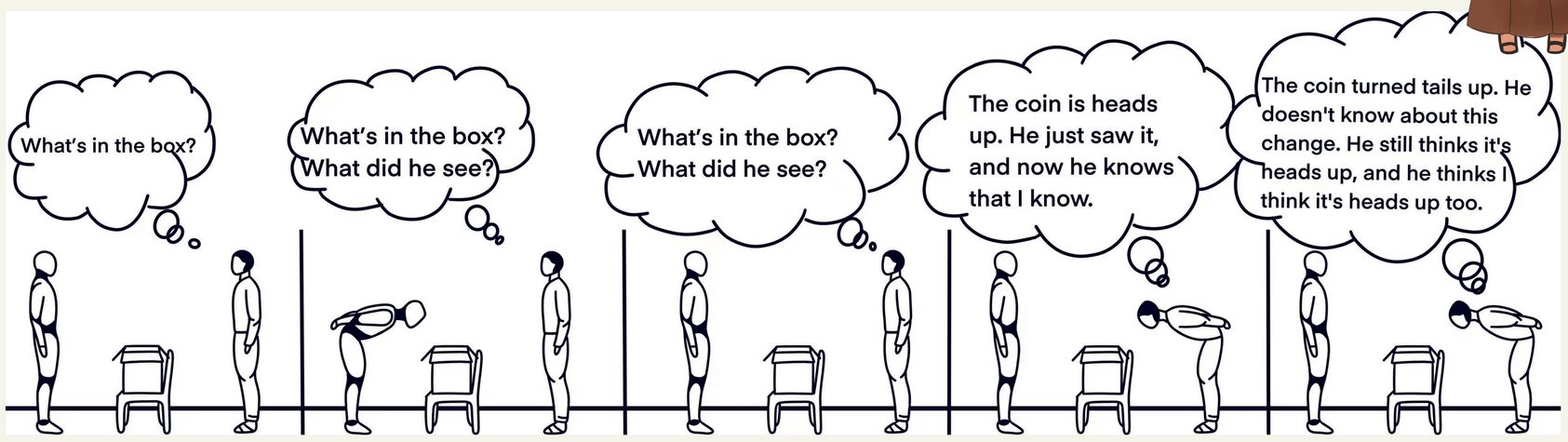
Modeling Higher-order Human Beliefs Using the Justified Perspective Model

Wanchun Li*, Chenyuan Zhang^* , Weijia Li*, Guang Hu*, Yangmengfei Xu*
***University of Melbourne, ^Monash University**

Keywords

- Computational Cognitive Science
- Theory of Mind
- Epistemic Planning
- Human Belief Model
  - Higher-order
  - Reasoning
  - Generalizable



Background

Theory of Mind (ToM)
How agents infer others' beliefs, crucial for predicting behavior in HRI.

Epistemic Planning (EP)
Combines logic and planning to anticipate agents' knowledge and beliefs, but lacks human validation.

Justified Perspective Model

- Arbitrary nesting
- Action model free
- Observation-based

Two key human-like assumptions:

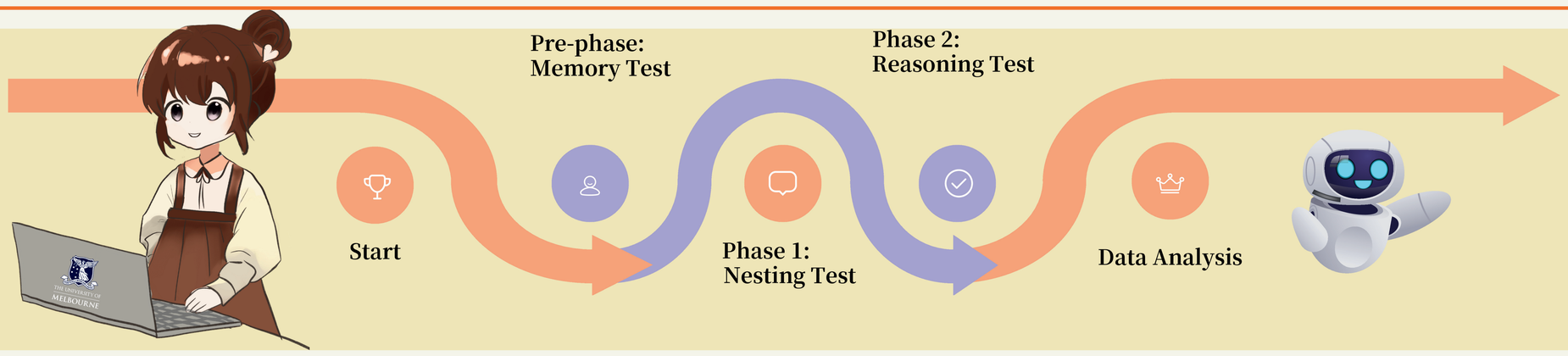
- Humans believe what they see.
- For unseen parts, humans rely on past observations unless contradicted.

Goal

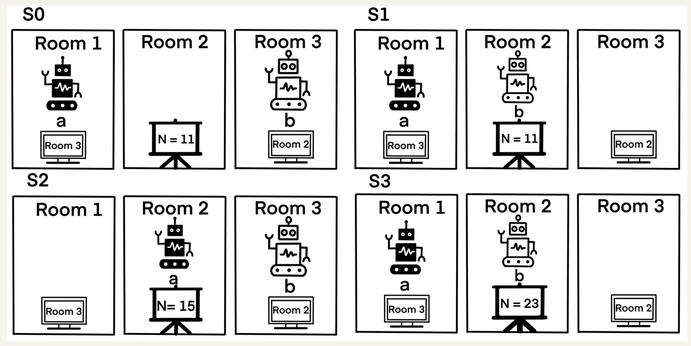
- Explore the feasibility of using the Justified Perspective (JP) model to understand higher-order human beliefs.

Hypotheses

(a) Reasoning ability of individuals is consistent across various scenarios.
(b) Human belief reasoning abilities are positively correlated to their nesting abilities.

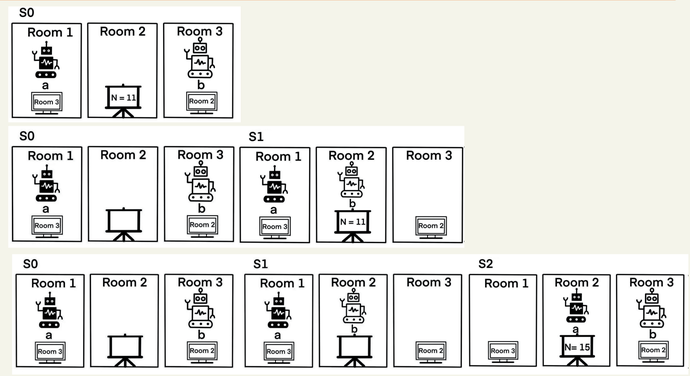


Phase 1: Nesting Test



Task: Answer eight questions assessing nested beliefs (e.g., Ba Bb N) across four levels.
"Ba Bb N" means "a believes b believes the number is".
Purpose: Measure participants' ability to understand nested beliefs in an omniscient setting.

Phase 2: Reasoning Test



Task: Answer eight questions per trial, recalling numbers under memory load, with action sequences visible.
Purpose: Assess reasoning ability under limited information, reflecting real-world constraints.

Analysis

Used IRT (2PL model) to estimate reasoning ability (theta) via Maximum Likelihood Estimation.

Preliminary Results:

- Positive correlation between nesting and reasoning abilities (Hypothesis a).
- Low variance in theta across scenarios, supporting consistency (Hypothesis b).

Result

Subject	Memory test	Nesting test	Reasoning test $\hat{\theta}_1$	$\hat{\theta}_2$	$\hat{\theta}_3$	$\hat{\theta}_4$	Variance
Subject 1	4	2	2.44	2.45	2.44	2.46	0.0001
Subject 2	5	3	3.00	3.00	3.00	3.00	0.0000
Subject 3	4	3	2.94	2.96	3.00	3.00	0.0009
Subject 4	3	2	2.54	2.56	2.54	2.57	0.0002
Subject 5	4	3	2.88	2.86	3.00	3.00	0.0057

Contribution

- Proposed a novel IRT-inspired algorithm to measure belief reasoning under the JP model.
- Conducted a pilot study validating the experimental paradigm.
- Identified limitations and provided insights for future research, enhancing HRI system design.

Future Work

- **Pilot Study:** Conducted with 5 participants to explore higher-order human belief anticipation.
- **Model Used:** Leveraged the Justified Perspective (JP) model for formalizing belief reasoning.
- **Key Contribution:** Demonstrated feasibility of generalizing higher-order belief modeling.
- **Impact:** Advances understanding of human cognition in human-robot interaction (HRI).
- **Application Potential:**
  - Human-robot collaboration
  - Assistive robotics
- **Towards Real-World Use:** Bridges the gap between theory and practical HRI scenarios.