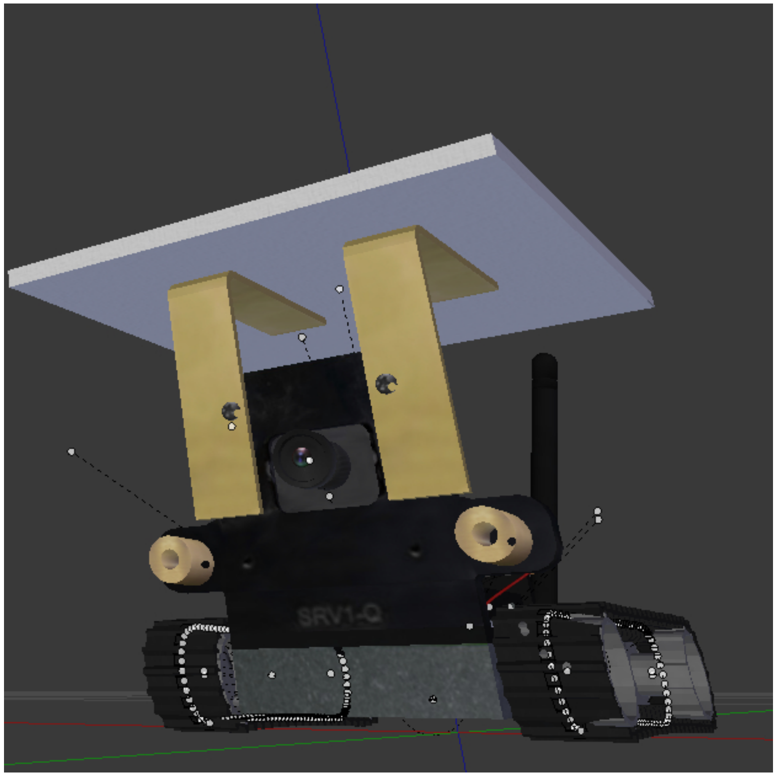
research environment: physical robot test facility

research environment: composite view from 6 overhead cameras

research environment: Surveyor[1] Blackfin robot



physical robot



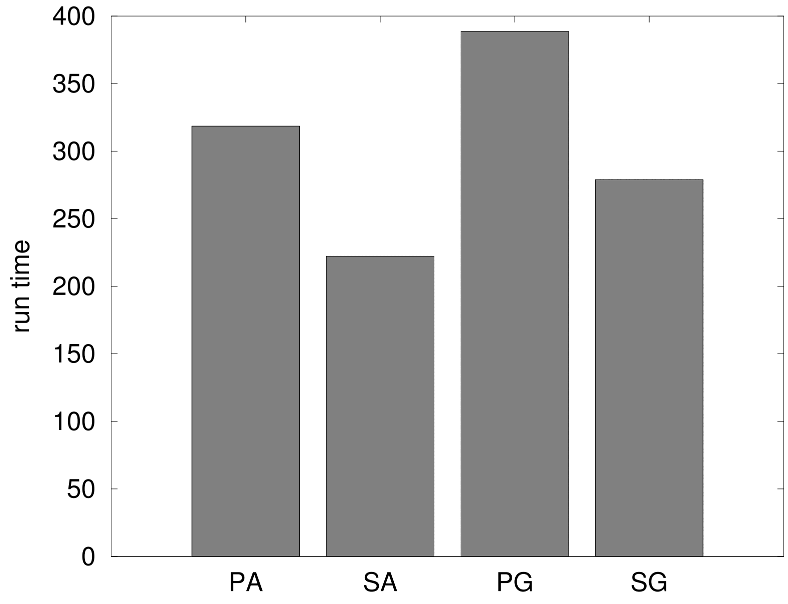
Blender model

[1]http://www.surveyor.com

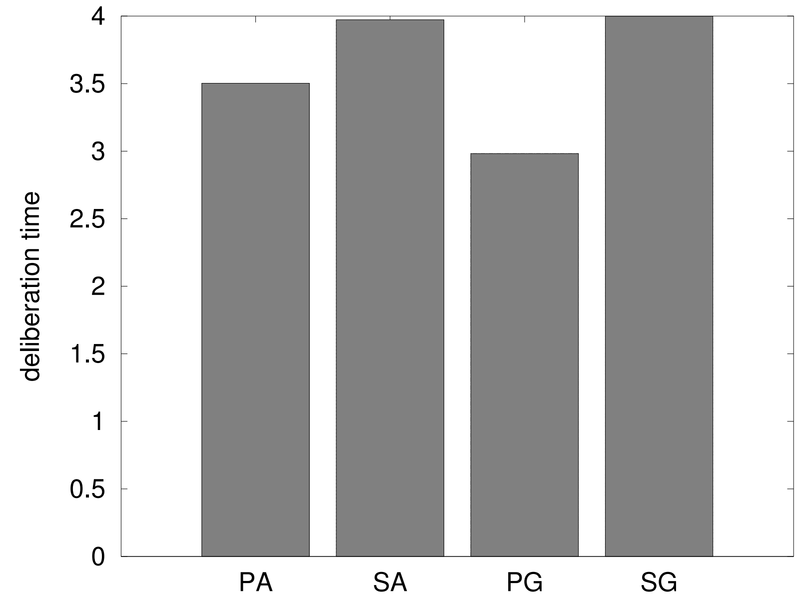
coordinated task allocation

- *aim: to study the application of market-based coordination mechanisms to multi-robot routing problems*
- problem definition:
  Given n robots and m "interest points" (i.e., tasks), allocate tasks to robots.
- metrics:
  - run time
  - deliberation time
  - distance travelled
  - idle time
  - number of "near collisions"
  - delay time
- test conditions: **P**hysical robots vs **S**imulated robots (in Stage)
- task allocation strategies tested here: **G**reedy taxi vs simple **A**uction

coordinated task allocation: run time and deliberation time



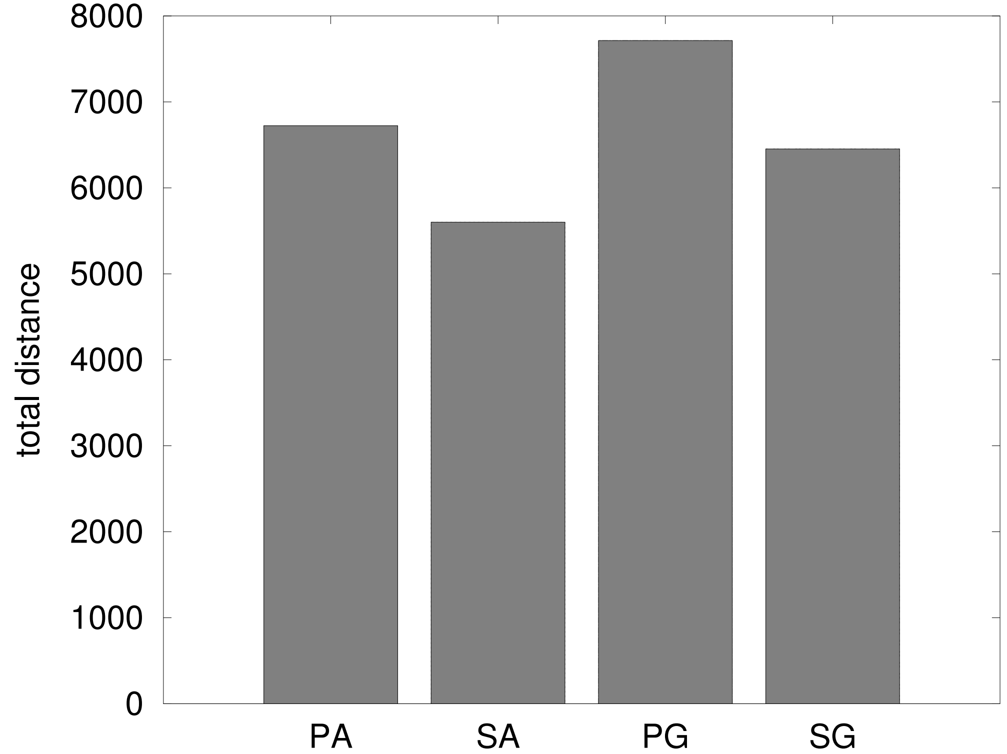
run time



deliberation time

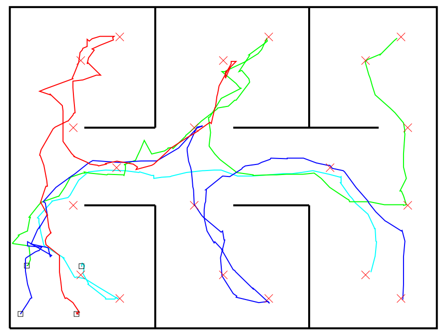
- auction mechanism produces shorter run time, despite longer deliberation time

coordinated task allocation: distance travelled

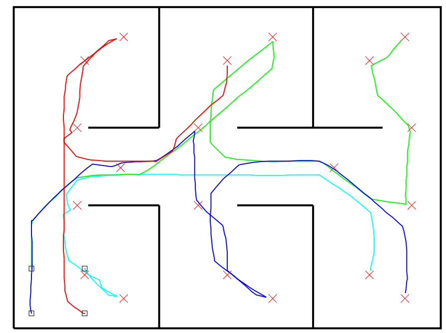


- greedy taxis travel farther, because auction mechanism attempts to minimise distance
- physical robots travel farther. why?

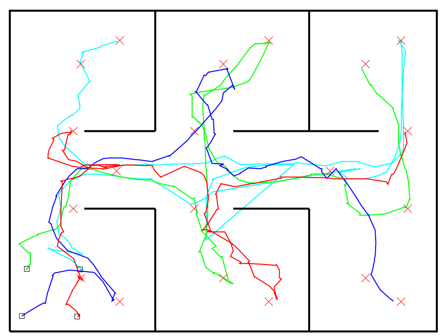
coordinated task allocation: distance travelled (cont.)



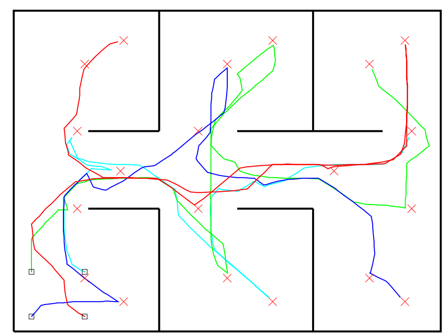
PA



SA



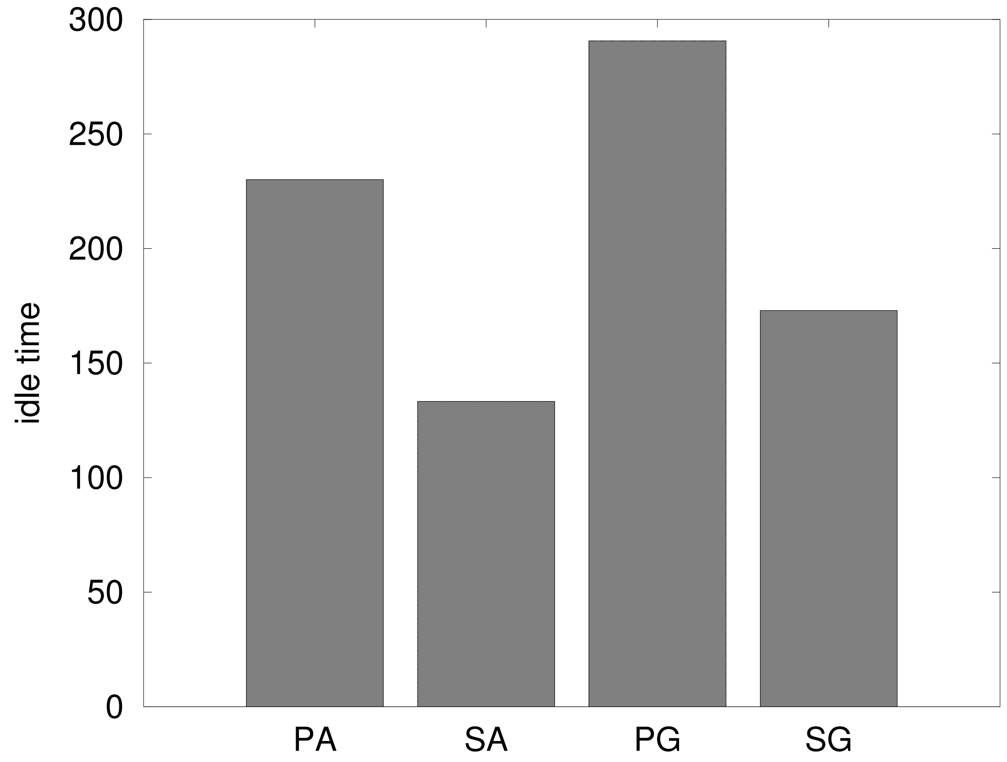
PG



SG

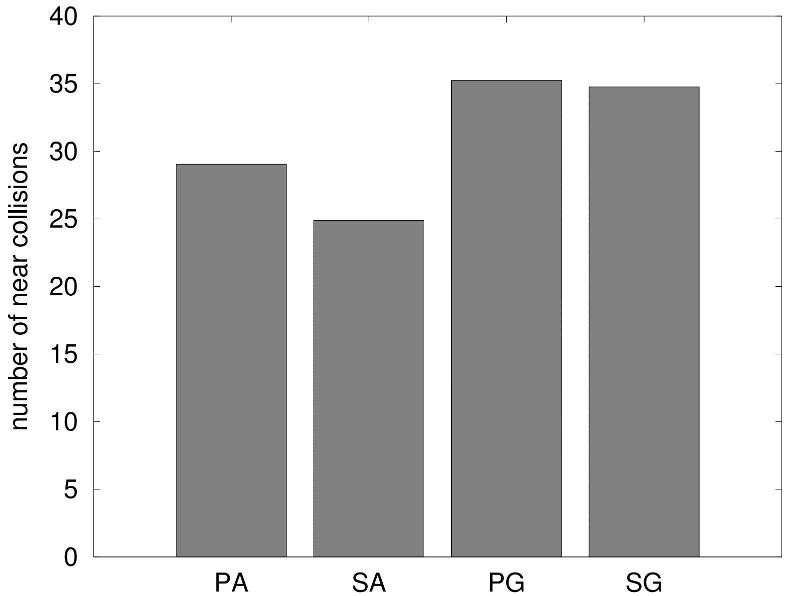
- because physical robots wiggle more than simulated robots

coordinated task allocation: idle time

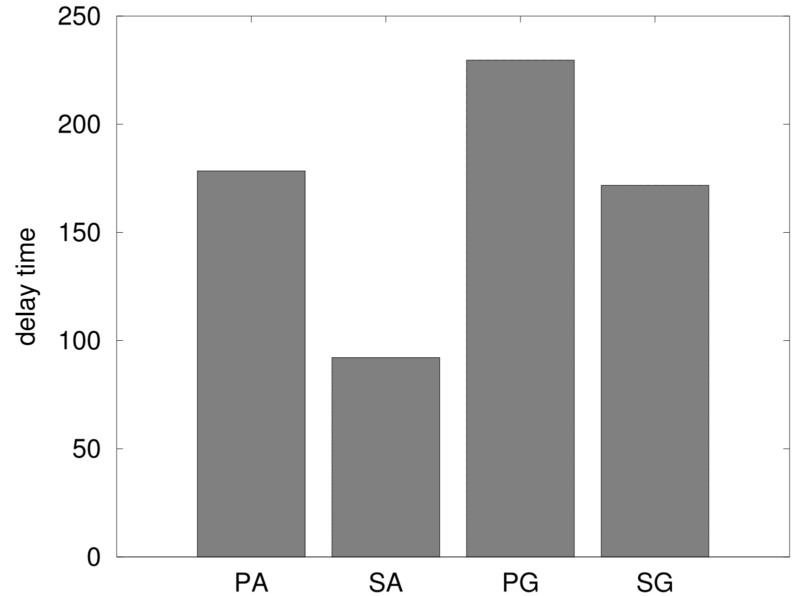


- greedy taxis spend more time idle
- tasks are more evenly distributed using auction mechanism

coordinated task allocation: "near" collisions



near collisions



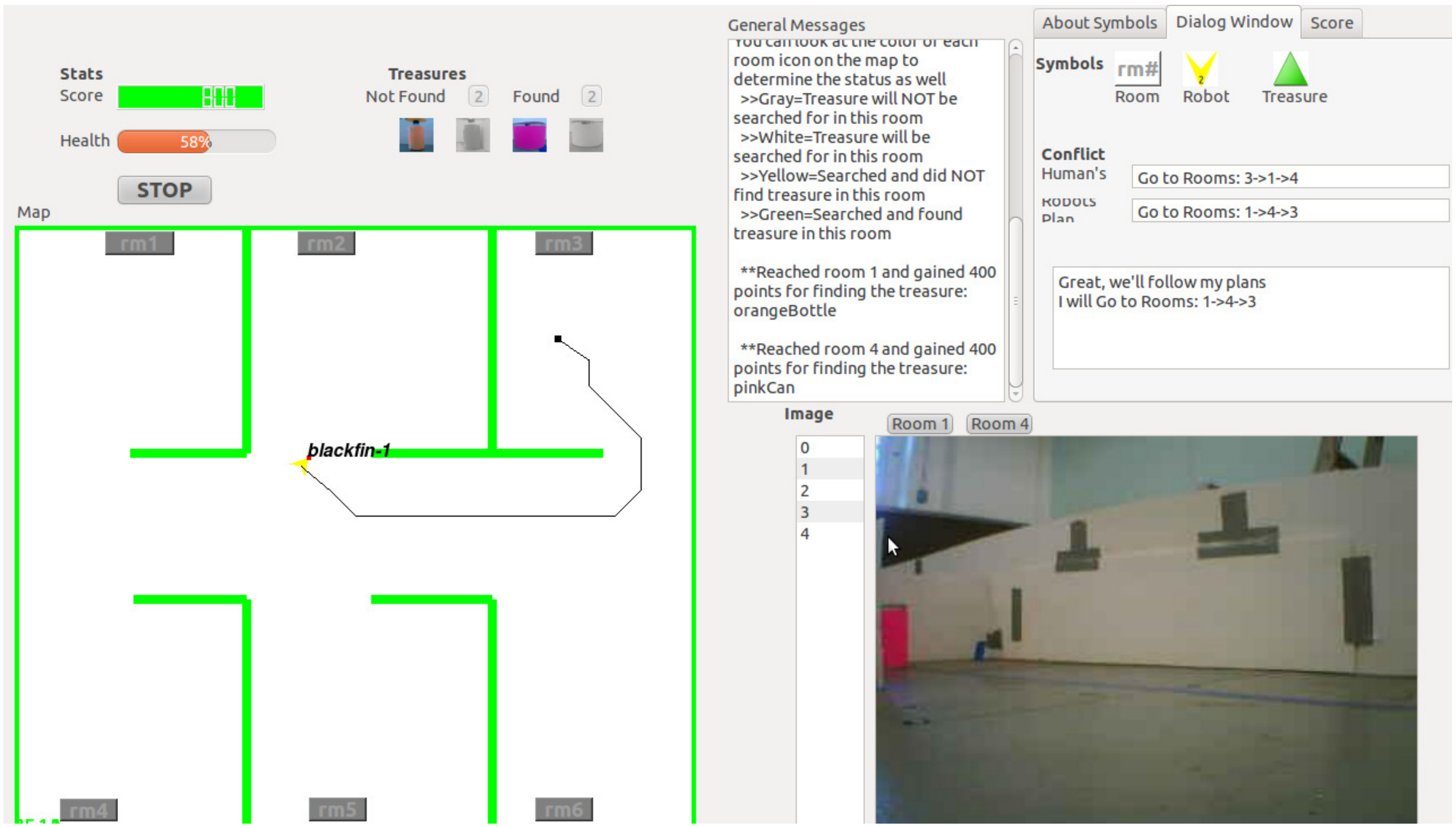
delay time

- auction mechanism produces fewer "near collisions", and hence less delay time

cooperative decision making

- *aim: to study the application of argumentation-based dialogue to human-robot interaction*
- important point: this work is **not** about natural language dialogue, but about *argumentation*— a well-studied paradigm founded in logic that describes formal methods for the presentation of *evidence* as reasons for and against particular *conclusions*
- typical human-robot interaction (HRI) implementations engage robot as a *subordinate*, rather than a *peer*
- in risky / inaccessible environments, human has to trust robot to obtain sensor data and sometimes be able to make decisions on its own
- test domain—
  variant of Treasure Hunt Game: Human and robot together explore a region where only robot has physical access. Robot can transmit sensor data to human. Robot can perform some analysis of sensor data. Human and robot have to find and correctly identify n treasures. Robot has limited "energy". *Game:* points awarded for finding treasures; points deducted for incorrect identifications and for energy usage.

cooperative decision making: user interface



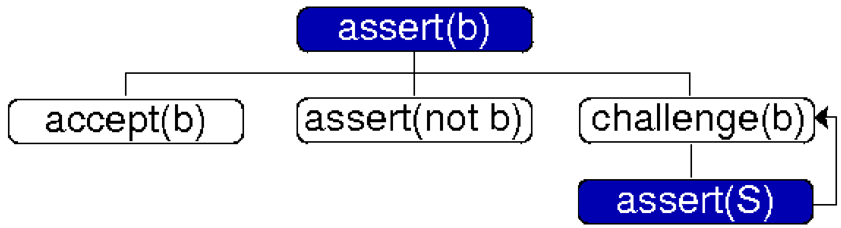
cooperative decision making: underlying ArgHRI model

- we explore the following types of argumentation-based dialogue:
  - *information seeking*—where one believes the other knows; e.g., robot asks human to analyse an image
  - *inquiry*—where neither knows; e.g., robot and human agree that robot should collect sensor data about an unknown region
  - *persuasion*—where one wants to convince the other; e.g., robot's analysis of sensor data differs from human's analysis
- a bit of notation:
  - Σ_i = complete knowledge base of agent Ag_i; belief $b \in \Sigma_i$
  - Δ_i = agent Ag_i's private beliefs
  - $\Gamma_i(j)$ = agent Ag_i's beliefs about what agent Ag_j believes
  - in the table below: H = human and R = robot

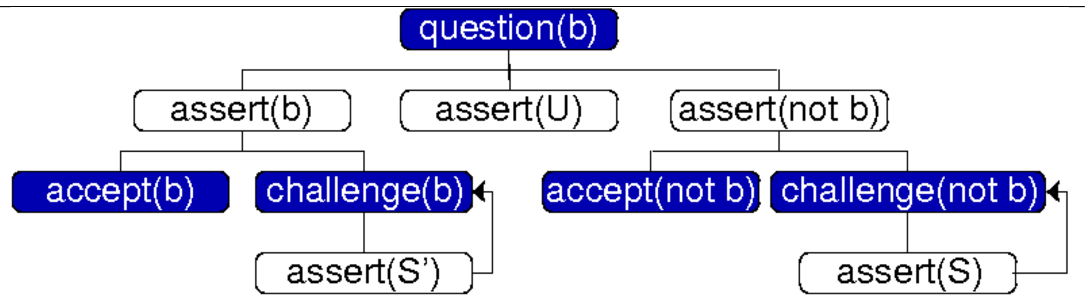
	$b \in \Delta_R$	$b \notin \Delta_R$	$\neg b \in \Delta_R$
$b \in \Gamma_R(H)$	*agreement*	information-seeking	persuasion
$b \notin \Gamma_R(H)$	persuasion	inquiry	persuasion
$\neg b \in \Gamma_R(H)$	persuasion	information-seeking	*agreement*

cooperative decision making: dialogue protocols

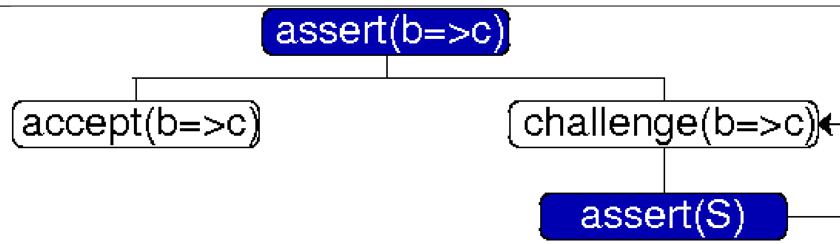
persuasion:



information-seeking:



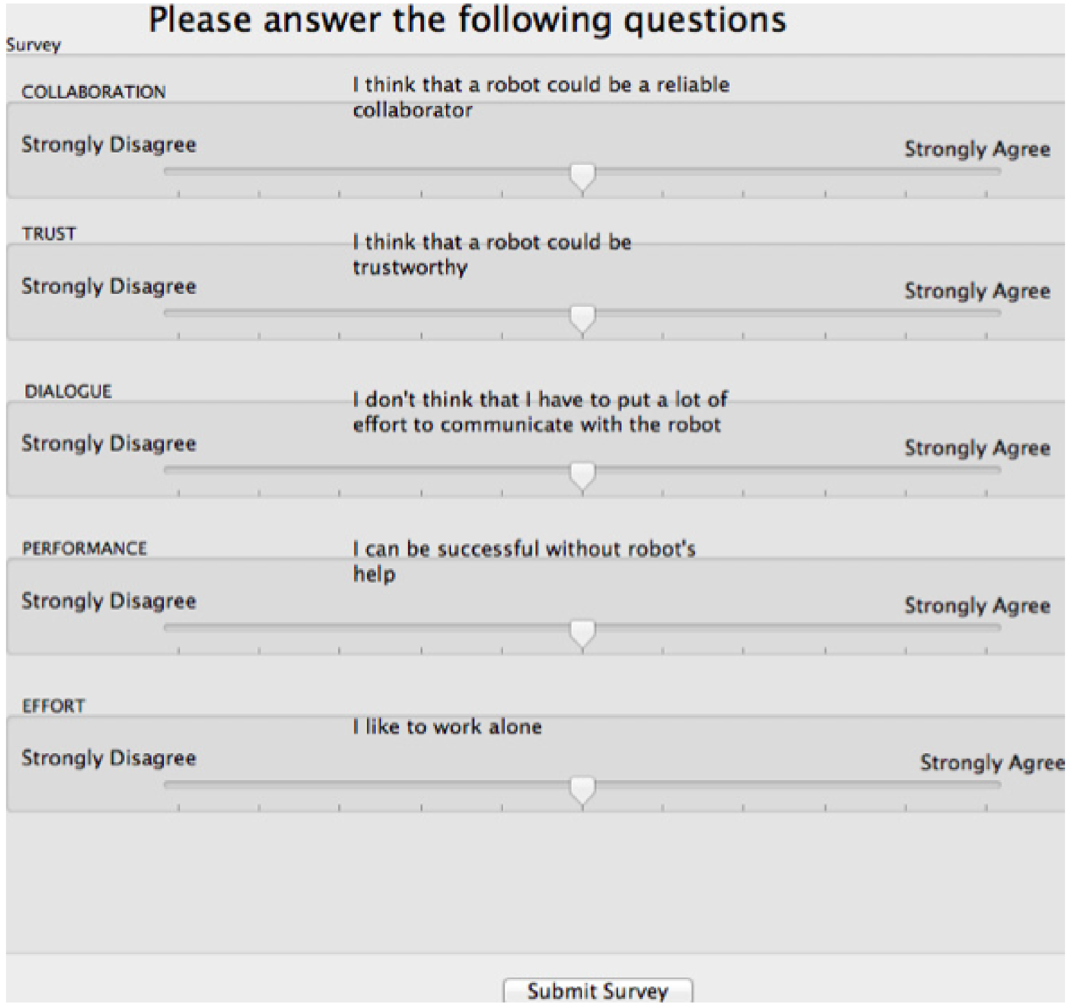
inquiry:



cooperative decision making: pilot user study

- 39 human subjects (20 with simulated robots, 19 with physical robots)
- mission: play Treasure Hunt Game; only tested persuasion dialogue
- experimental conditions: minimal dialogue vs full dialogue modes
- metrics:
  - collaboration
  - trust
  - dialogue as a means of communication
  - perceived performance
  - effort

cooperative decision making: pilot study survey



cooperative decision making: pilot study results

	pre	*mid*	*post*	*change*
collaboration	3.79	4.05	4.21	0.42 (8.42%)
trust	3.53	3.79	4.00	0.47 (9.47%)
dialogue	3.05	3.32	3.68	0.63 (12.63%)
performance	3.53	3.32	3.63	0.11 (2.11%)
effort	3.11	3.26	3.16	-0.05 (1.05%)

with physical robots

	pre	*mid*	*post*	*change*
collaboration	3.85	4.25	4.35	0.50 (10.00%)
trust	3.50	4.00	4.30	0.80 (16.00%)
dialogue	2.65	3.65	3.75	1.10 (22.00%)
performance	3.00	2.95	3.30	0.30 (6.00%)
effort	2.90	2.90	2.70	-0.20 (-4.00%)

with simulated robots

- *average metrics showed increase in collaboration, trust, dialogue and performance from pre to minimal to full dialogue mode, and decrease in effort*

current and future work

- coordinated task allocation
  - testing different auction mechanisms
- cooperative decision making:
  - testing all 3 types of dialogue
- related projects:
  - learning when to use existing mechanisms and learning new mechanisms
  - learning how to coordinate

acknowledgments

- *funding agencies* — National Science Foundation (grants CNS-0851901, IIS-1117000, CNS-1117761); City University of New York (grants PSC-64630-00-42, CIRG-1642); Army Research Office (Science of Security Lablet); US-UK Fulbright Commission (2013-24 Scholar Award)
- *faculty collaborators* — Prof Susan L. Epstein (CUNY Hunter College),
- *PhD students* — Sadat Chowdhury (CUNY), J. Pablo Muñoz (CUNY), Jordan Salvit (CUNY)
- *undergraduate research fellows (all from CUNY)* — Farah Abbasi, Ofear Balas, Michael Costantino, Joel Gonzalez, David Lettier, Mark Manashirov

THANK YOU!