UNIVERSITY OF CAMBRIDGE | Institute for Technology and Humanity

Building Good Benchmarks

CFI LEVERHULME CENTRE FOR THE FUTURE OF INTELLIGENCE

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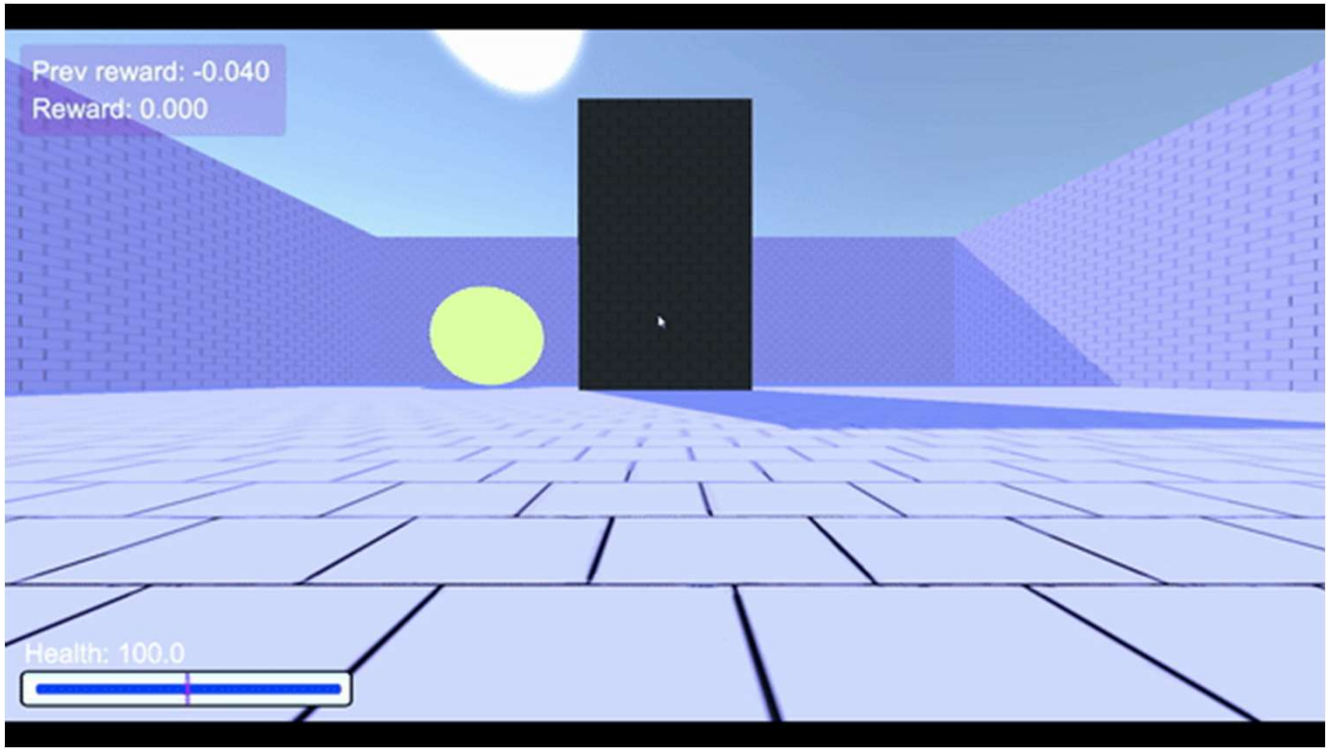
Session Plan

- Introduce key considerations for developing a useful benchmark for a measurement layout.
- Motivate the role of **theoretical knowledge** about capabilities in benchmark design and measurement layout development.
- Incrementally build a complex measurement layout for evaluating **object permanence** (and related capabilities).
- Apply this measurement layout to **real data** from DRL agents.
- Introduce several **model diagnostics** for Hierarchical Bayesian Networks.
- BONUS (if time): Extend the measurement layout to the **multivariate case**.

Choosing A (Primary) Capability

- Reinforcement Learning:
    - Long-term planning
    - Tool-use
    - Intuitive physics (object permanence, causality, solidity, inertia)
- Language Models:
    - Theory of Mind
    - Arithmetic
    - Detecting deception

Today’s Capability: Object Permanence

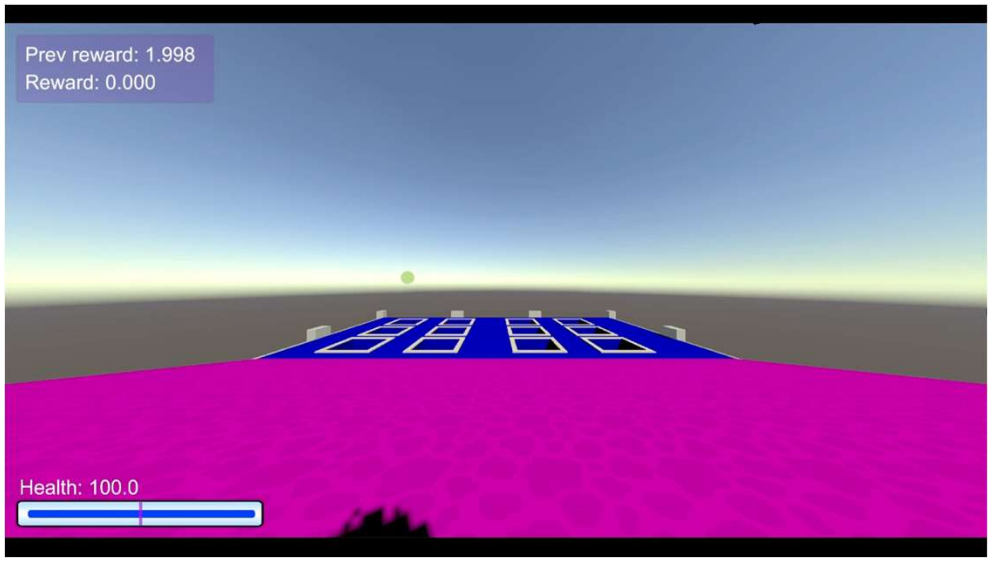


Construct Validity

- To what degree does a test accurately measure what it is intended to measure?
- Difficult to guarantee:
    - Tests require validation against other measures.
    - Measures need to be reliable (test-retest).
    - May ultimately be circularly defined.
- In AI Evaluation, we can often draw on research evaluating capabilities in other systems: humans and other animals.

Tests of Object Permanence

Chimpanzee - Success

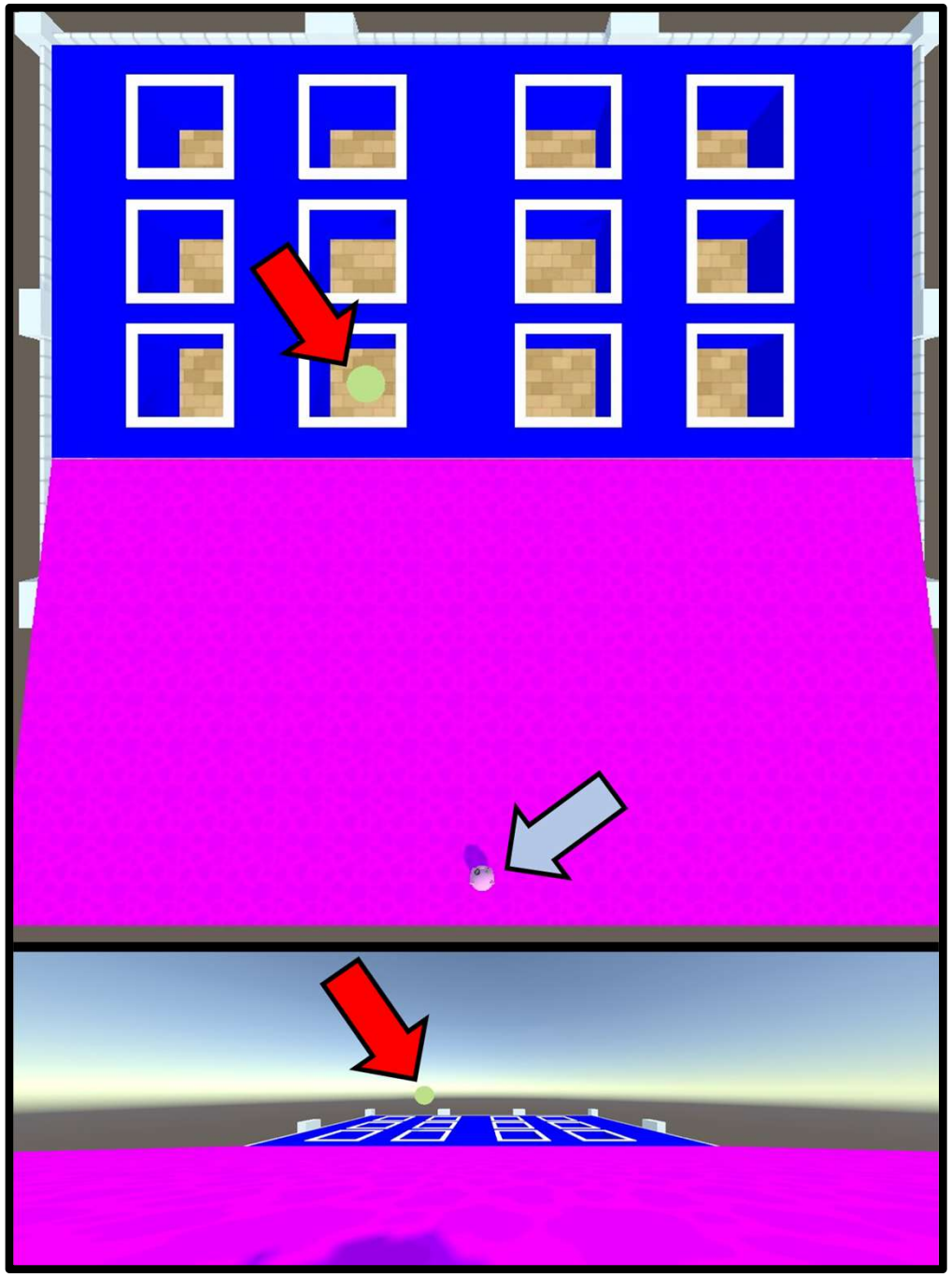


6-Year-Old Human - Fail

Herrmann, E., Call, J., Hernández-Lloreda, M. V., Hare, B., & Tomasello, M. (2007). Humans have evolved specialized skills of social cognition: The cultural intelligence hypothesis. science, 317(5843), 1360-1366.
Voudouris, K., Donnelly, N., Rutar, D., Burnell, R., Burden, J., Hernández-Orallo, J., & Cheke, L. G. (2022). Evaluating object permanence in embodied agents using the animal-AI environment. *Proceedings of the Evaluation Beyond Metrics Workshop, Vienna, 2022.*.

Internal Validity

- What could explain success/failure on this task?
- Object permanence
- Spatial Navigation
- Visual Acuity
- Idiosyncrasies of the test



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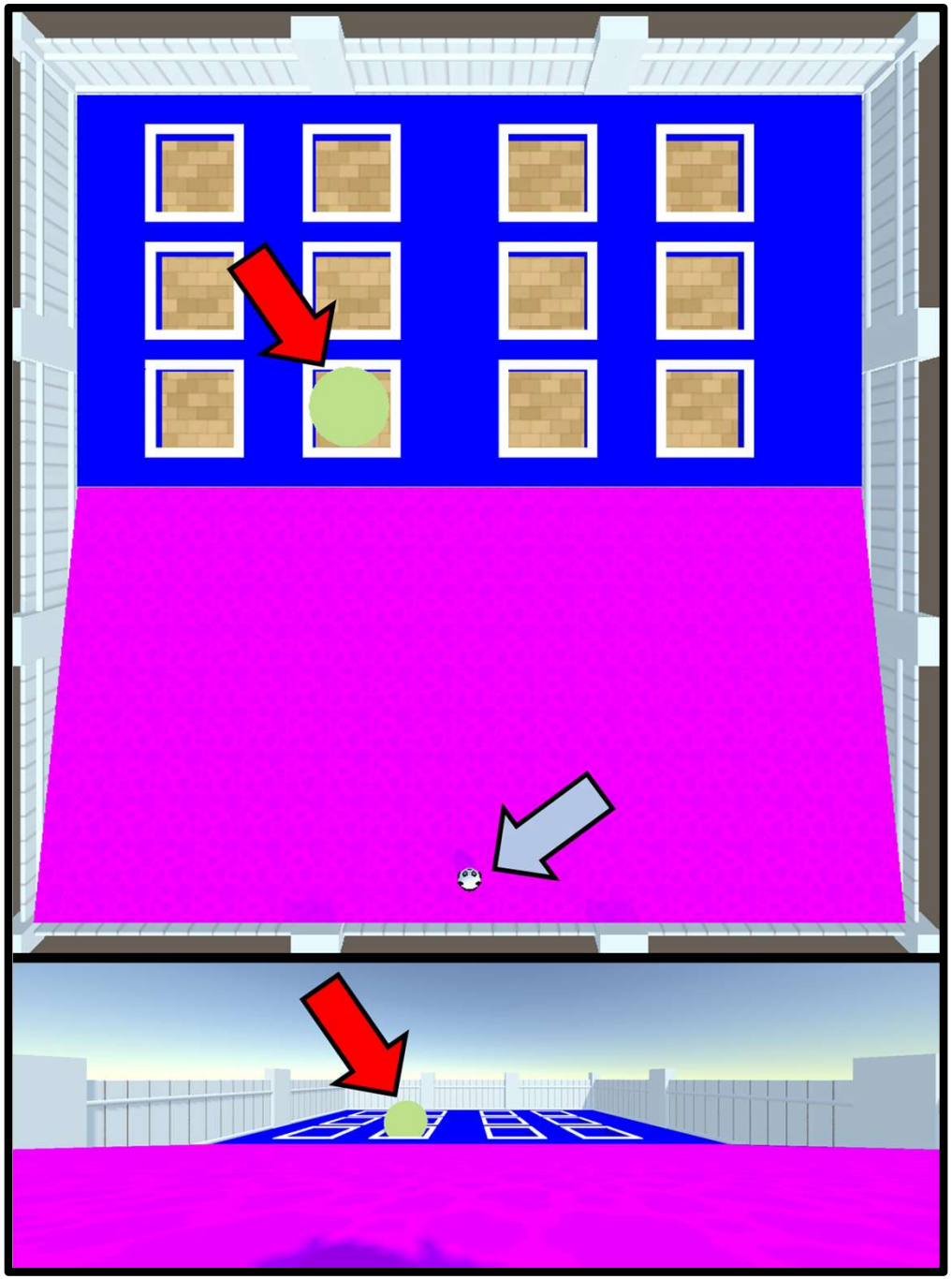

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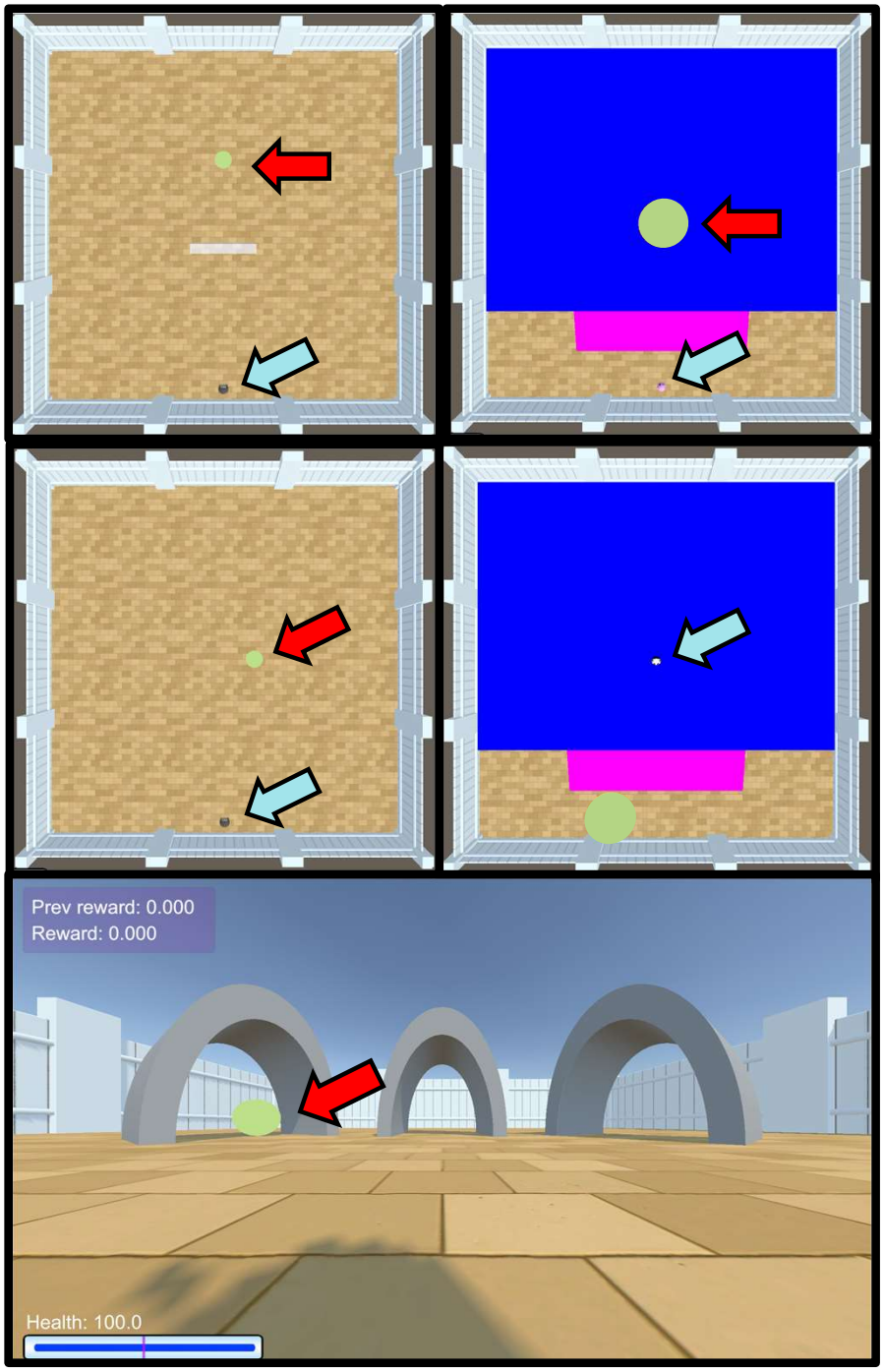


A Battery of Tasks

- 119 Basic Tasks
- 240 Grid Practice Tasks
- 192 Grid Object Permanence Tasks
- Varying:
    - Goal size (`mainGoalSize`)
    - Goal position (`goalPosition`) – centred at zero, left negative
    - Whether goal is occluded (`goalOccluded`)
    - How many holes there are in the grid (4, 8, 12)

A Battery of Agents

- Random Action Agent

  - Randomly samples actions with equal weight and takes that action for a number of steps sampled from $U(1,20)$.

- Heuristic Agent

  - Navigates towards green goals, following a rigid rule.

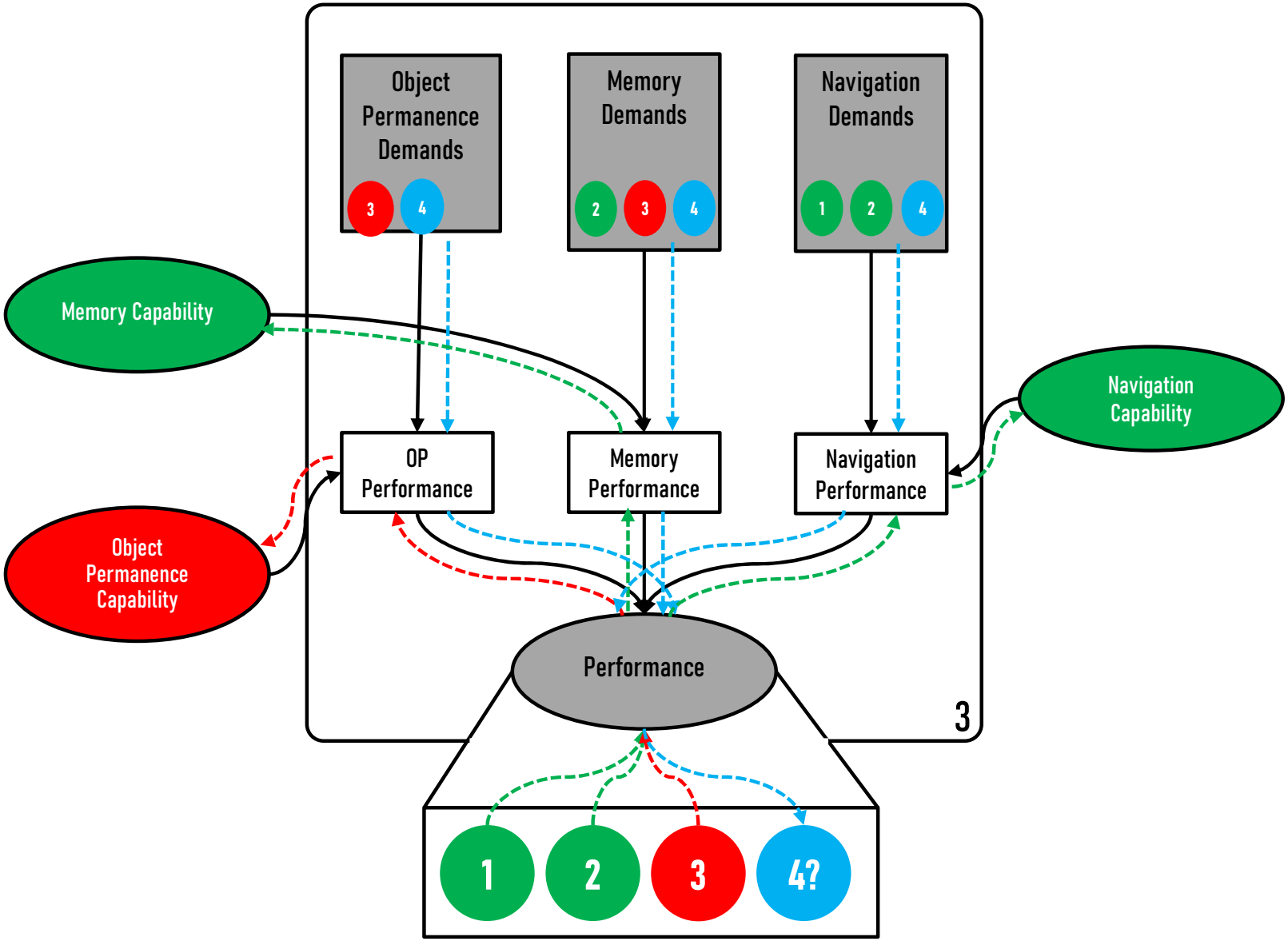
- Proximal Policy Optimisation (PPO) Agent

  - Two agents trained on different curricula.

- Dreamer-v3 Agent

  - Two agents trained on different curricula.

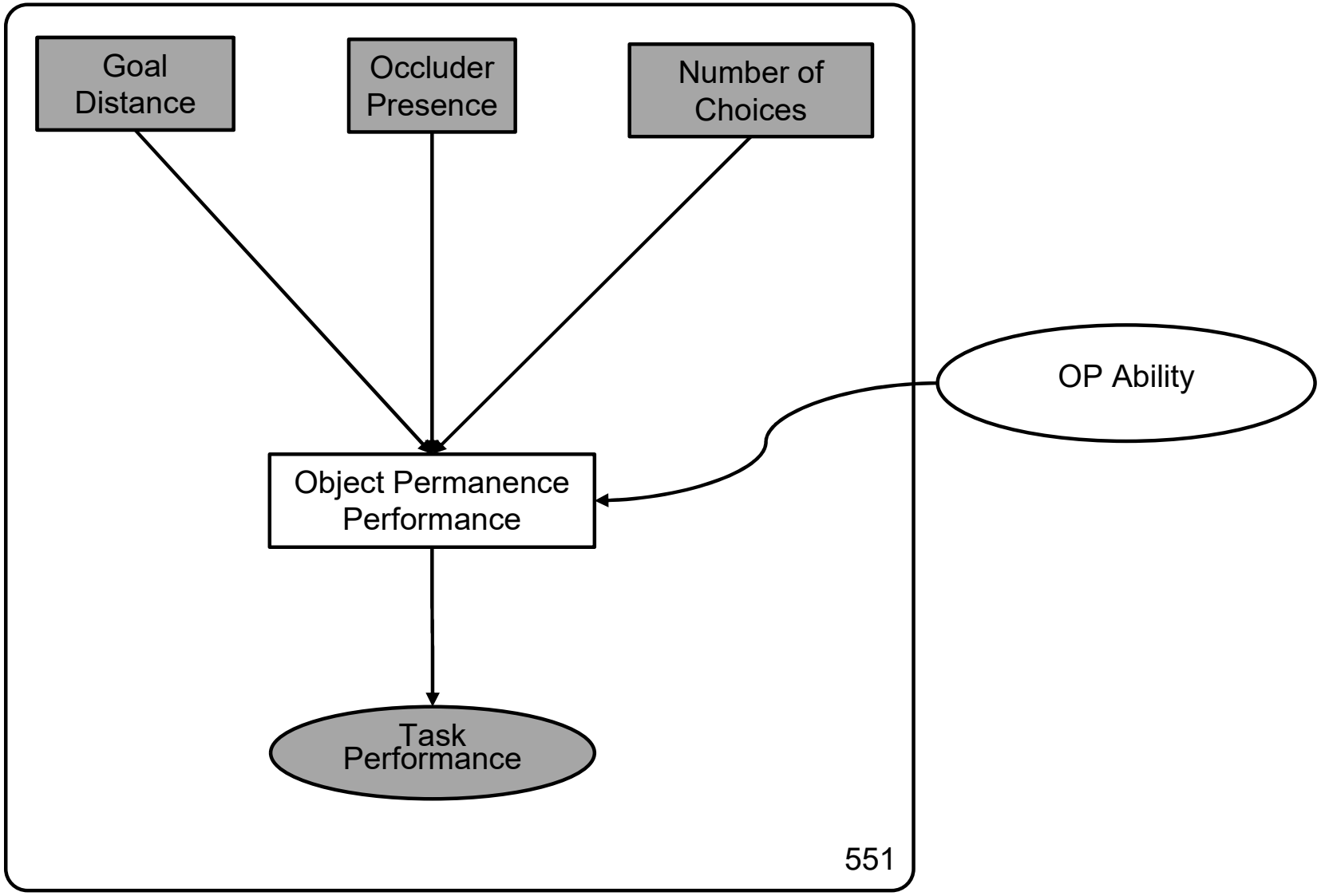
Let’s Start Building



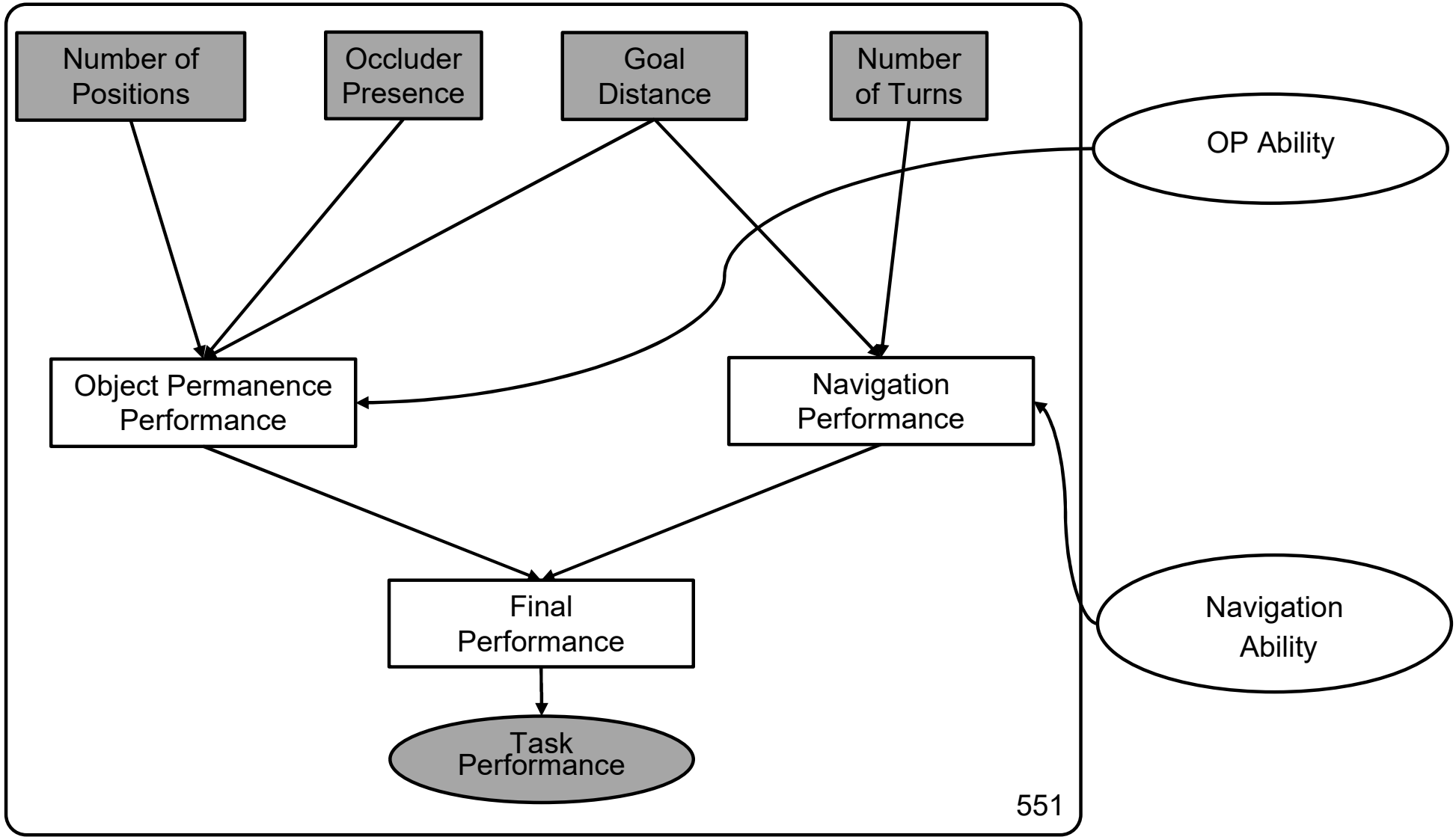
How to Define Object Permanence?

- Cognitive science tells us that it is (in part) a working memory task.
- The longer an object is occluded, the harder the task (decaying memory traces)
- The more places an object *could* be occluded, the harder the task (memory substitutability)
- The more objects to be tracked under occlusion, the harder the task (working memory load)

Object Permanence



Introducing Navigation



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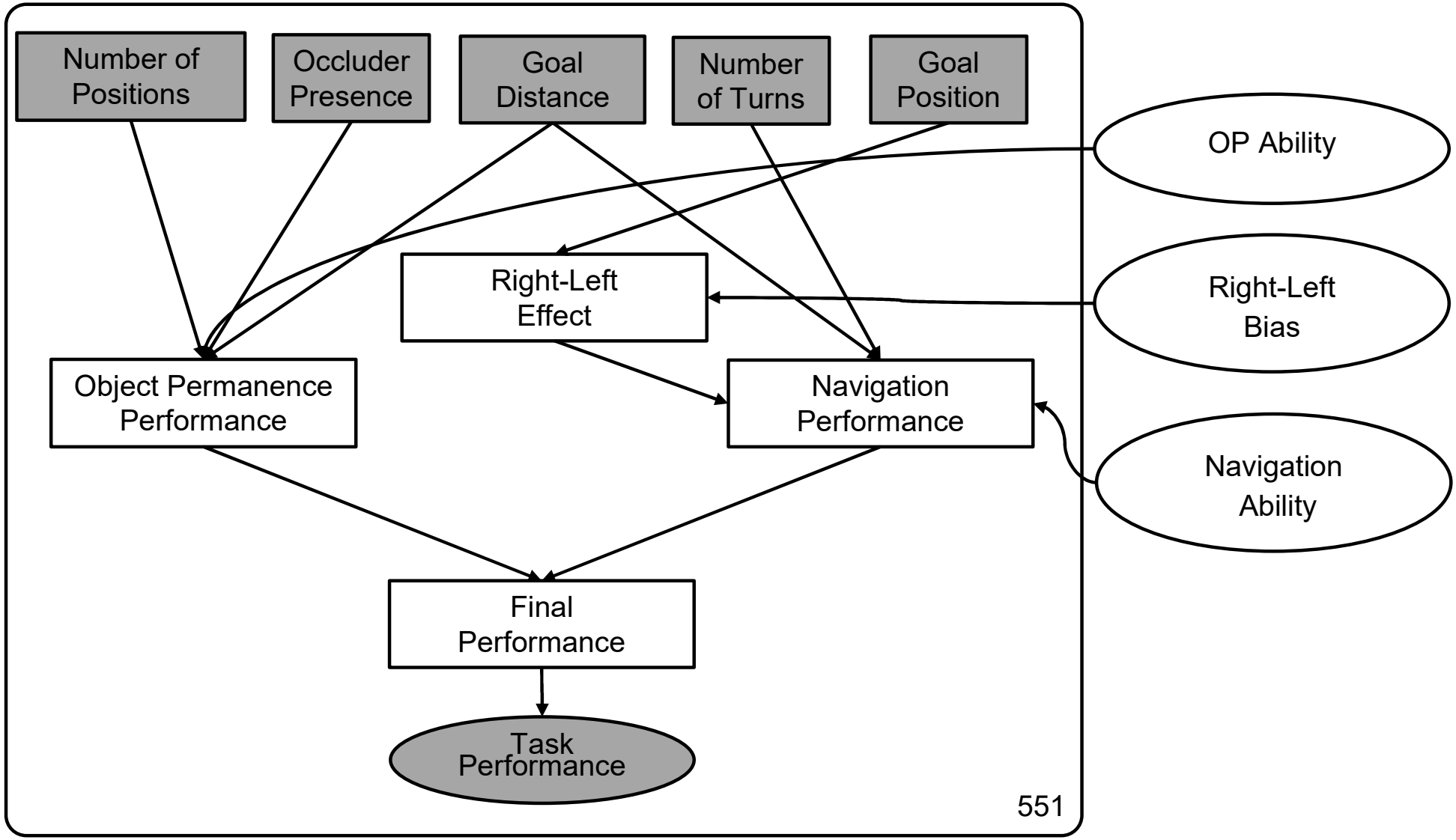
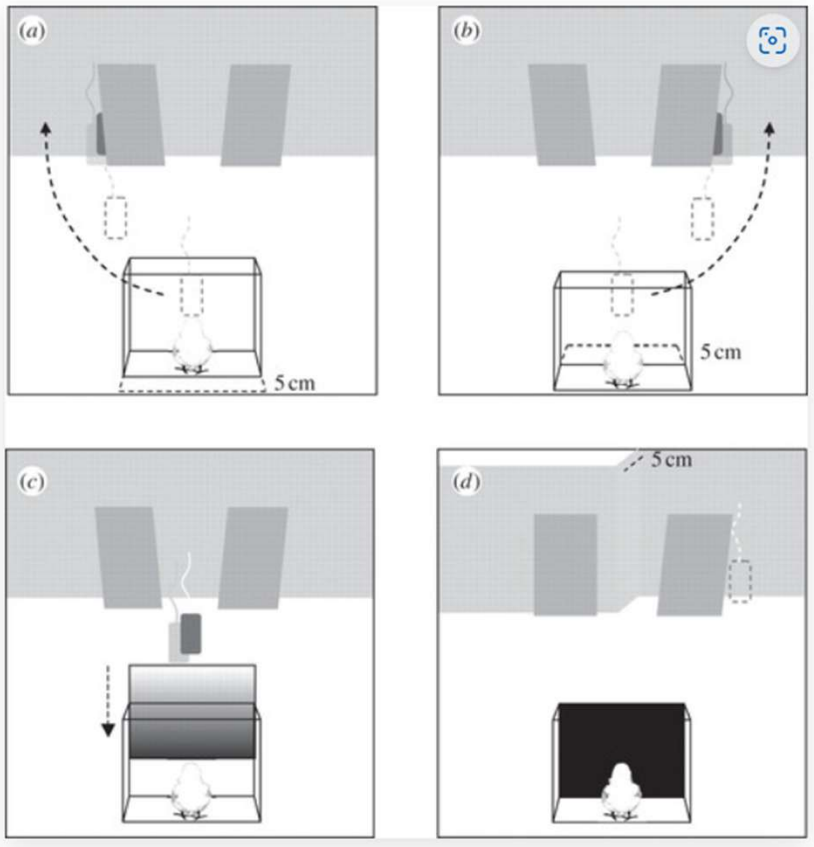


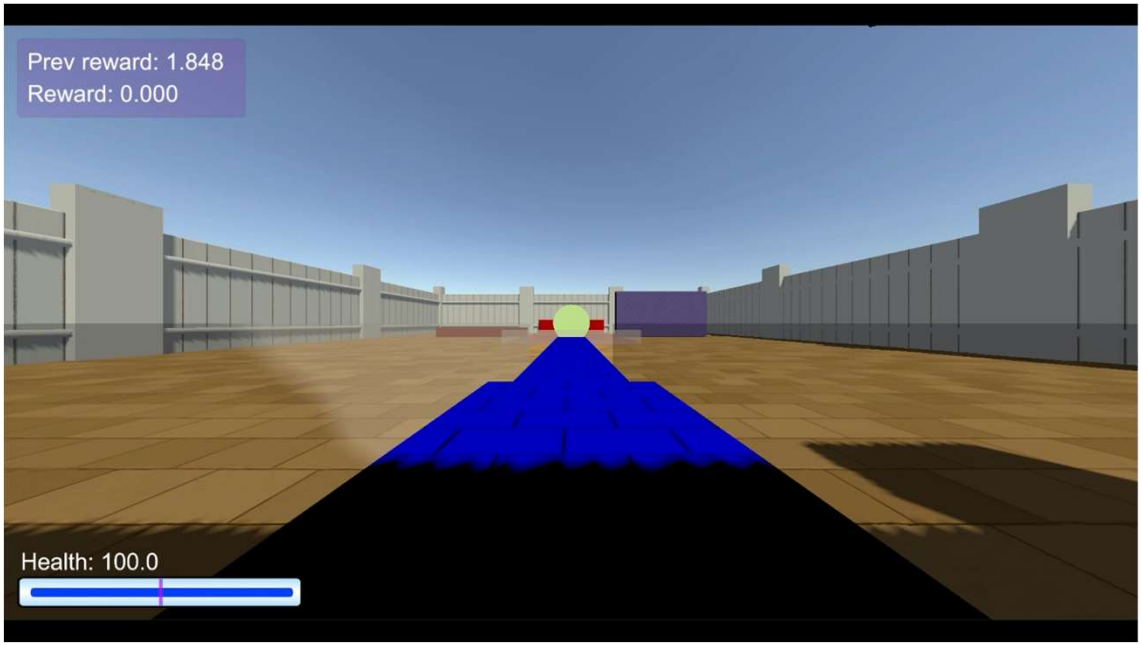
Run Inference On Agents & Run Diagnostics!

Extending To The Multivariate Case

- Is task success the best probe of object permanence?
- These tasks are fundamentally search tasks – but what if the agent can't search?
- Can we use information about the *choices* that agents make to build a more robust measurement layout?
- Let's expand the test battery to include another kind of test

A Second Test of Object Permanence



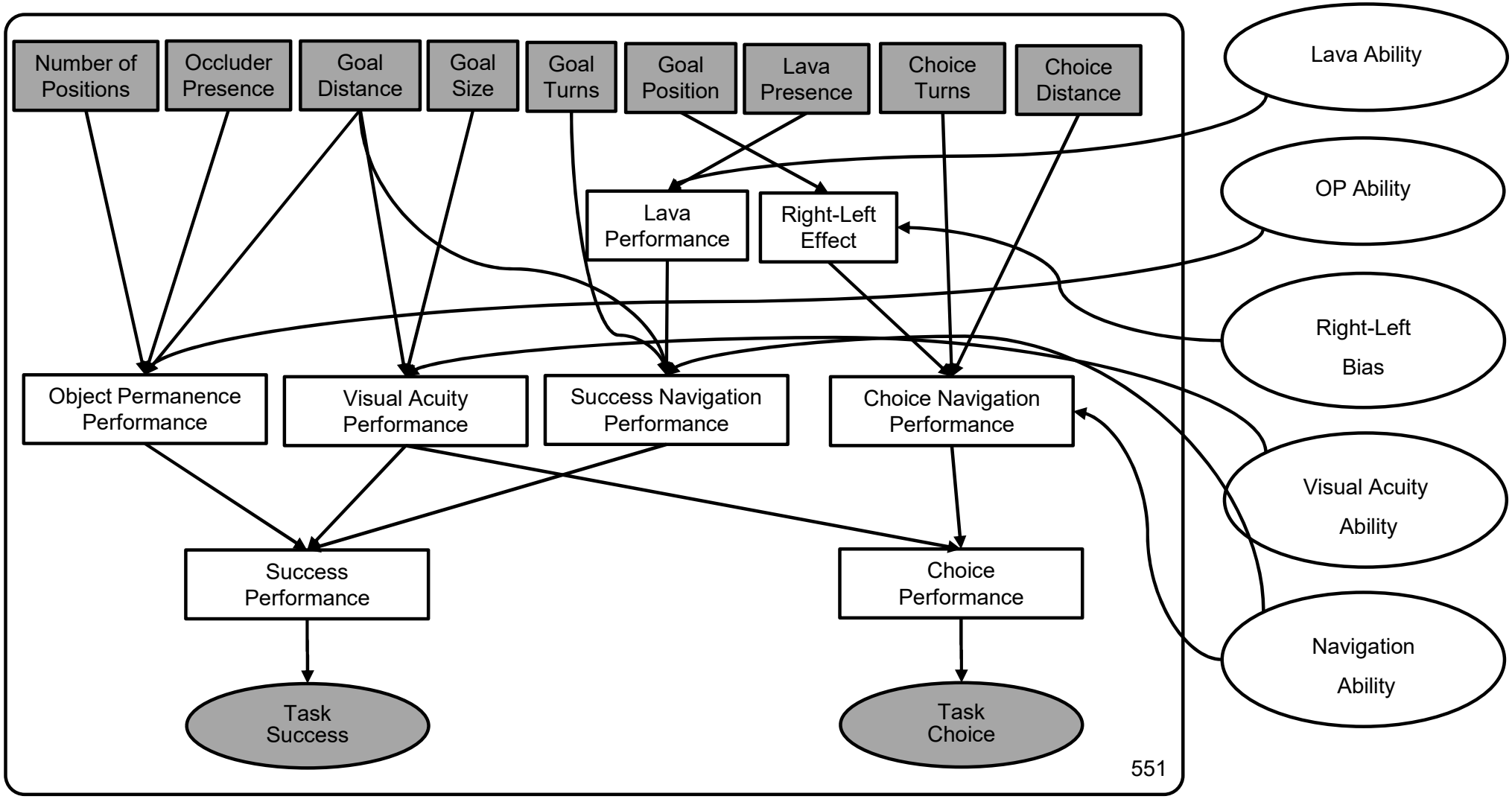


Chiandetti, C., & Vallortigara, G. (2011). Intuitive physical reasoning about occluded objects by inexperienced chicks. *Proceedings of the Royal Society B: Biological Sciences*, *278*(1718), 2621-2627.

A Larger Battery of Tasks

- 127 Basic Tasks (new Lava tasks)
- 240 Grid Practice Tasks
- 192 Grid Object Permanence Tasks
- 1452 CV Chick Practice Tasks
- 126 CV Chick Object Permanence Tasks
- Varying:
    - Goal size (`mainGoalSize`)
    - Goal position (`goalPosition`) – centred at zero, left negative
    - Whether goal is occluded (`goalOccluded`)
    - How many holes there are in the grid (4, 8, 12)
- Task Success and Correct Choice as binary response variables

A Multivariate Measurement Layout



Recap

- Building a benchmark should proceed in tandem with developing a measurement layout.
- Defining the capability, demands, and precursor capabilities is key – to handle construct and internal validity.
- Cognitive science can be a major source of inspiration for benchmark and measurement layout design.
- The measurement layout approach is powerful and flexible – extending to the multivariate case and to complex, non-linear interactions between demands and capabilities.
- Extensions: hierarchical measurement layouts for population-level analyses (talk to us about ongoing work on this!)