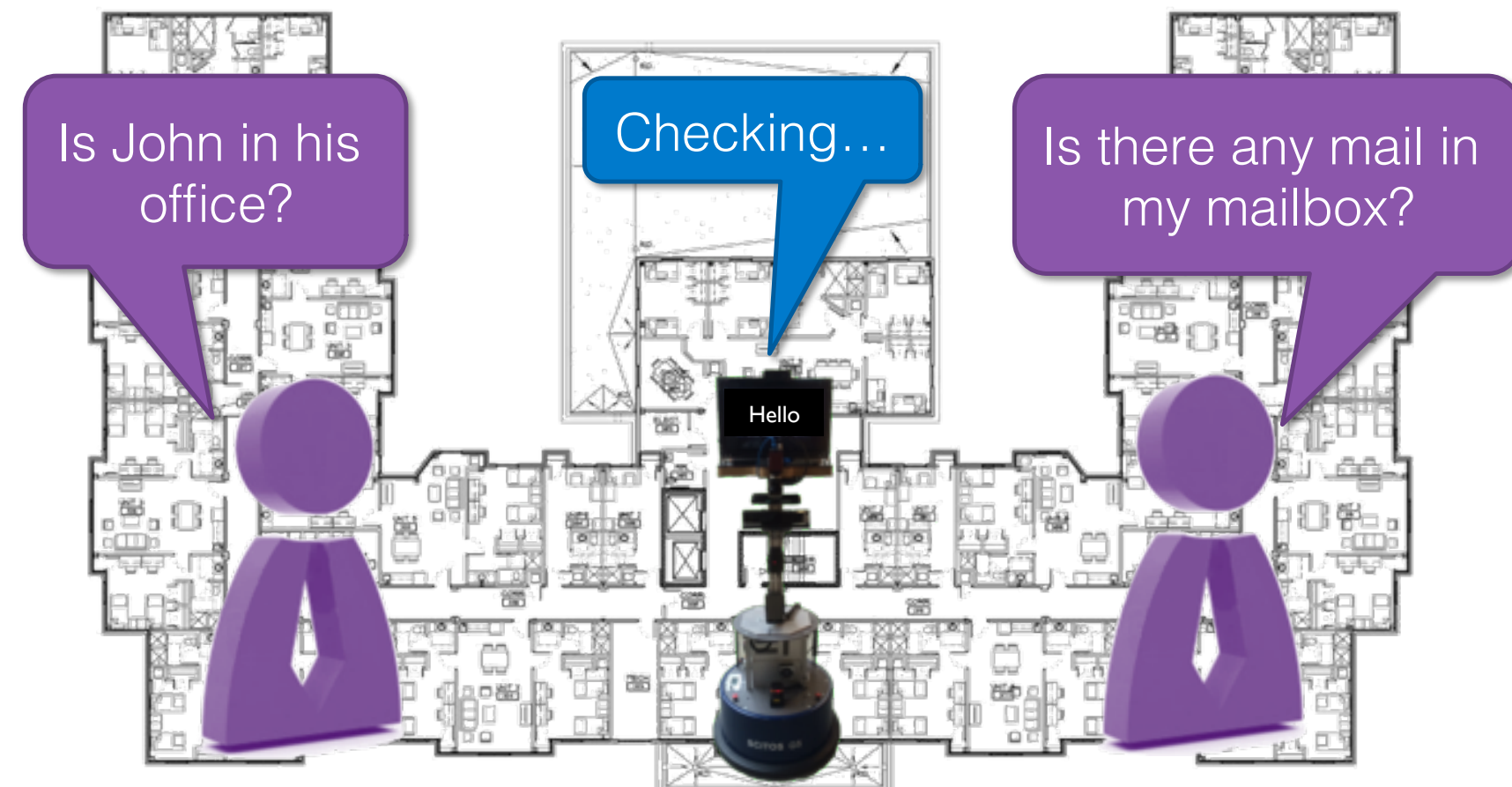


Autonomous Question Answering with Mobile Robots in Human Populated Environments

InfoBot: Information Gathering Robots

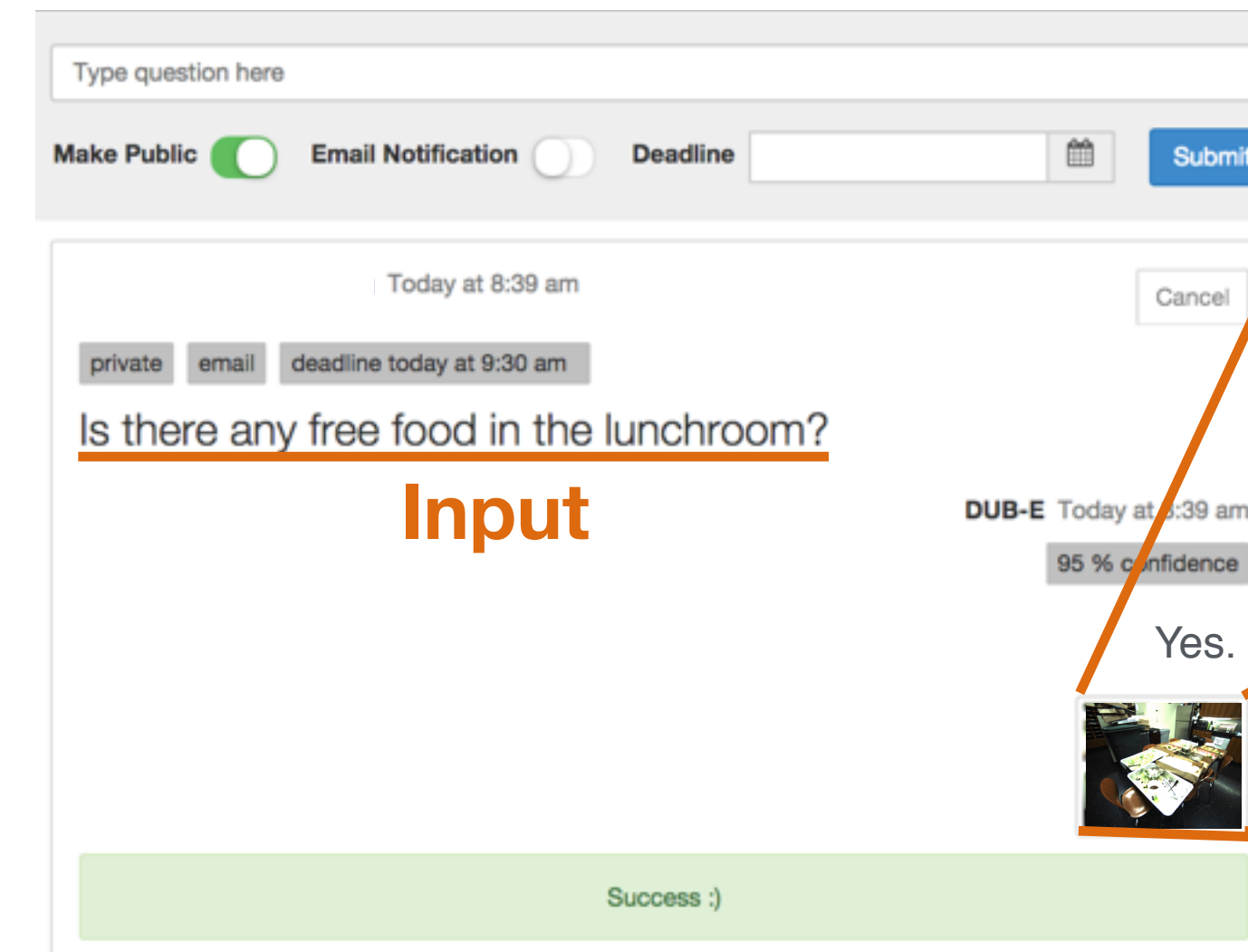
- Humans in **large dynamic environments** spend considerable time collecting up-to-date information.
- Continuously operating, autonomous mobile robots equipped with multiple sensors has a potential to become **powerful information gathering** agents.
- **InfoBots assist humans** by providing them with **up-to date environment knowledge** (e.g. **checking tasks** in Chung et al. IROS 2015).



Challenges

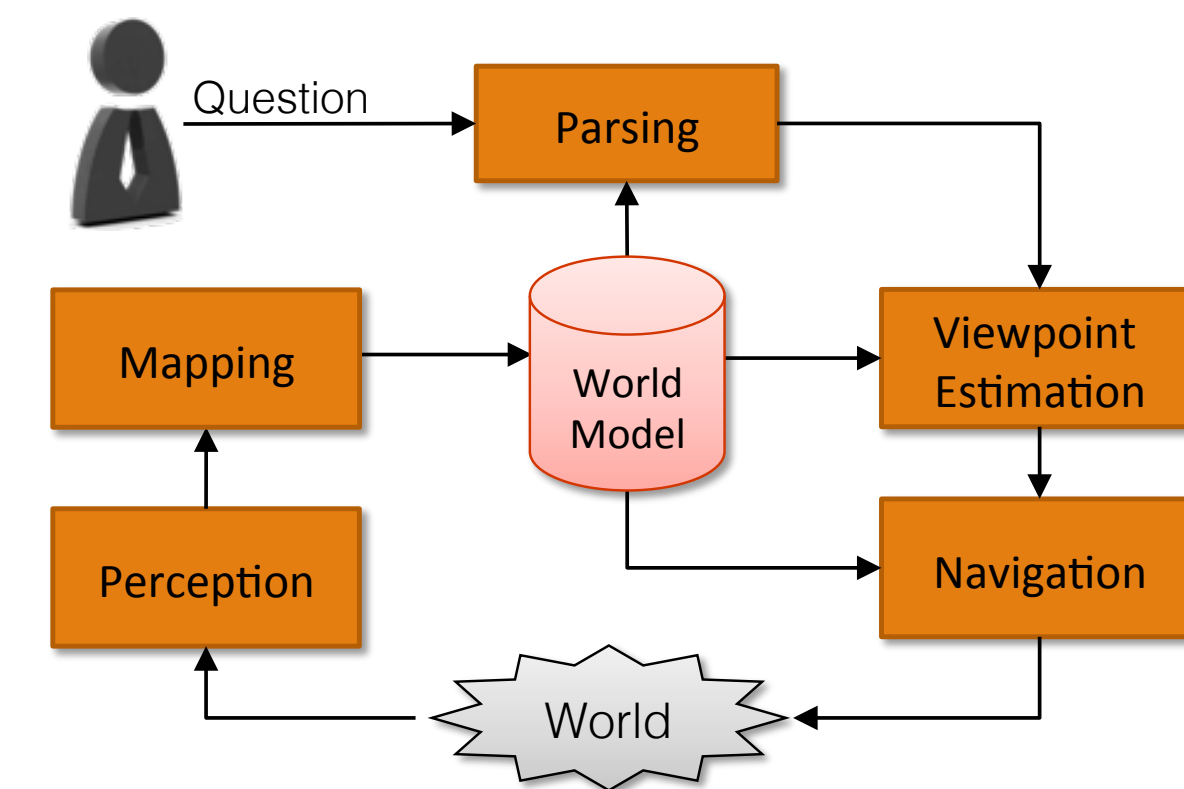
- InfoBots must **understand** unstructured human environments.
- InfoBots must **handle** dynamic changes in human environments.
- InfoBots must understand **natural language instructions**.
- InfoBots must obtain and deliver **relevant information** to the user.

End to end System



Operation

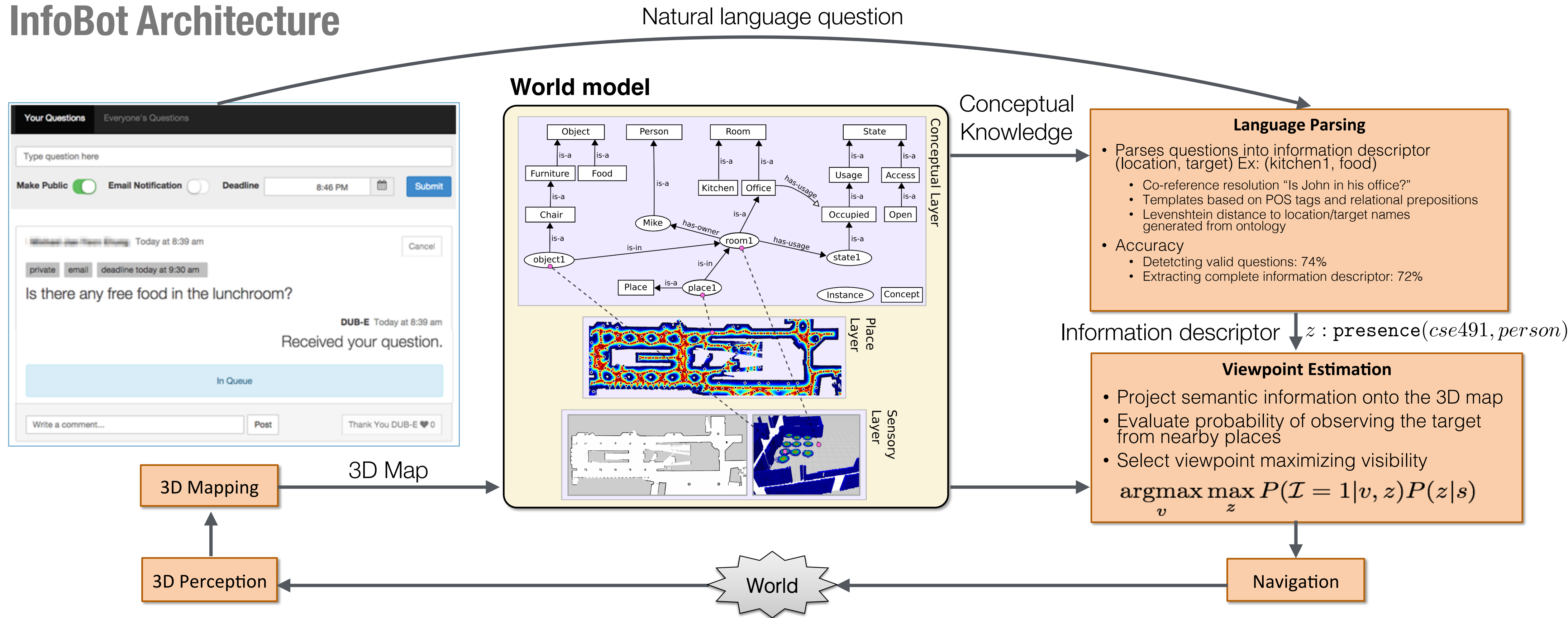
1. **Parse** natural language question
2. **Estimate** an initial viewpoint answering the question
3. **Navigate** to the viewpoint, while:
 - **updating** 3D environment representation
 - **refining** the viewpoint estimate
4. **Deliver** an answer (e.g. a picture) to the user via web UI



Autonomous Question Answering with Mobile Robots in Human Populated Environments



InfoBot Architecture



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* equal contribution

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Autonomous Question Answering with Mobile Robots in Human Populated Environments



Formative Study: WoZ Deployment

Procedure

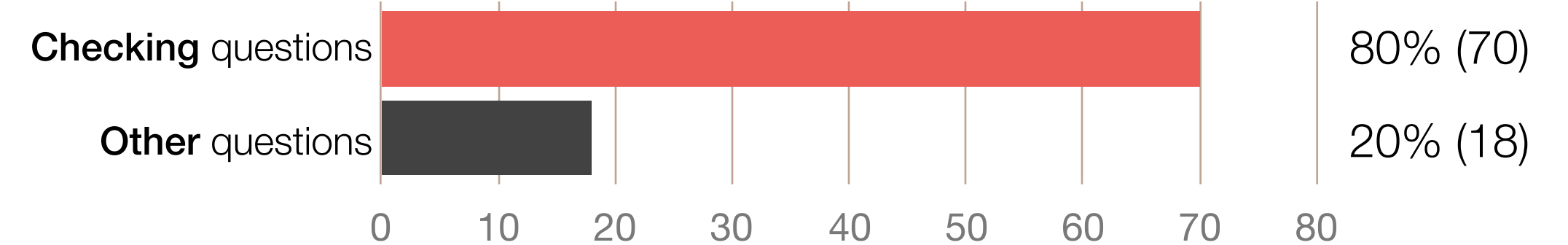
- Deployed InfoBots service for 4 days (9am-5pm) in UW CSE building.
- The operator accepted the question only if it was a valid question that could be answered through a static picture taken by the robot.
- Received total 88 questions from 45 unique users.
- Conducted a post-deployment survey 20 users who were interested in participating.

User interface

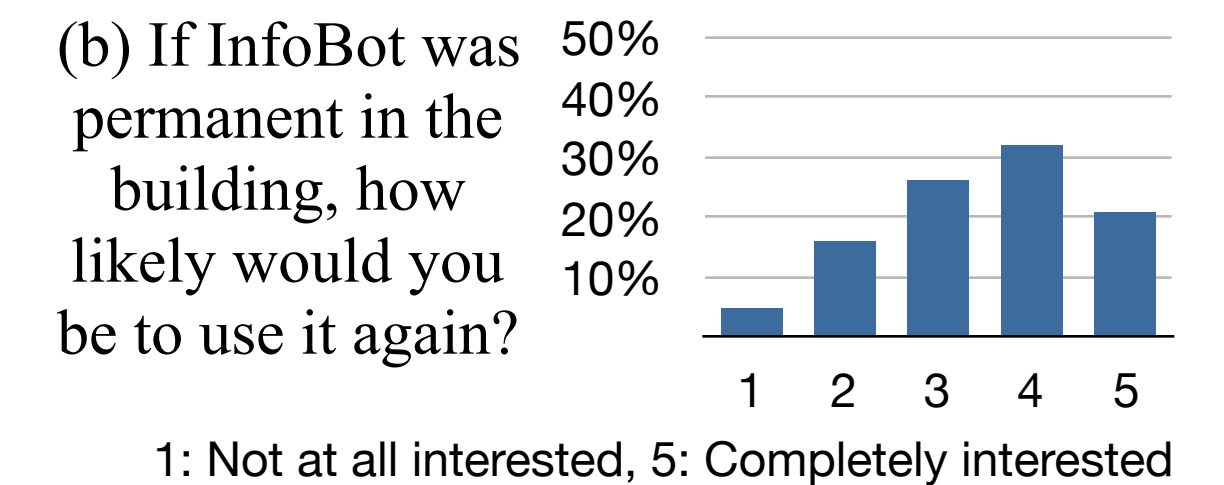
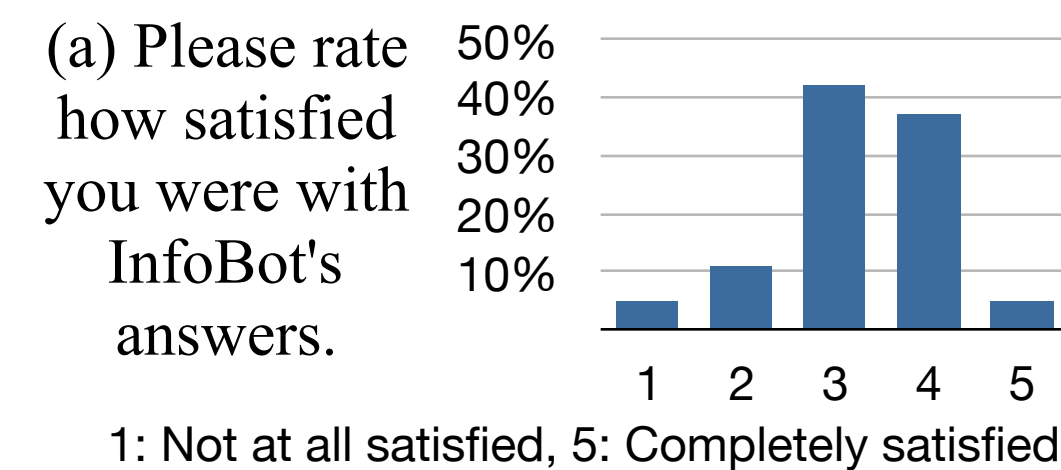
Output



Sampled user question	Type
<i>Is there anyone in {location}?</i>	checking
<i>Is {person} in his/her office?</i>	checking
<i>Is there any food in the downstairs kitchen?</i>	checking
<i>Is there anything in my mailbox?</i>	checking
<i>Does {name}'s office have a sofa?</i>	checking
<i>Is the reception still open?</i>	checking
<i>Who let the dogs out? :)</i>	other
<i>Has {name} arrived yet today in the CS building?</i>	other
<i>Which meeting room has the best visibility of the {landmark} today?</i>	other



Post-deployment Survey



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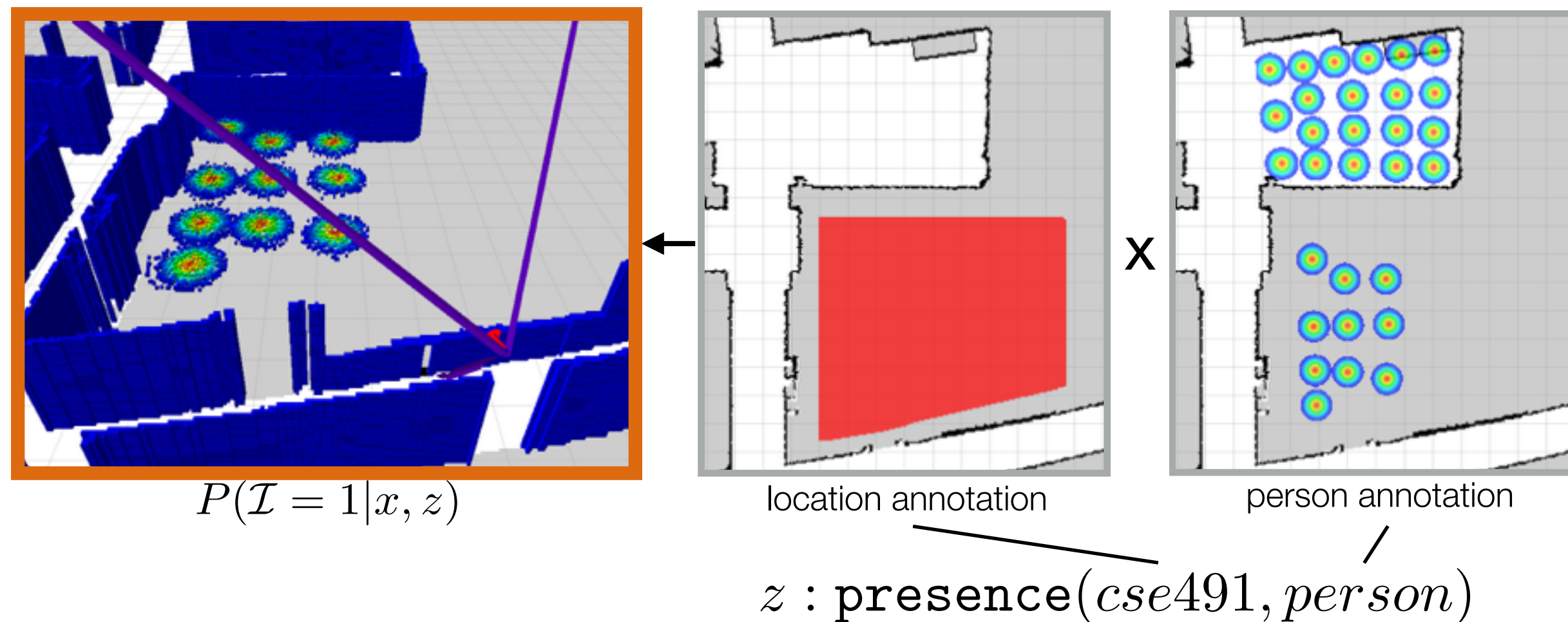


Viewpoint Estimation

$$v^* \approx \operatorname{argmax}_v \max_z P(\mathcal{I} = 1 | v, z) P(z | s)$$

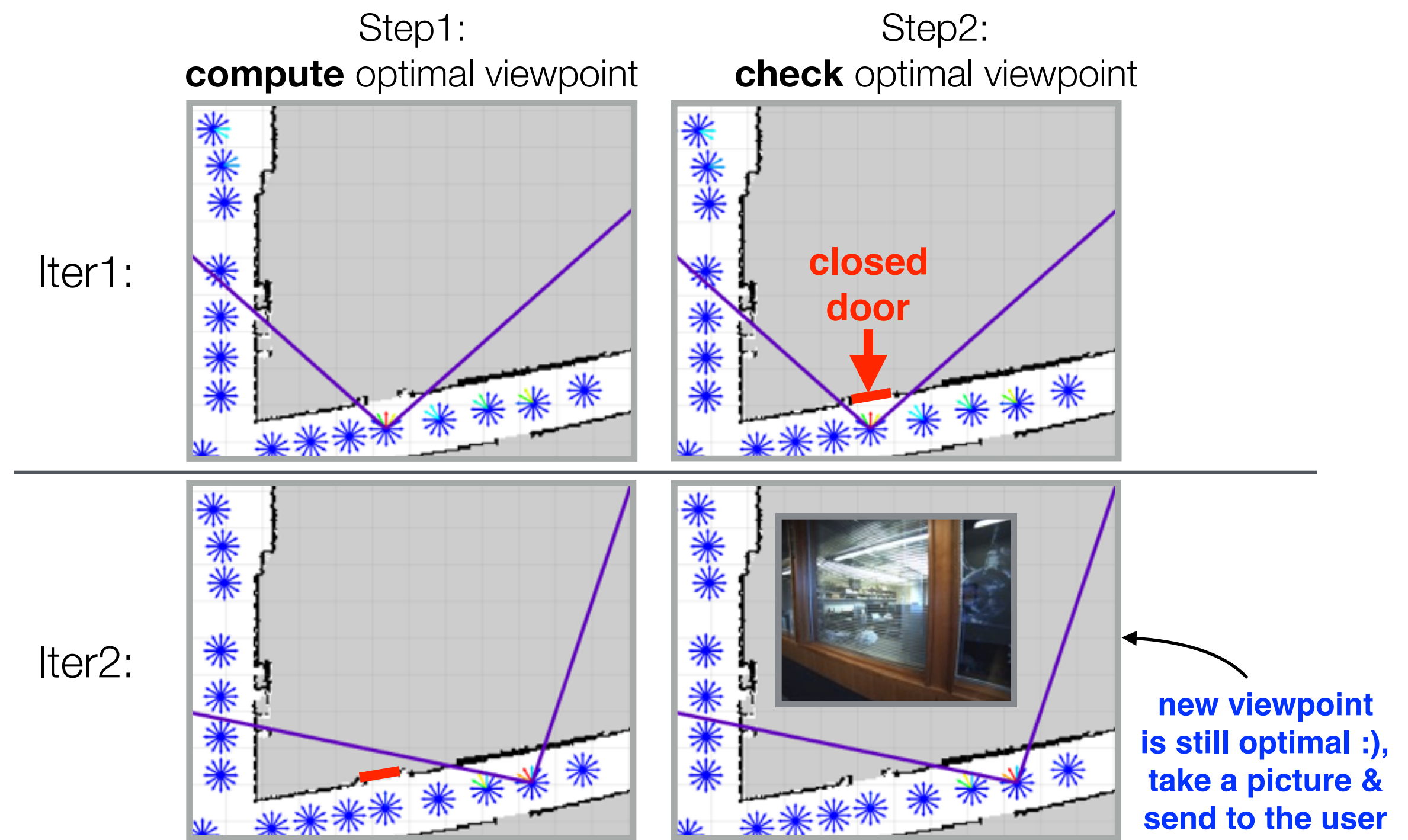
$$P(\mathcal{I} = 1 | v, z) = \sum_x P(\mathcal{I} = 1 | x, z) P(x | v)$$

information presence
visibility



Iterative Refinement

$$v^* \approx \operatorname{argmax}_v \max_z P(\mathcal{I} = 1 | v, z) P(z | s)$$



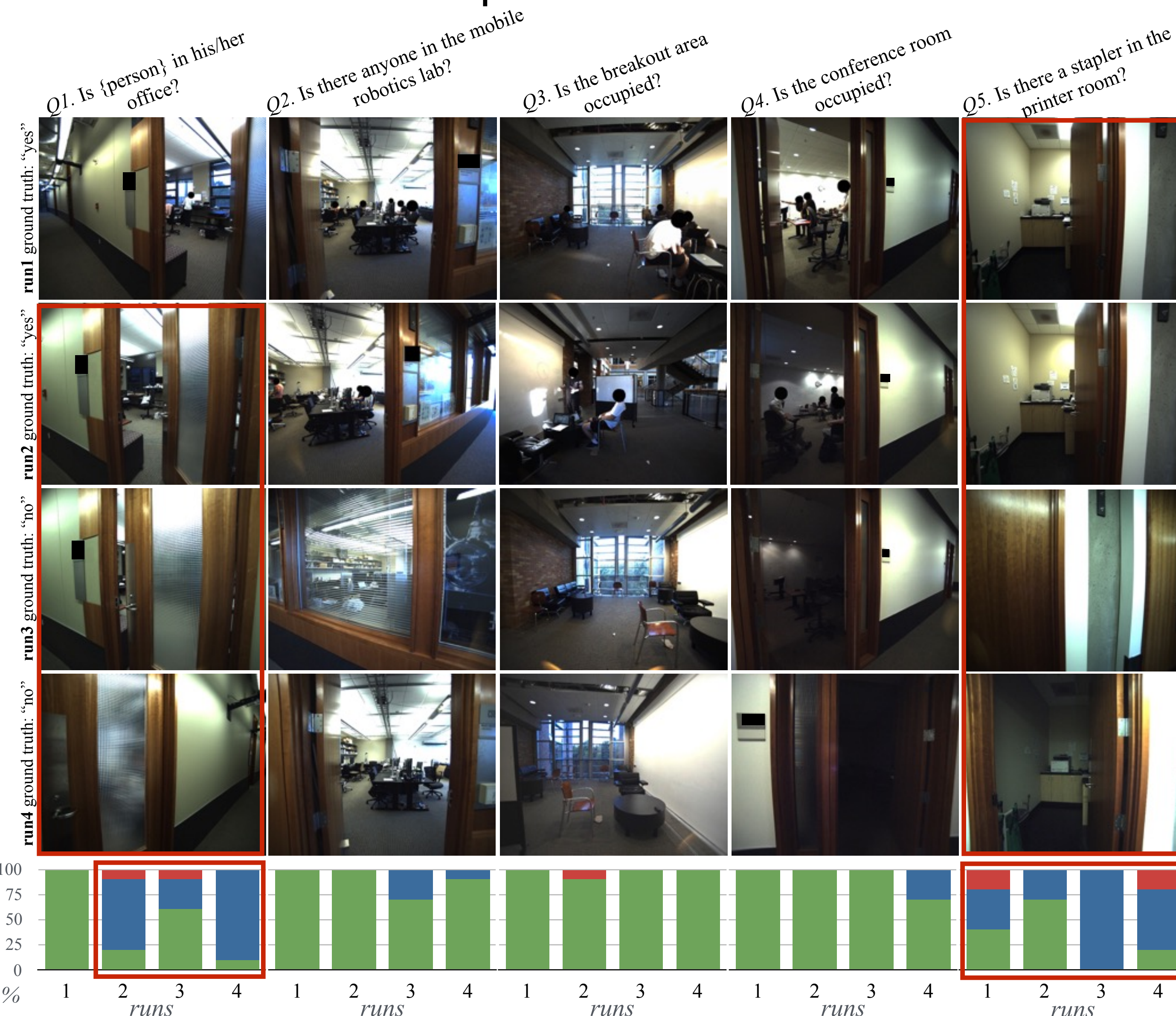
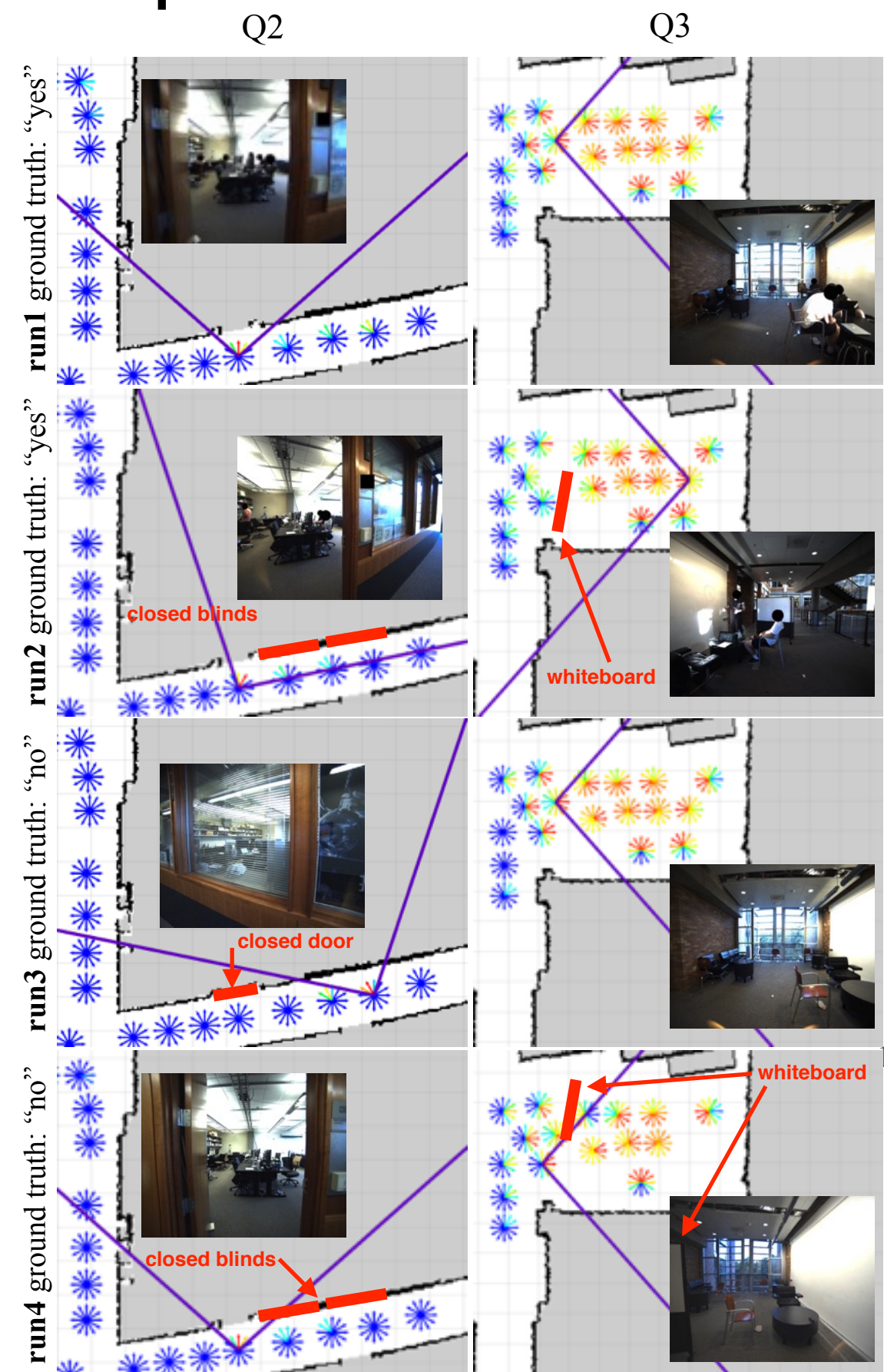
Autonomous Question Answering with Mobile Robots in Human Populated Environments



Experiment 1

- Ran viewpoint estimation on 5 real user questions for 4 times.
- Carefully controlled the environment to have 2 “yes”s and 2 “no”s.
- Asked 10 building occupants to answer the corresponding questions.

Viewpoint estimation details



Summary

- Q2—Q3 achieved above %80 average accuracy
- Cases where the algorithm struggled is due to the physical limitation of the robot.

Experiment 2

- Ran viewpoint estimation algorithm on previously collected data with inputs:
Q6: Was {person} in his/her office
Q7: Was the breakout area occupied?



Calculated using the ground truth labels