

A Practical Approach to Human/Multi-Robot Teams

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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 \Rightarrow multi-robot routing
 - human-robot context \Rightarrow 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.)

⇒ **research opportunities !!**

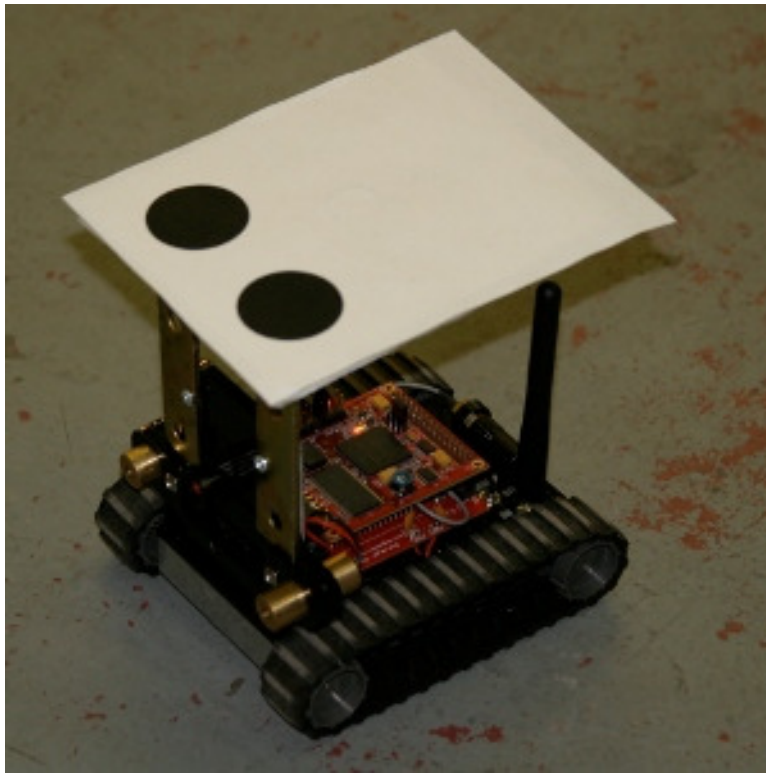
research environment: physical robot test facility



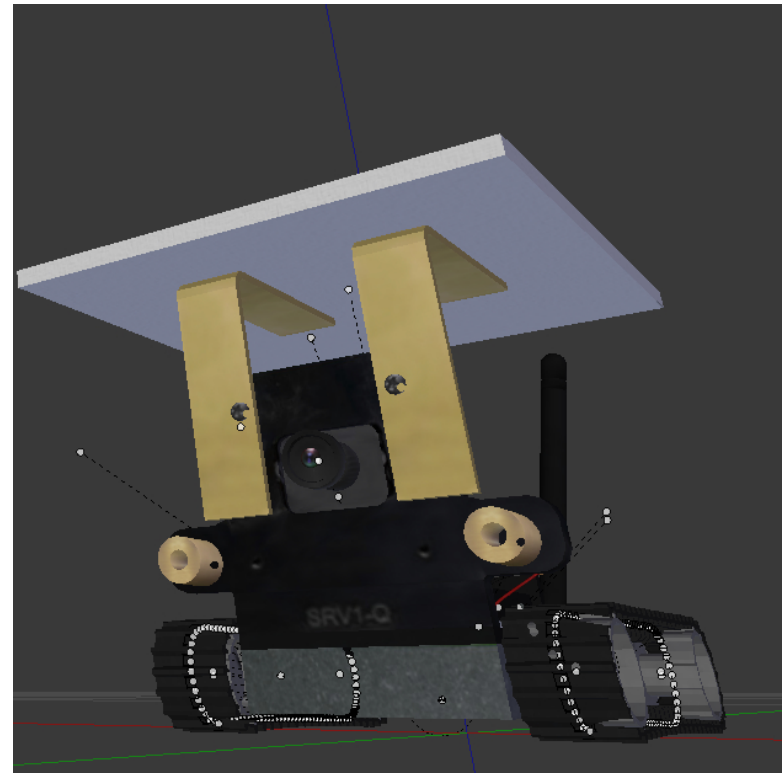
research environment: composite view from 6 overhead cameras



research environment: Surveyor¹ Blackfin robot



physical robot



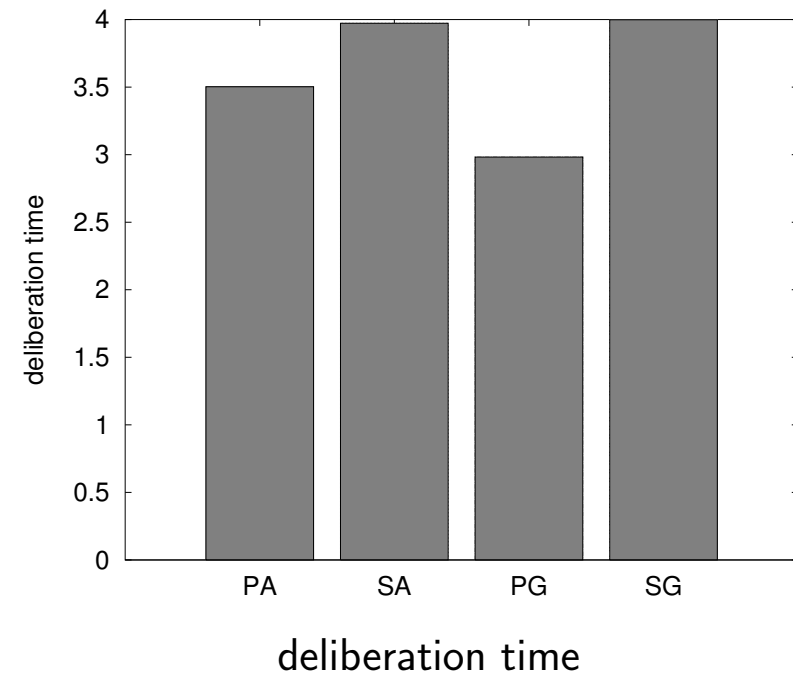
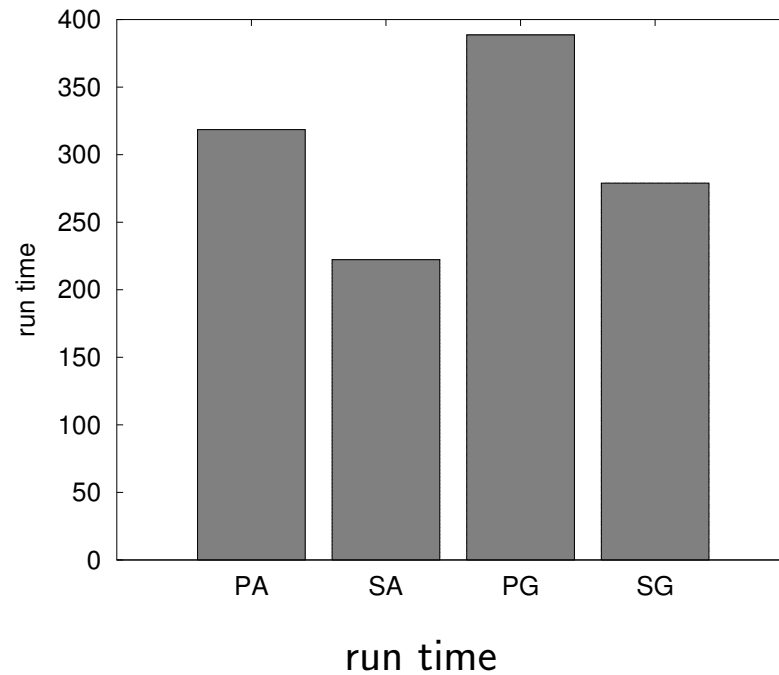
Blender model

¹<http://www.surveyor.com>

coordinated task allocation

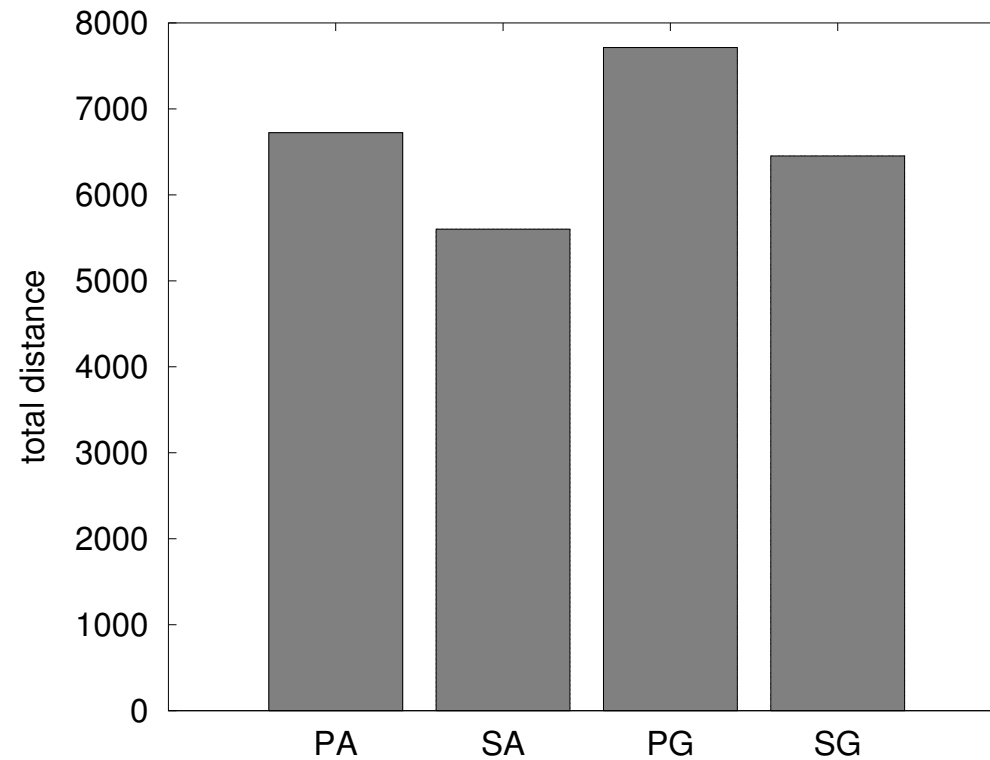
- *aim: to study the application of market-based coordination mechanisms to multi-robot routing problems*
- problem definition:
Given n robots and m “interest points” (i.e., tasks), allocate tasks to robots.
- metrics:
 - run time
 - deliberation time
 - distance travelled
 - idle time
 - number of “near collisions”
 - delay time
- test conditions: **Physical robots** vs **Simulated robots** (in Stage)
- task allocation strategies tested here: **Greedy taxi** vs **simple Auction**

coordinated task allocation: run time and deliberation time



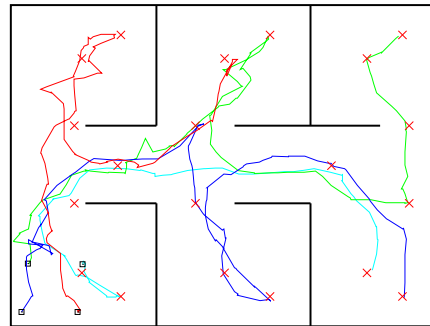
- auction mechanism produces shorter run time, despite longer deliberation time

coordinated task allocation: distance travelled

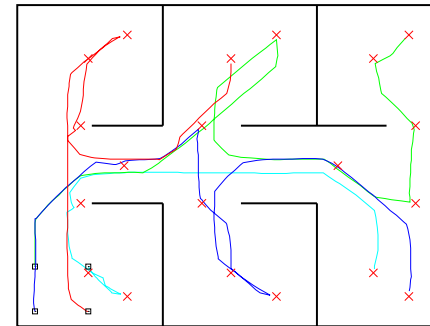


- greedy taxis travel farther, because auction mechanism attempts to minimise distance
- physical robots travel farther. why?

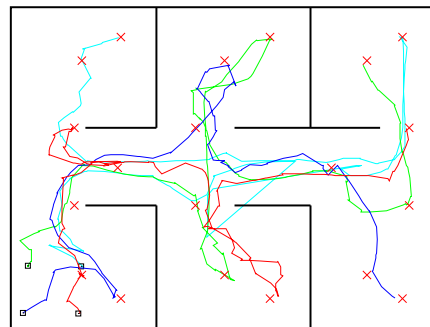
coordinated task allocation: distance travelled (cont.)



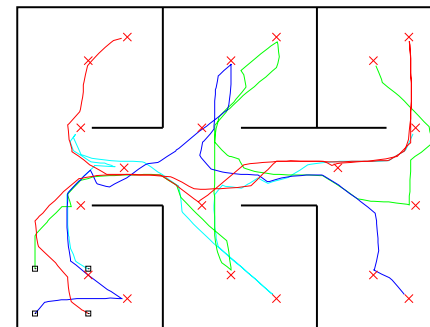
PA



SA



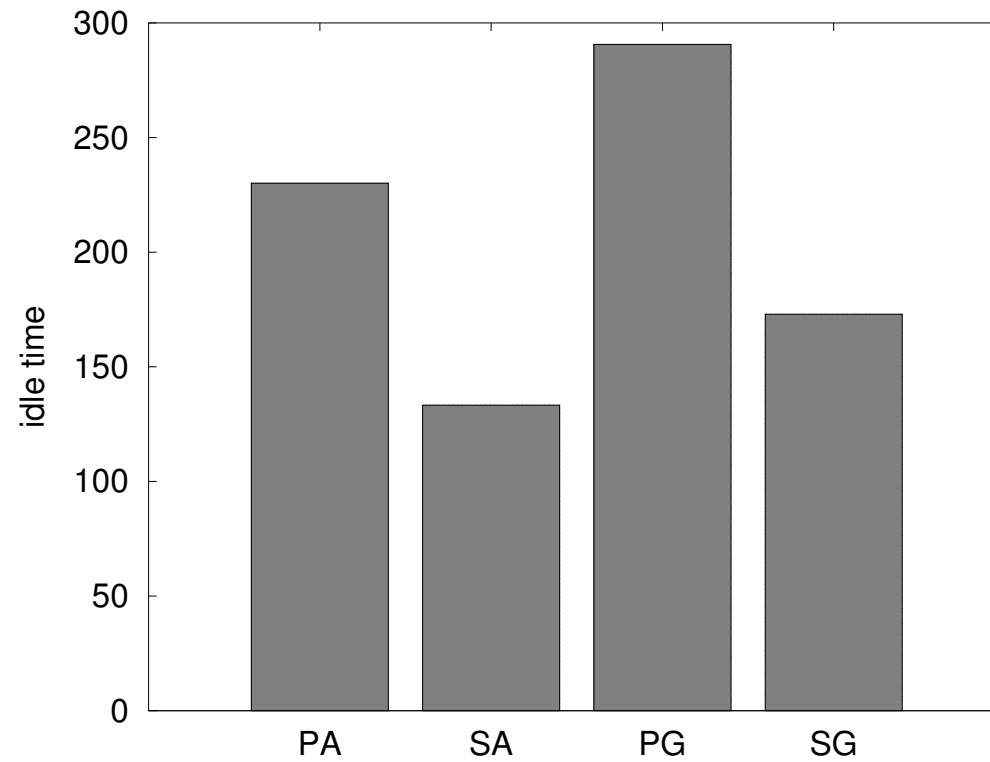
PG



SG

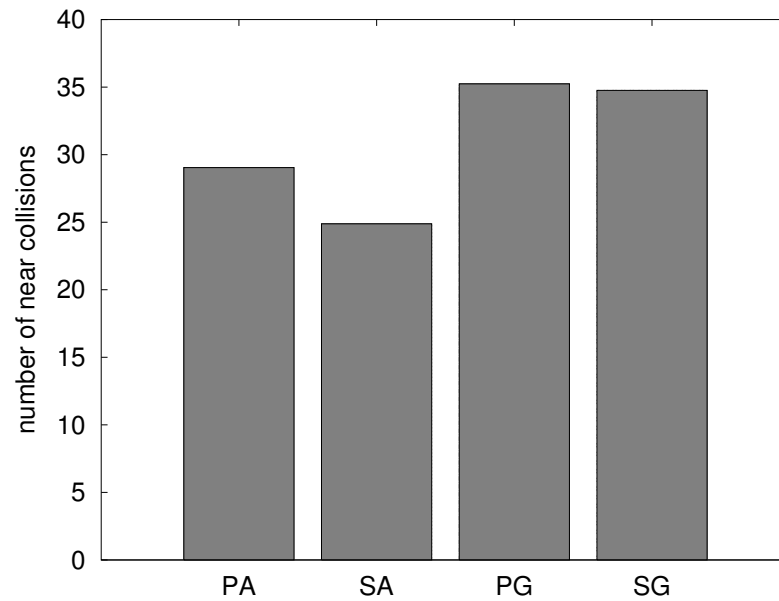
- because physical robots wiggle more than simulated robots

coordinated task allocation: idle time

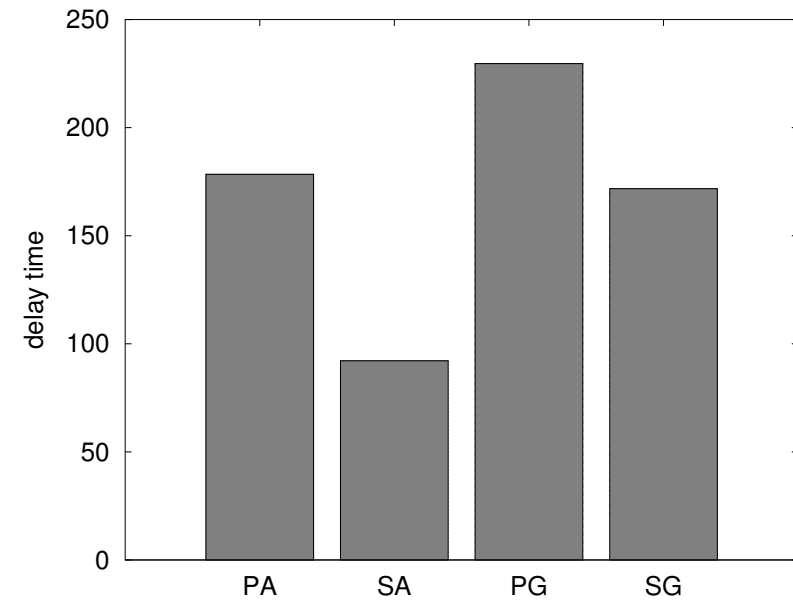


- greedy taxis spend more time idle
- tasks are more evenly distributed using auction mechanism

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

The screenshot displays a user interface for a cooperative decision-making system. The interface is divided into several sections:

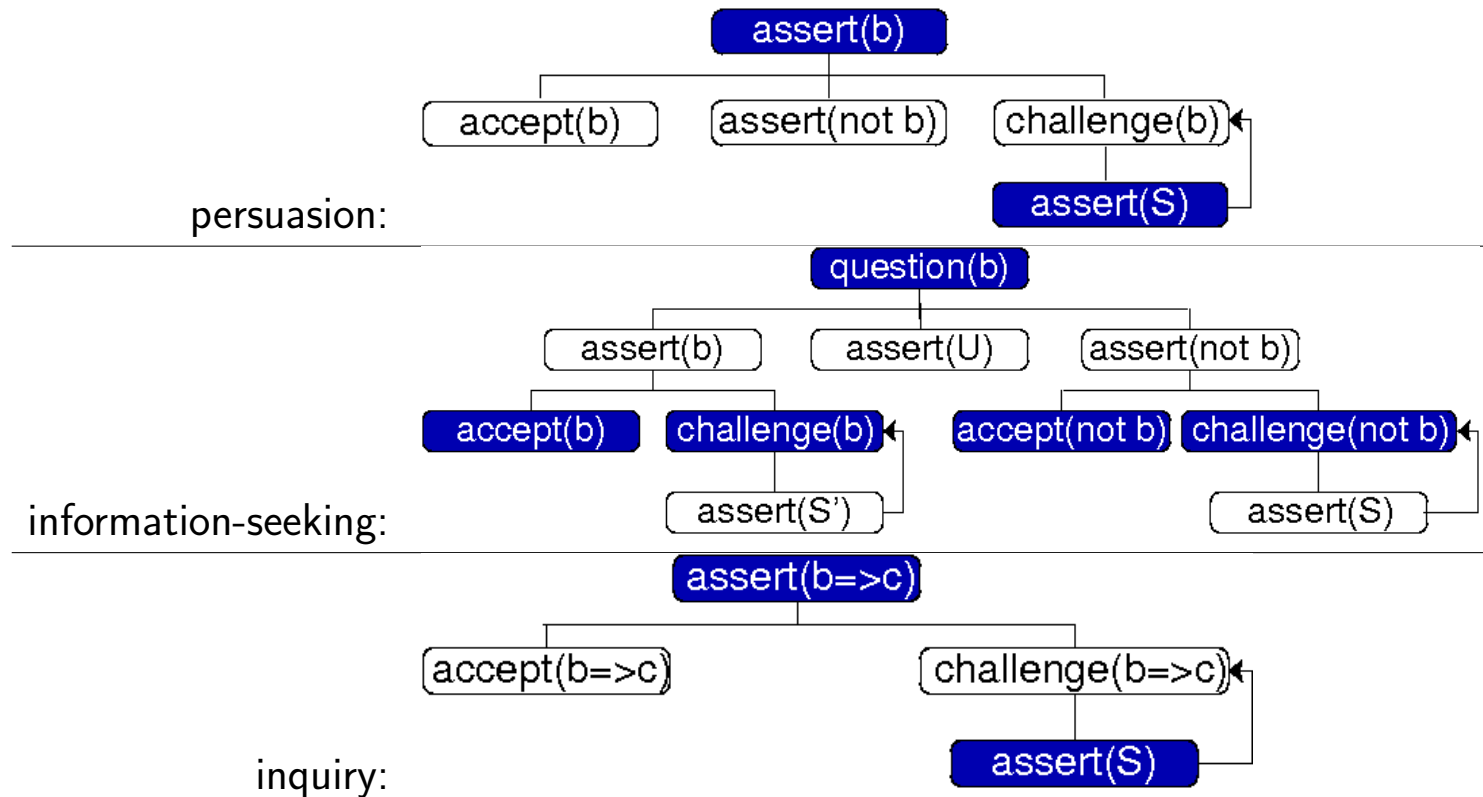
- Stats:** Includes a green progress bar for 'Score' and an orange progress bar for 'Health' at 58%. A 'STOP' button is located below the health bar.
- Treasures:** A section with icons for 'Not Found' (2) and 'Found' (2) treasures, each with a corresponding color-coded icon (blue, gray, purple, and white).
- Map:** A top-down view of a maze with six rooms labeled 'rm1' through 'rm6'. A green line indicates a path through the maze, and a yellow arrow points to a location labeled 'blackfin-1'.
- General Messages:** A text area providing instructions on how to use the map and room icons to determine treasure status. It lists color-coded messages: Gray (Treasure will NOT be searched for), White (Treasure will be searched for), Yellow (Searched and did NOT find treasure), and Green (Searched and found treasure). It also includes two messages about reaching rooms and gaining points for finding treasures: 'orangeBottle' and 'pinkCan'.
- Conflict:** A section with tabs for 'About Symbols', 'Dialog Window', and 'Score'. It shows a 'Conflict' between 'Human's' and 'Robot's' plans. The Human's plan is 'Go to Rooms: 3->1->4' and the Robot's plan is 'Go to Rooms: 1->4->3'. A text box below states: 'Great, we'll follow my plans I will Go to Rooms: 1->4->3'.
- Image:** A section with a list of images (0-4) and a video feed showing a robot in a room. The video feed is labeled 'Room 1' and 'Room 4'.

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



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

Survey

Please answer the following questions

COLLABORATION I think that a robot could be a reliable collaborator

Strongly Disagree Strongly Agree

TRUST I think that a robot could be trustworthy

Strongly Disagree Strongly Agree

DIALOGUE I don't think that I have to put a lot of effort to communicate with the robot

Strongly Disagree Strongly Agree

PERFORMANCE I can be successful without robot's help

Strongly Disagree Strongly Agree

EFFORT I like to work alone

Strongly Disagree Strongly Agree

Submit Survey

cooperative decision making: pilot study results

	<i>pre</i>	<i>mid</i>	<i>post</i>	<i>change</i>
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

	<i>pre</i>	<i>mid</i>	<i>post</i>	<i>change</i>
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

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