

Probabilistic Online Prediction of Robot Actions Results based on Physics Simulation

“Functional Imagination“

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Is a Cambrian Explosion Coming for Robotics?

Gill A. Pratt

Eight Technical Drivers

1. Exponential growth in computing performance
2. Improvements in electromechanical design tools and numerically controlled manufacturing tools
3. Improvements in electrical energy storage
4. Improvements in electronics power efficiency
5. Exponential expansion of the availability and performance of local wireless digital communications
6. Exponential growth in the scale and performance of the Internet
7. Exponential growth of worldwide data storage
8. Exponential growth in global computation power

Is a Cambrian Explosion Coming for Robotics?

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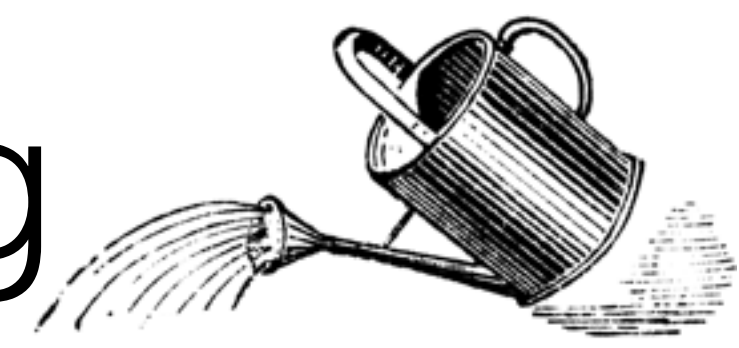
Cloud Robotics: Big Idea #3: Learning from Imagination



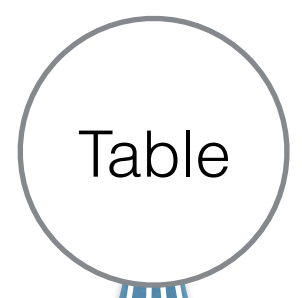
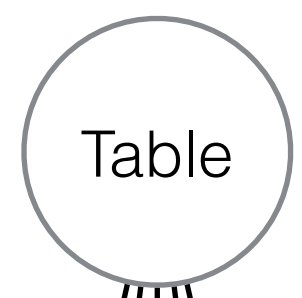
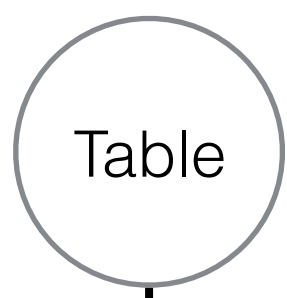
Outline

1. Related Work
2. Architecture & Integration
3. Uncertainty
4. Experiments & Results
5. Conclusion

Task Planning



symbolism



discreteness

x,y,z

x,y,z

x,y,z

x,y,z

x,y,z

x,y,z

...

continuity



Functional Imagination

- improve task-planning based system
- use prediction from physical simulation
- integrate prediction
- use predicted results to adapt plan execution
- forestall failures

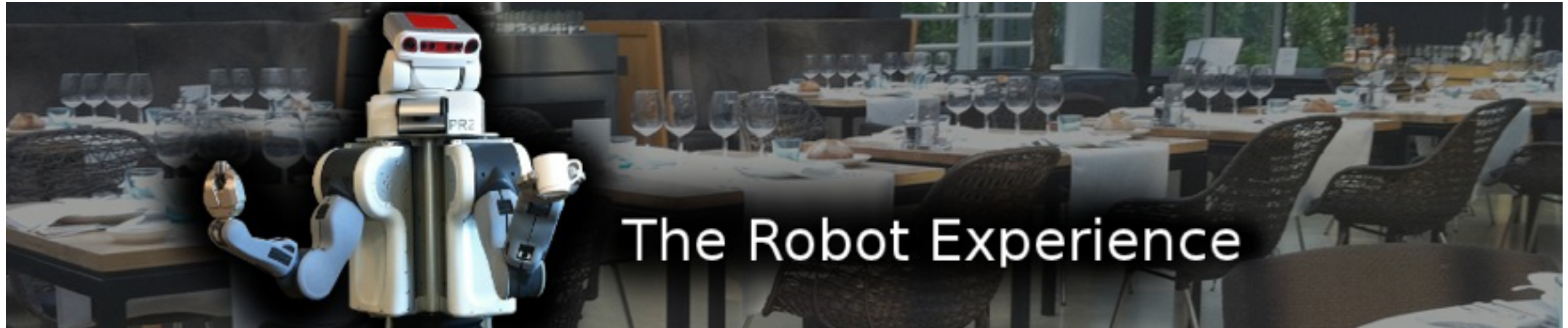


Related Work

- concurrent reactive planning (Beetz 2000)
- meta-CSP: hybrid planning/reasoning (Moffit et al. 2006)
- functional imagination (Marques et al. 2008)
- GTP + HTN (de Silva et al. 2013)

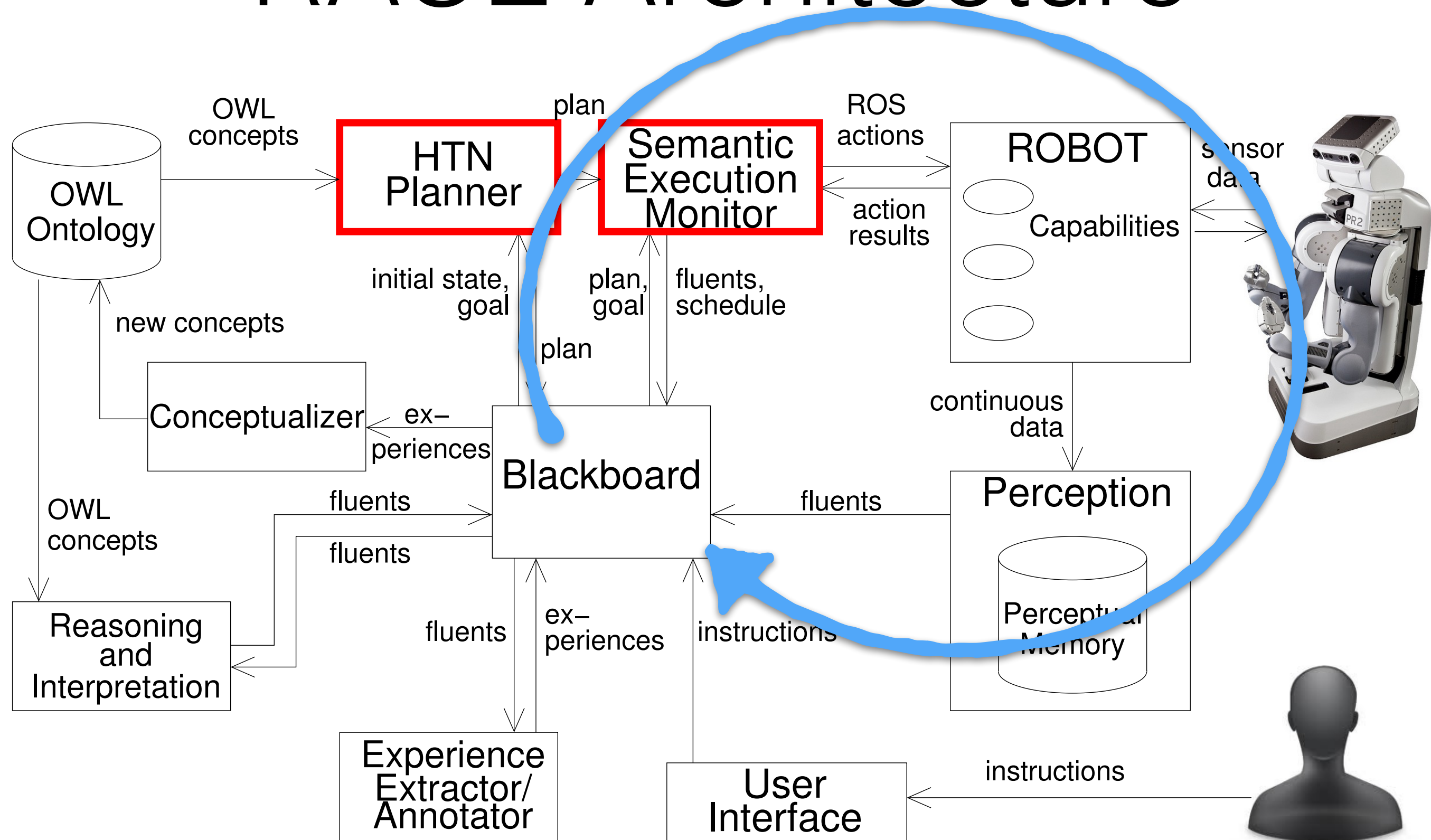


(2012-2015)



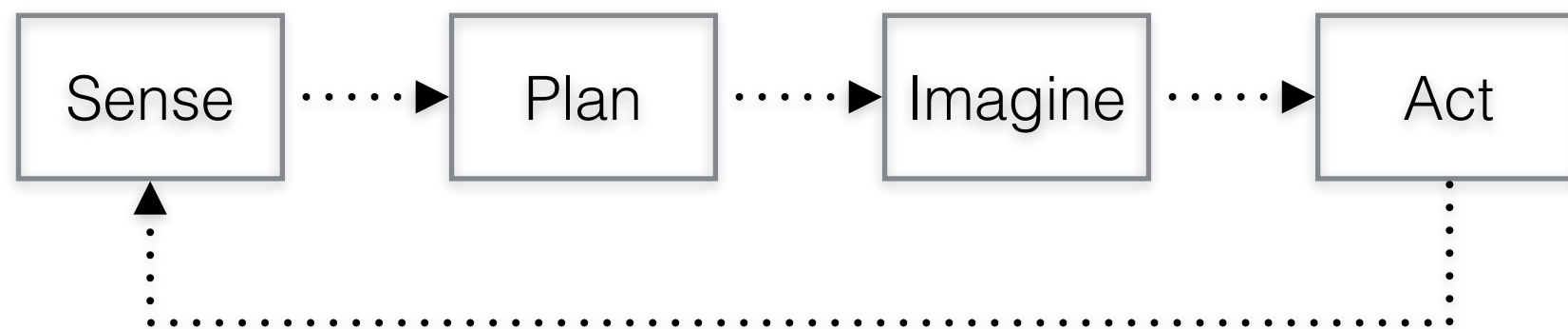
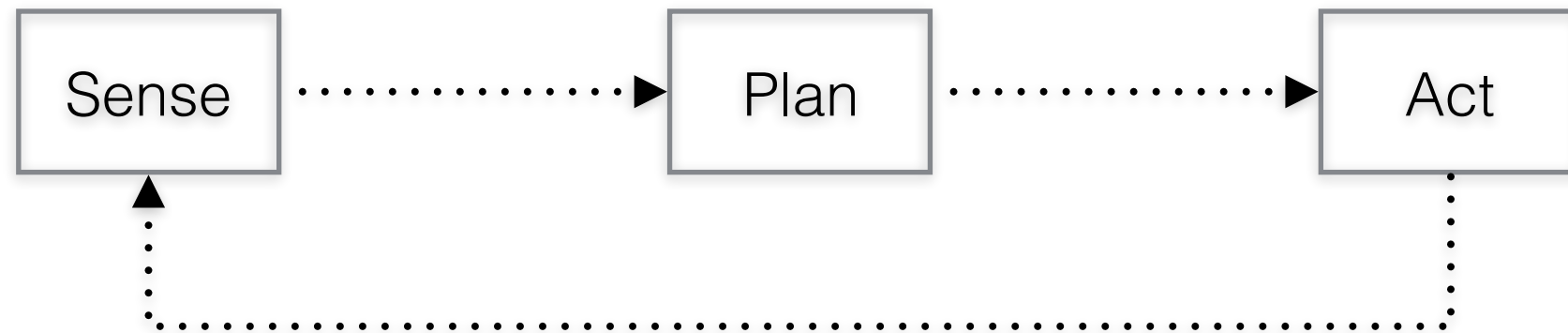
- "Robustness by Autonomous Competence Enhancement"
- high-level world representation
- multi-level experience representation
- learning and generalizing from experiences

RACE Architecture



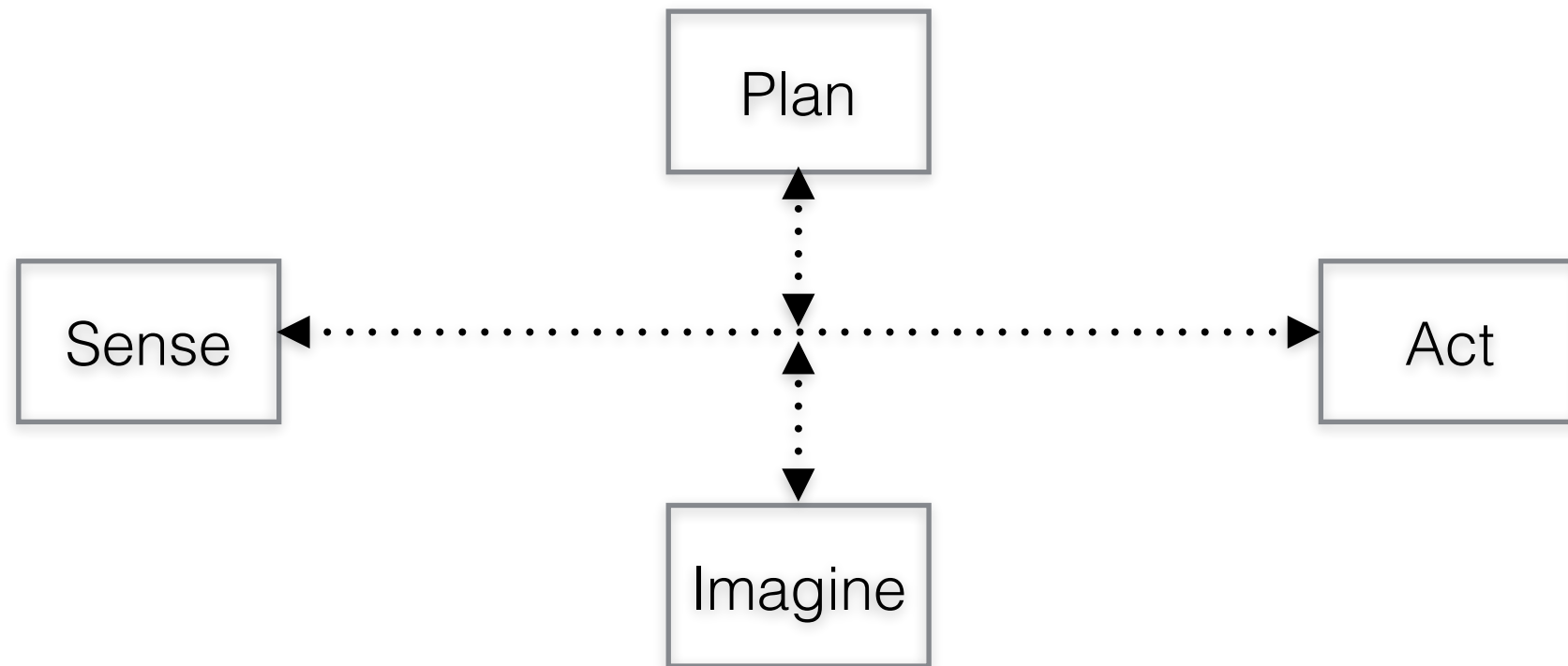
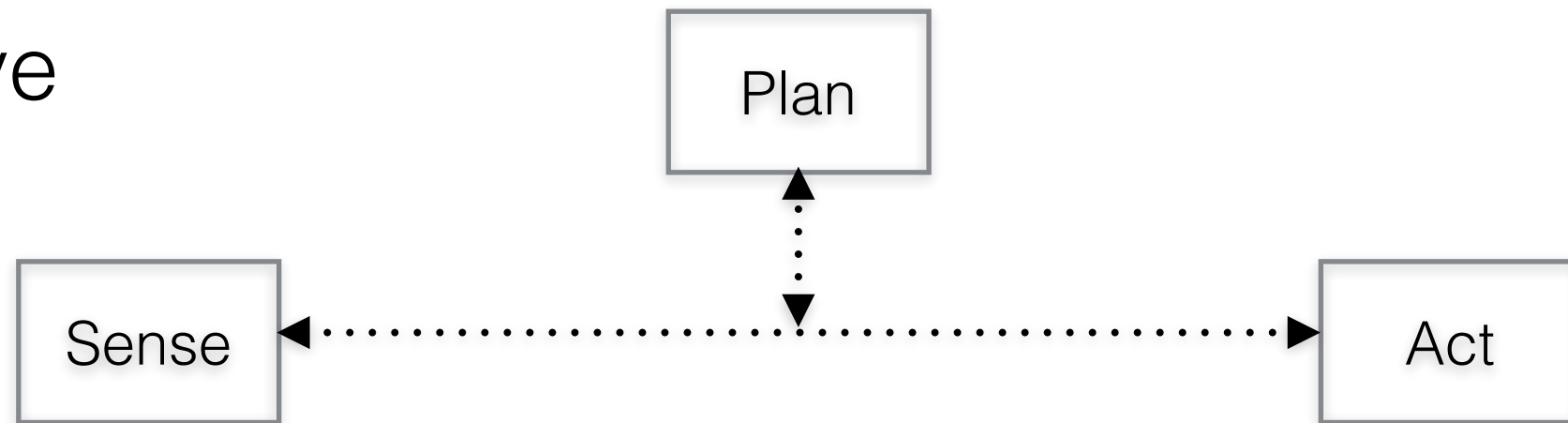
Methodology

hierarchical

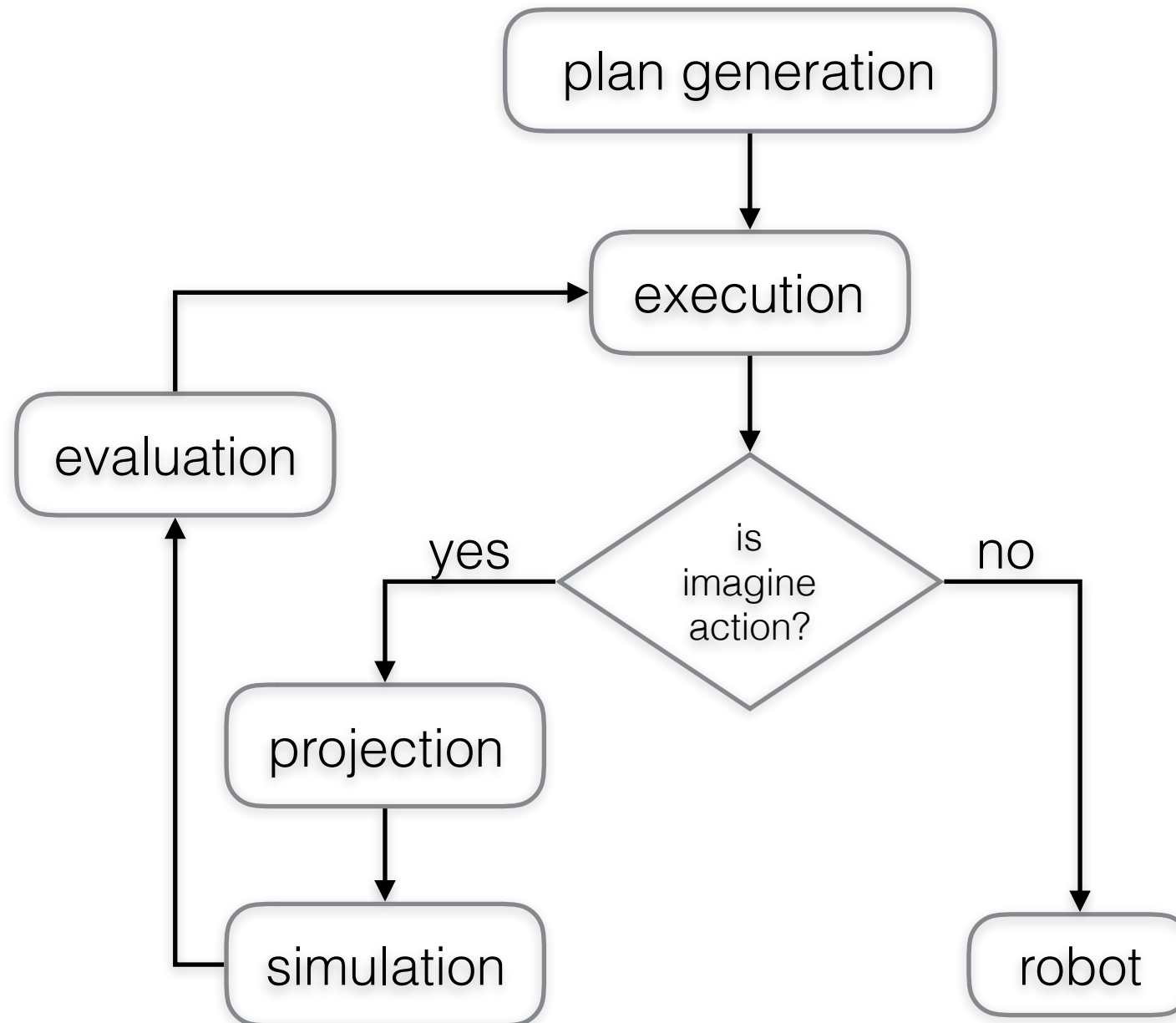


Methodology (cont'd)

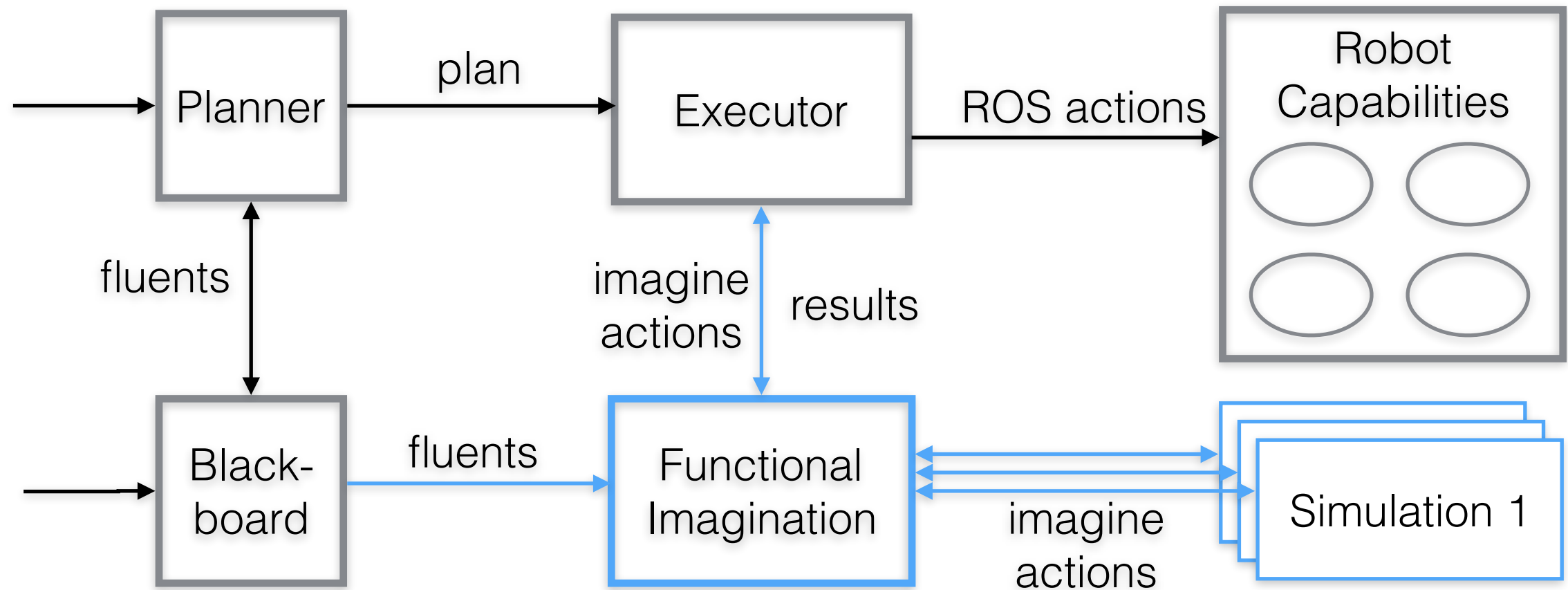
reactive



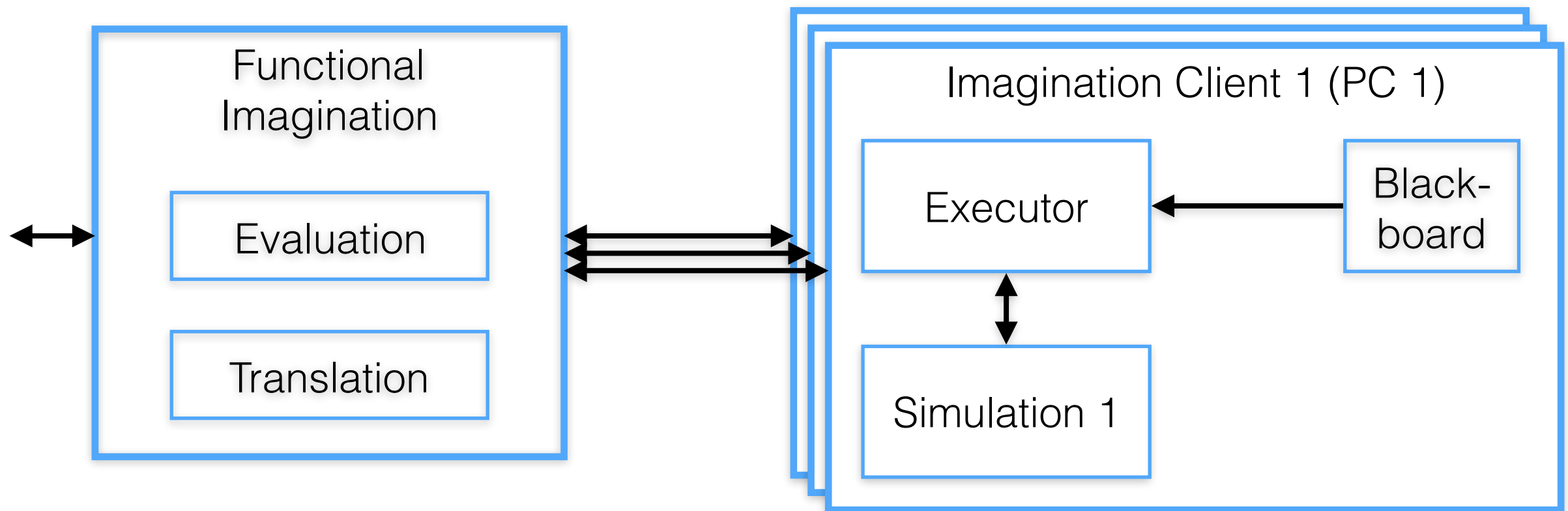
Processing



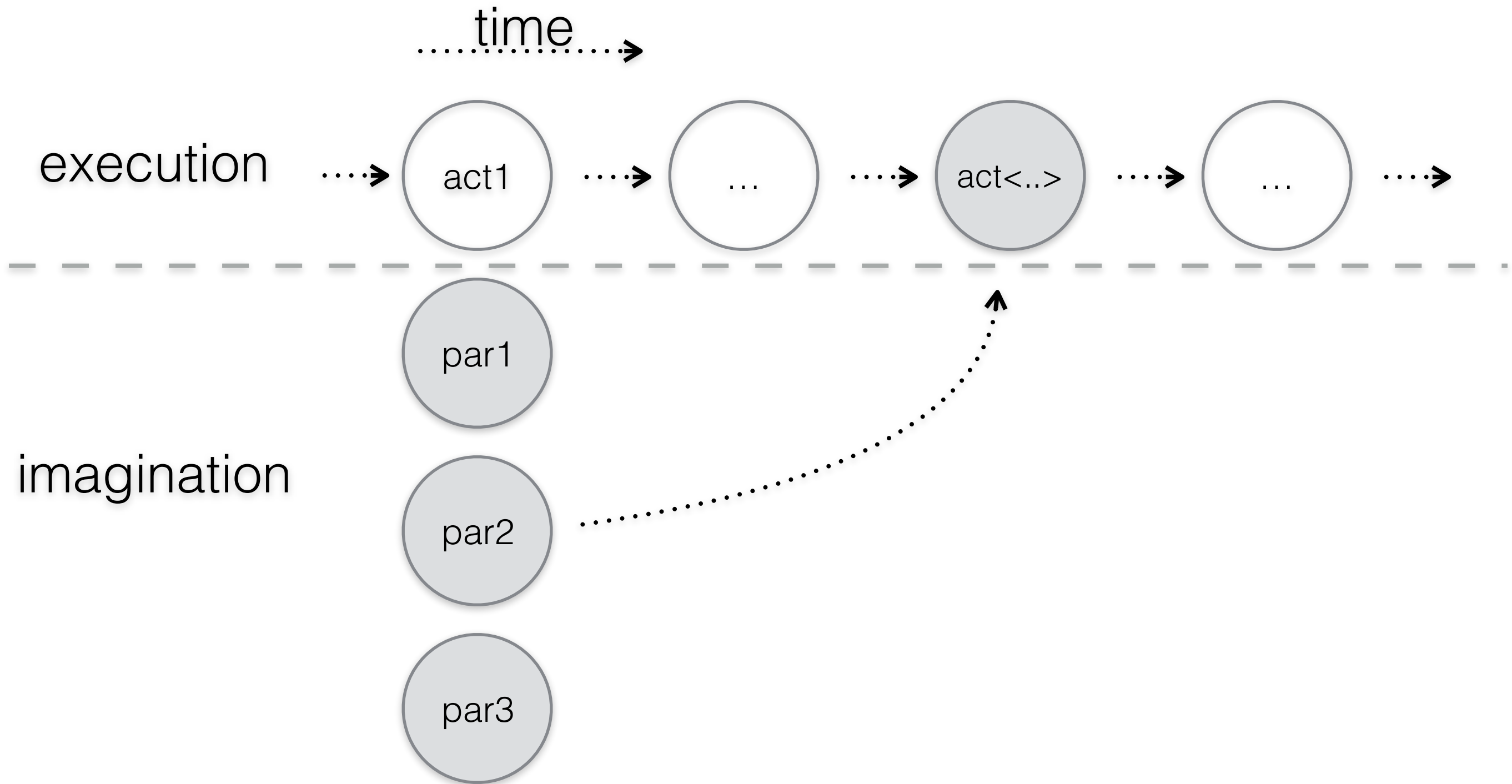
Architecture



Architecture (cont'd)

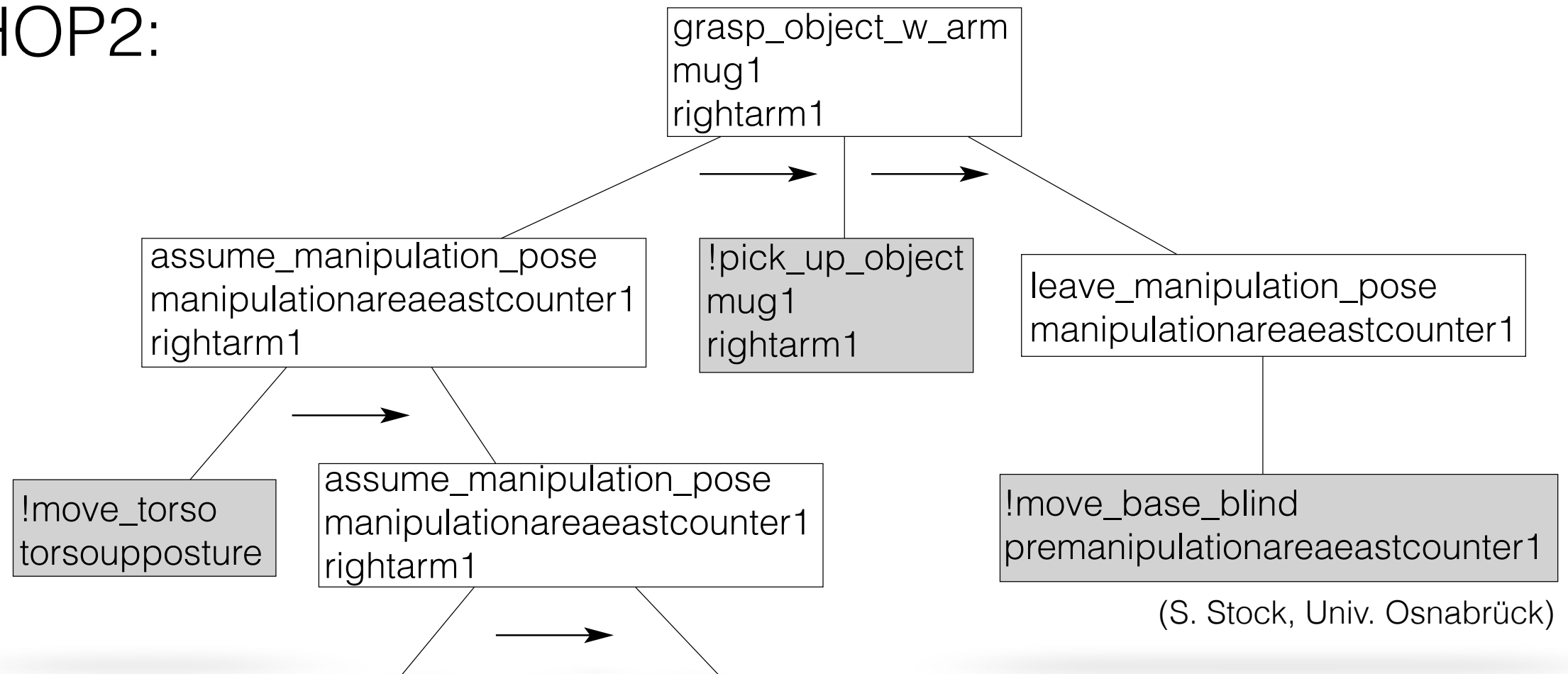


Plan Adaptation



Plan Adaptation (cont'd)

SHOP2:



(S. Stock, Univ. Osnabrück)

!imagine ?task ?arg1 ?arg2

!imagine !move_base_param ?area slow/fast

Execution & Imagination

- **projection**: generate world state for each `!imagine` action
- **translation**: converting symbolic (blackboard) values in discrete coordinates
- FI evaluates best confidence and shortest time
- FI returns ordered list of parametrization + duration

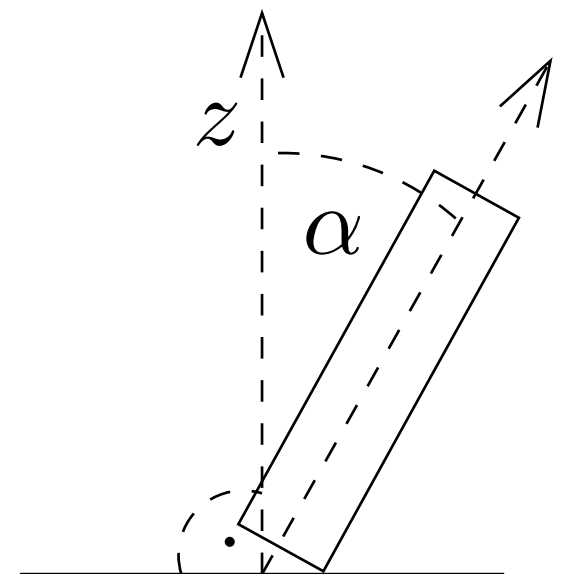
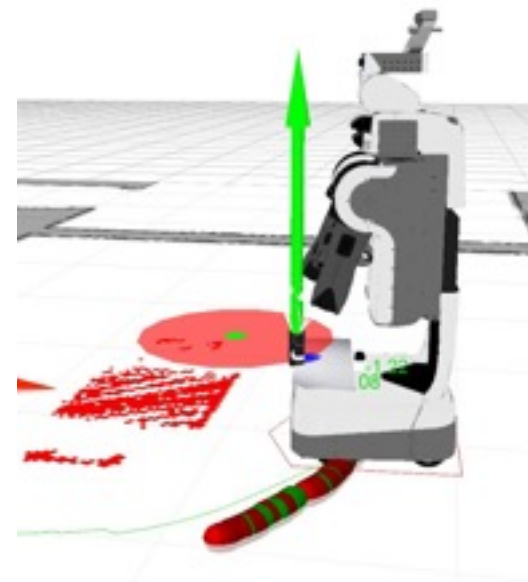
Sampling

- sampling: $f_s = 20Hz$

- discretization:
$$x = \begin{cases} event_1, & \text{if } condition_1 \\ event_2, & \text{if } condition_2 \\ event_3, & \text{if } condition_3 \\ \dots, & \dots \end{cases}$$

- carry tall object:

$$x = \begin{cases} notopple, & \text{if } \alpha \leq \alpha_n \\ topple, & \text{if } \alpha \geq \alpha_t \\ shaking, & \text{if } \alpha_n < \alpha < \alpha_t \end{cases}$$



Handling Uncertainty

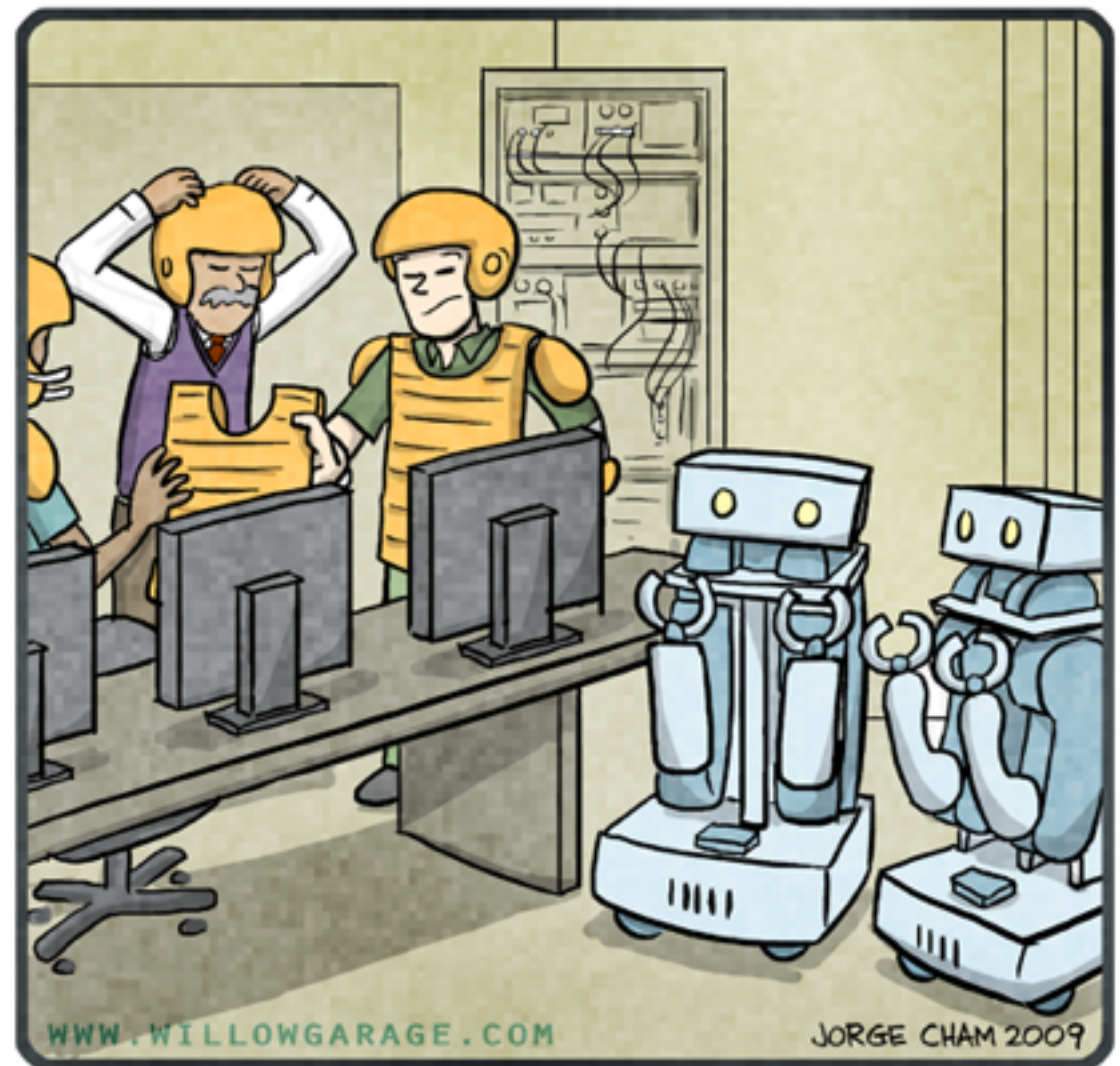
- variables: a_1 (event 1), a_2 (event 2), .. $a_n = \sum x_n$
- empirical coefficients: c_1 (event 1), c_2 (event 2), ..
- confidence:
$$c = \left(\frac{a_1 \cdot c_1 + a_2 \cdot c_2 + a_3 \cdot c_3 \dots}{a_1 + a_2 + a_3 \dots} \right)^{-1}$$
$$c = (0, 1] := \{c \in \mathbb{R}^+ \mid 0 < c \leq 1\}, a_1 + a_2 + a_3 \dots > 0$$
- carry tall object:
$$c = \left(\frac{a_t \cdot c_t + a_s \cdot c_s + a_n \cdot c_n}{a_t + a_s + a_n} \right)^{-1}$$
$$c_t = 100, c_s = 10, c_n = 1$$

Assumptions & Limitations

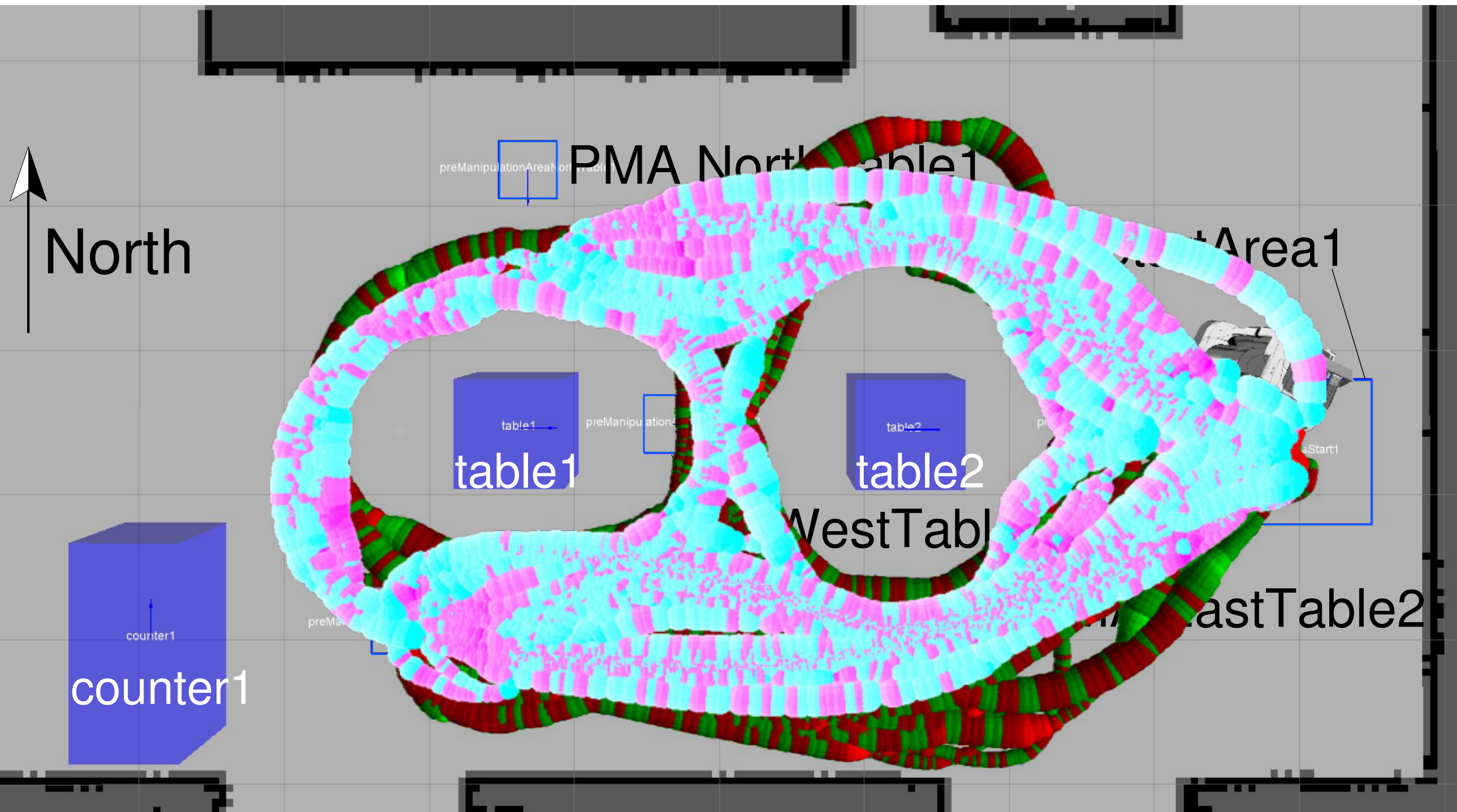
- discrete thresholds (empirically defined)
- discrete (action) parameter set
- one action per imagination (plan-step sync)
- performance correlation to simulation granularity
- exogenous events rarely occur
- "challenging" simulation

Experiments

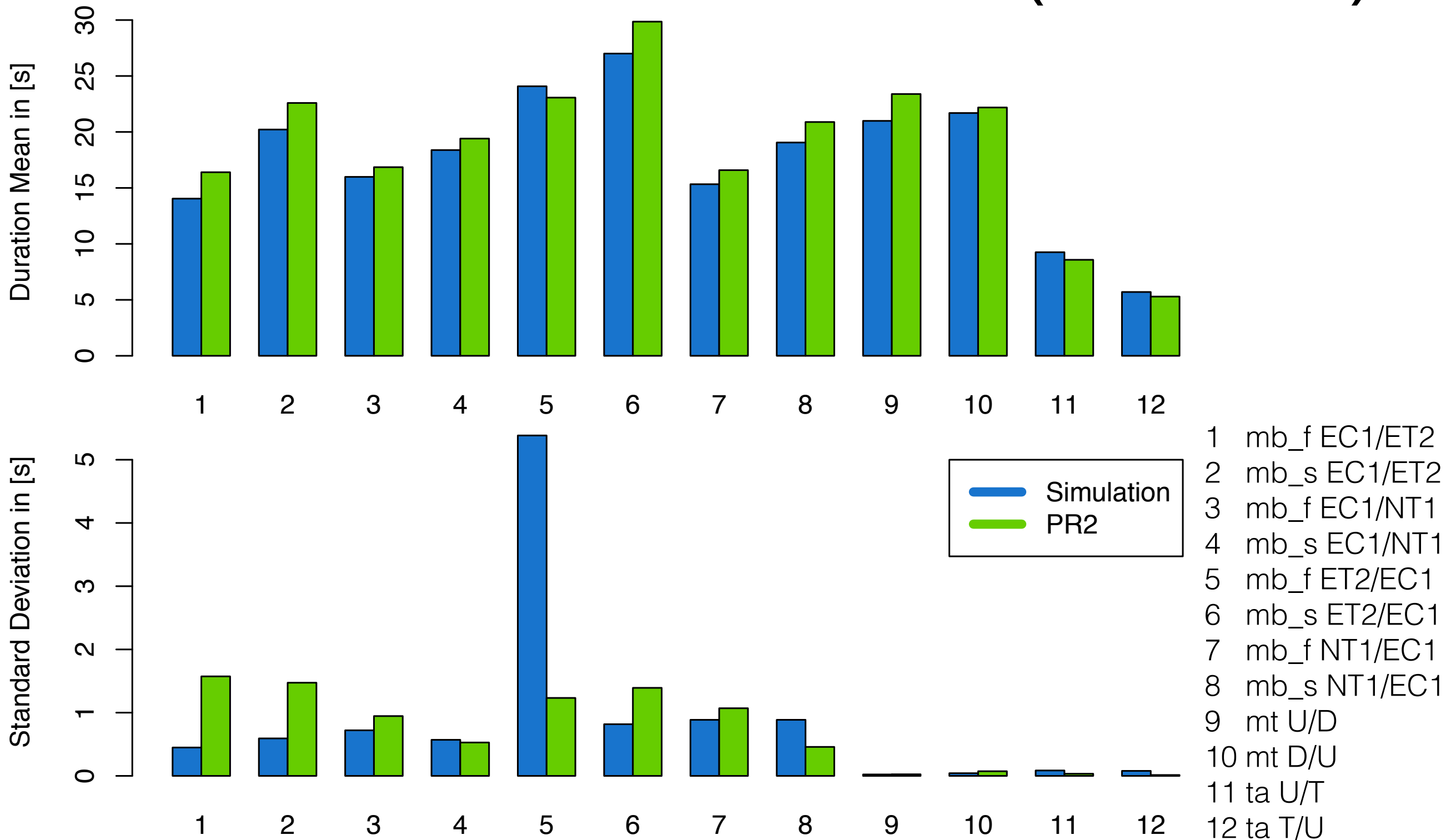
1. simulation validation
2. recognition & manipulation
3. serve a coffee
4. carry a tall object



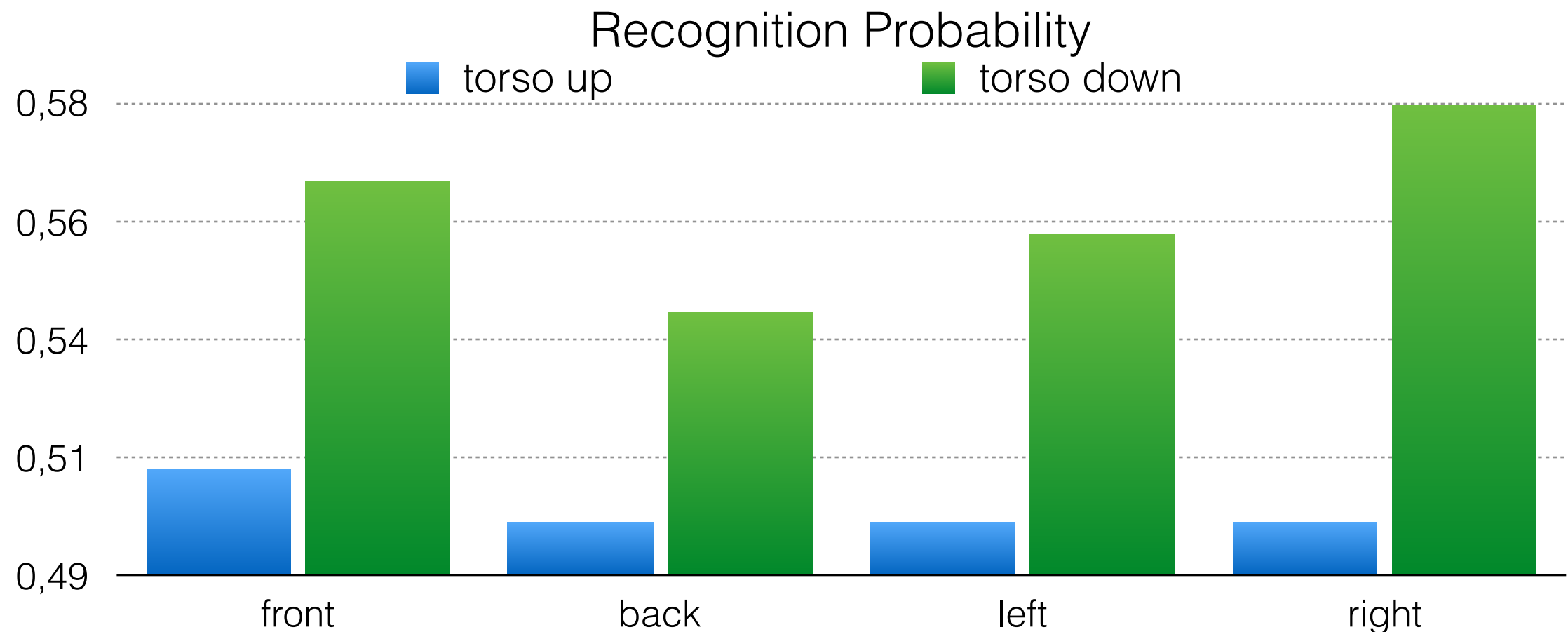
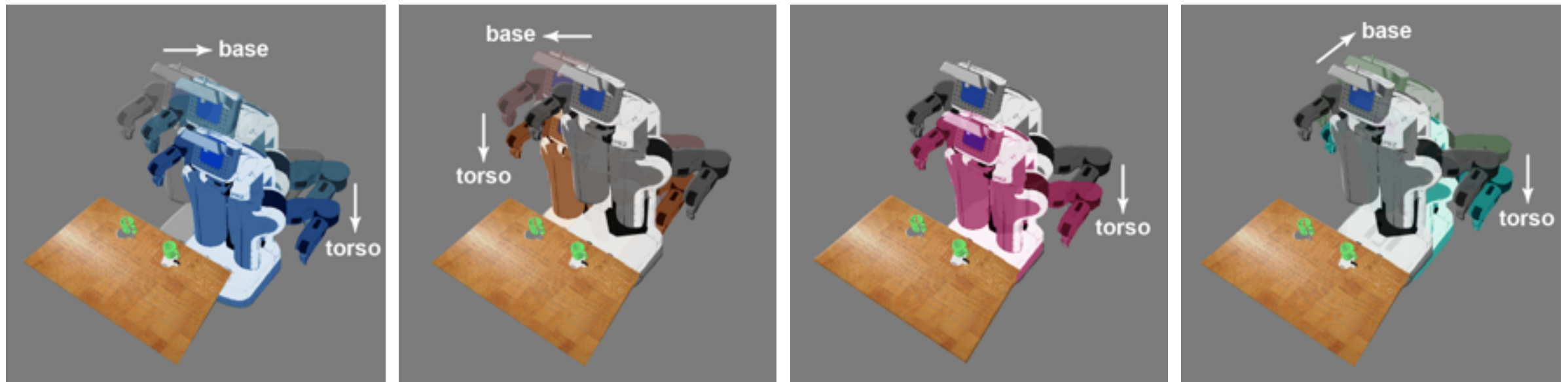
Simulation Validation



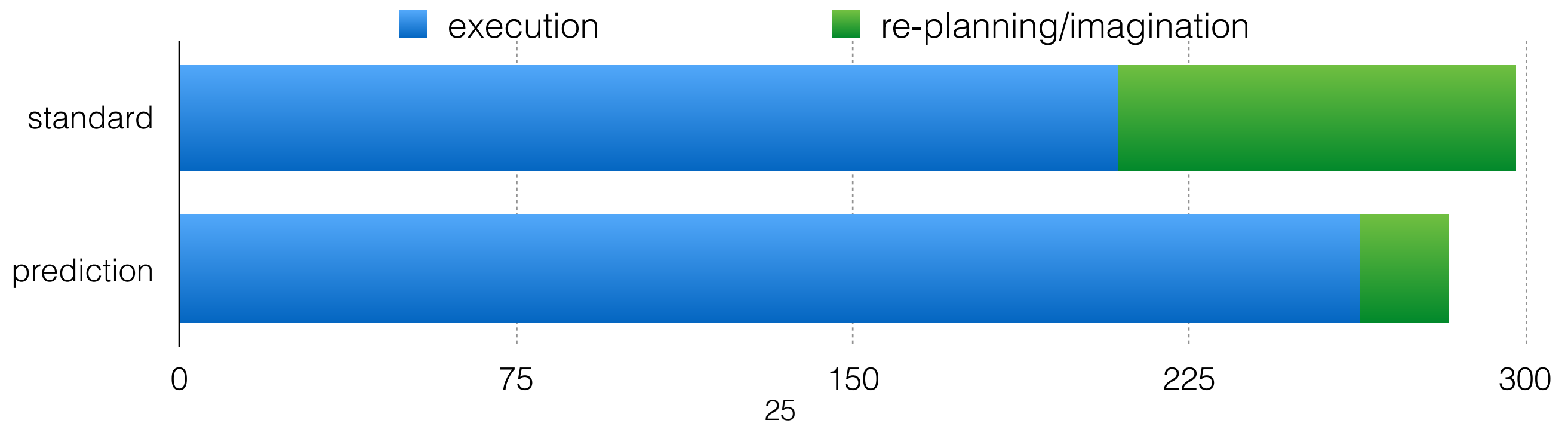
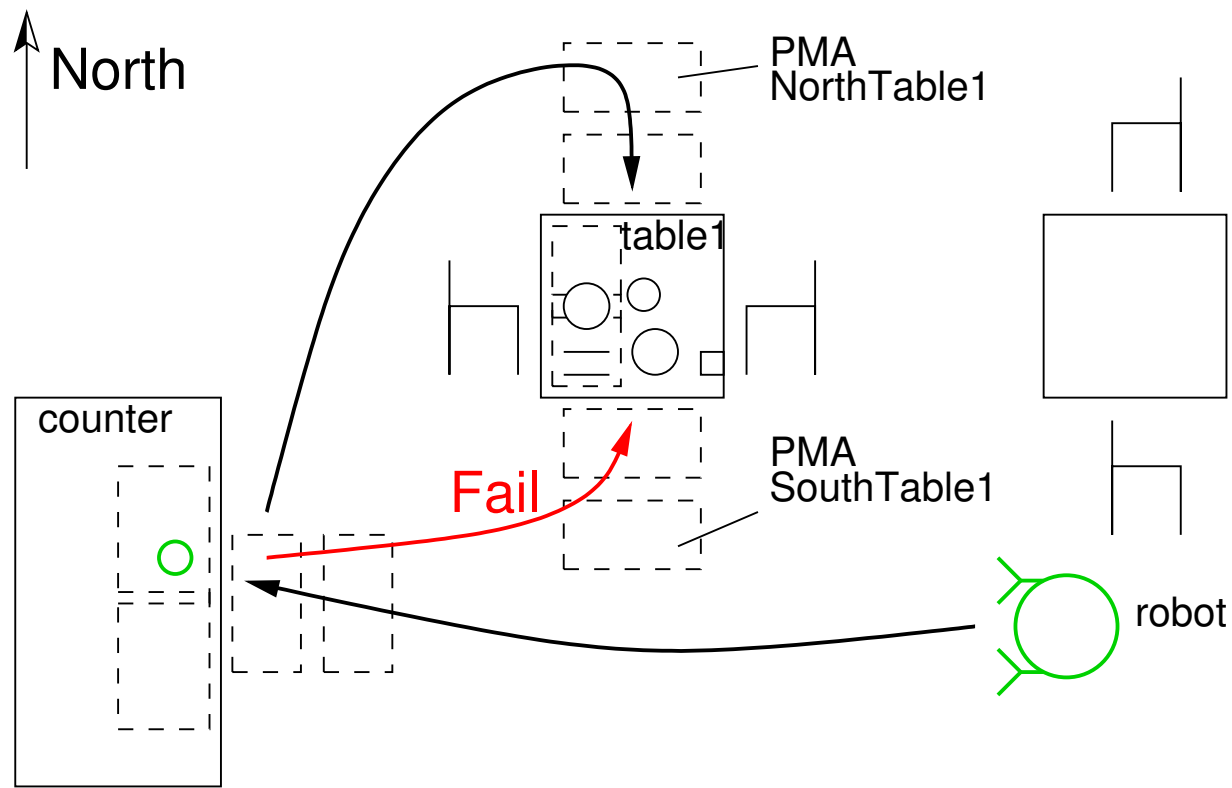
Simulation Validation (cont'd)



Recognition & Manipulation



Serve a Coffee (ICRA 2014)

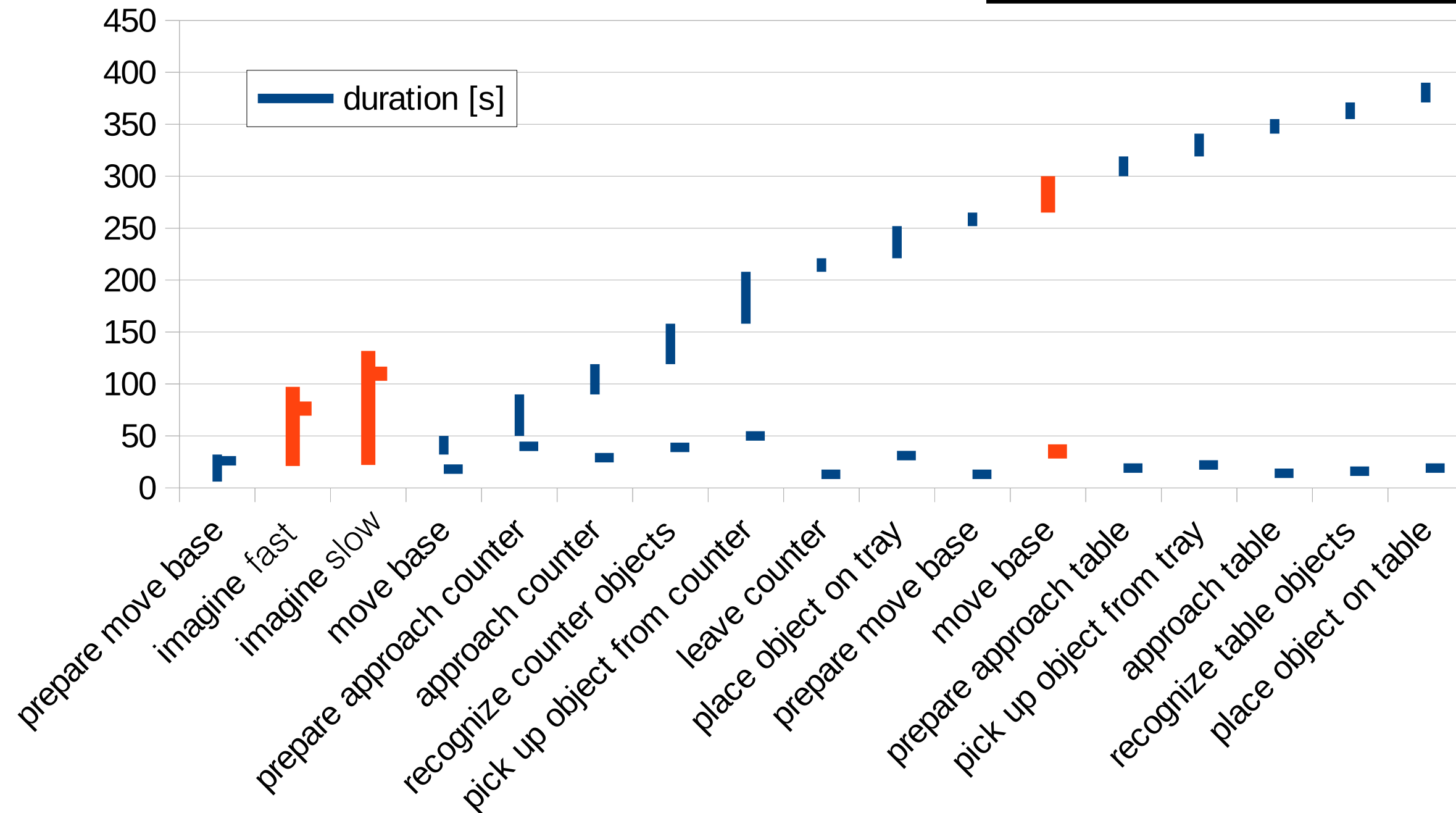
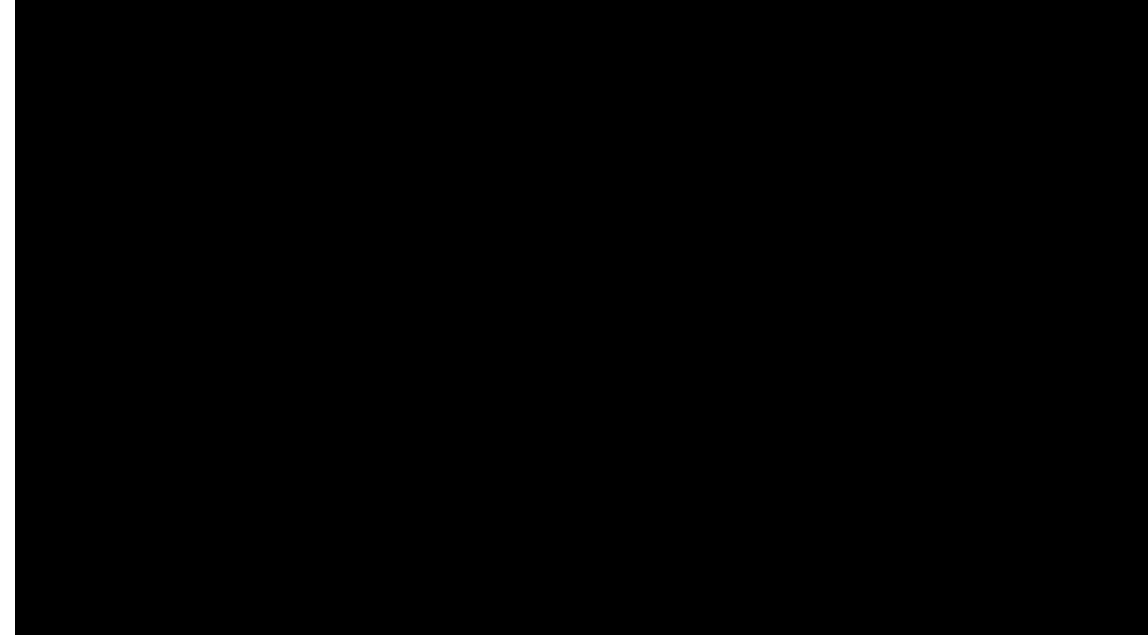


Carry a Tall Object (IROS 2015)

Carry a Tall Object

Object

(IROS 2015)



My code online available..

- https://github.com/buzzer/pr2_imagination
- https://github.com/buzzer/tams_pr2



Conclusion

- improved task-planning system with "functional imagination"
- "common-sense" physics-based prediction (cf. Marques, De Silva)
- enabling hybrid reasoning (cf. Moffit)
- based on action parametrization (cf. Beetz)
- probabilistic projection (sampling, confidence)
- validation of simulation
- new system on a PR2 (out-of-the-box HTN + Gazebo)



Future Research

- improve the robot's performance in changing and partly unknown worlds
- partial plan imagination
- continuous representations (parameter + sampling)
- exploit temporal aspects (re-scheduling)
- reactive perception + imagination
- cloud robotics

Thank you for your
attention!



References

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