Human and Machine Cognition Lab

What makes humans so uniquely intelligent?
How do people make the best use of limited cognitive resources?
What are the unique algorithms we use to learn from other people?

Lab Rotations and BSc/MSc Thesis Projects

hmc-lab.com

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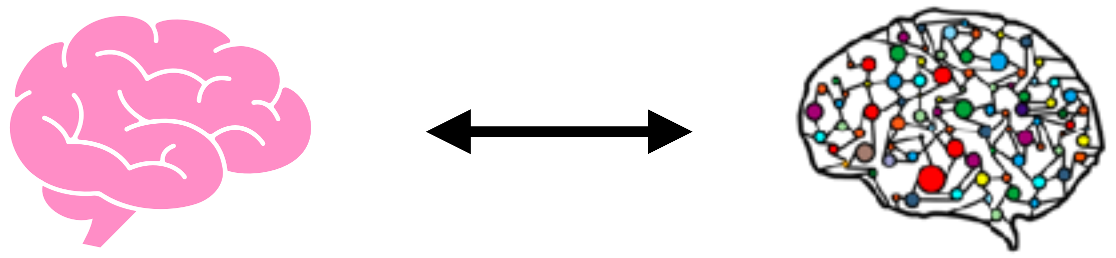
About the HMC Lab

The HMC Lab is an Independent Research Group led by Dr. Charley Wu, with the goal of understanding the gap between human and machine learning.



Our research methods include:

- online experiments (commonly in the form of interactive games)
- computational modeling of behavior (e.g., decisions, search trajectories, and reaction times)
- evolutionary models and simulations
- analyzing large scale real-world datasets
- developmental studies (comparing children and adults)
- lab-based virtual reality experiments
- neuroimaging using fMRI/EEG

We also have a rich collaboration network of researchers from Harvard, MIT, Princeton, and multiple Max Planck Institutes around Germany. To find out more, visit the lab website at **www.hmc-lab.com**

Project 1: LLM-based Program Induction from Natural Language

Research Question

The Language of Thought (LoT; Fodor, 1975) hypothesis proposes that we model the world through program-like representations. Recent computational advances have shown how program learning provides a rational account for a wide-range of intelligent behaviors (Ellis et al., 2023).

Yet, we don't have direct access to our LoT. Instead, we communicate with natural language, which we use to share conceptual structures and abstractions with one another (Wu et al,. 2024).

In this project, we aim to utilize large language models (LLMs) as a tool for translating natural languages into executable programs, providing new insights into the abstractions we use to represent the world around us.

Approach

- Use LLMs (e.g., LLM Solver, Codex, etc.) to translate natural language descriptions of objects, procedural planning, and other domains into executable programs (Wong*, Grand* et al., 2023)

Scope

- Evaluate the capability of LLMs to translate natural language descriptions into executable programs
- Determine whether LLMs can be used to identify reocurring subprograms shared across tasks, which can be used to populate a concept library
- (Bonus) Investigate the correspondence between the transcribed programs and human behavioral data

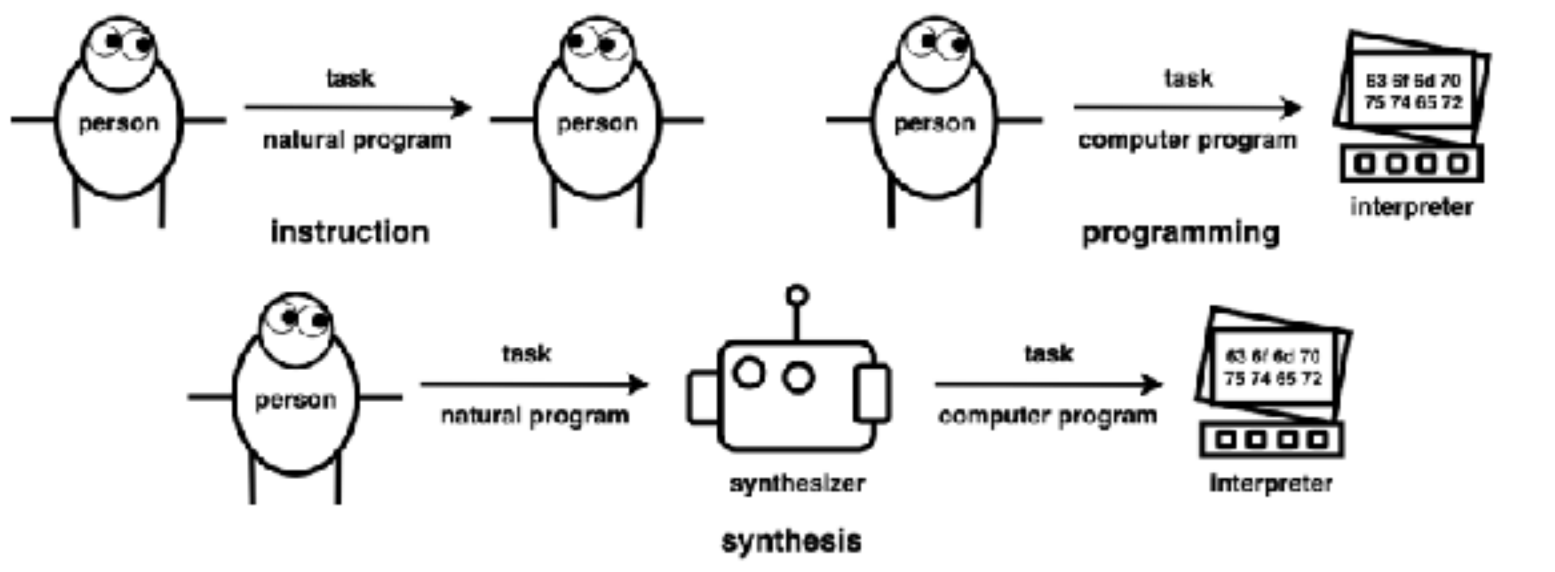
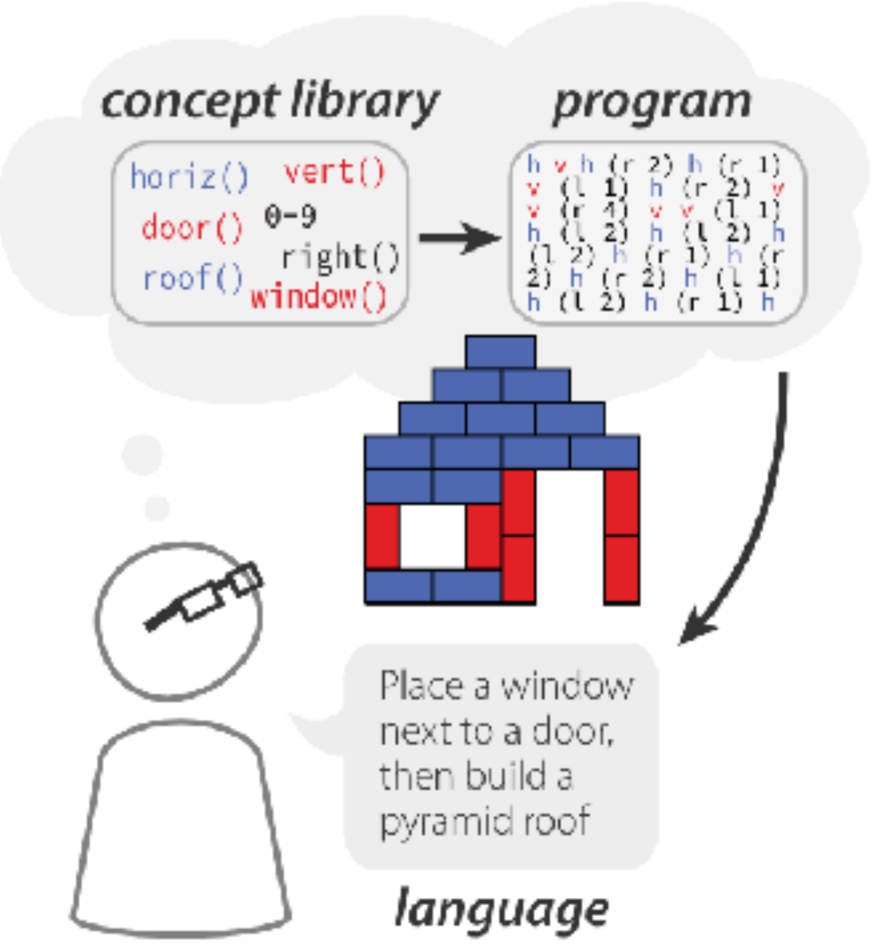


Figure 3: Three kinds of "programs": instruction (top-left), programming (top-right), synthesis (bot).

Aquaviva*, Pu* et al.,



McCarthy et al., (2021)

Project 2: Pedagogy and Tool Discovery

Research Question

Tool use is a key signature of human intelligence (Rawlings & Legare, TICS 2020),
yet the cognitive mechanisms underlying how we develop and innovate upon tools is not well understood.

Here, we focus on the role of pedagogy in amplifying individual innovations and unlocking cumulative cultural evolution

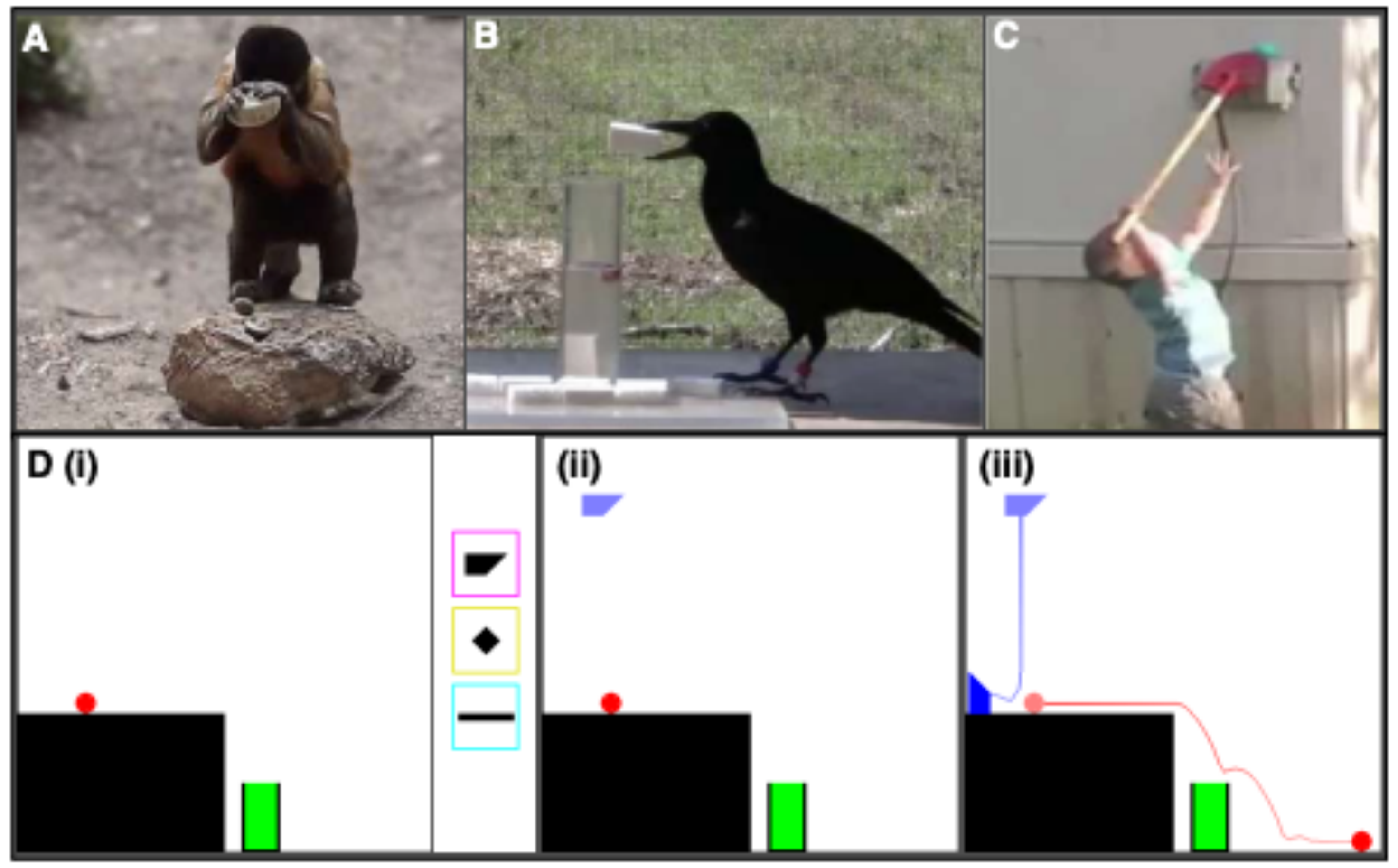
Approach

- Innovate upon a previous experiment (Allen*, Smith*, & Tenenbuam, PNAS 2020), where participants selected which tool they found most useful
- Here, we will allow people to develop their own tools and implement a transmission chain, where the solutions or instructions from one generation of participants will be passed along to the next
- Study the key ingredients for cumulative culture in tool use (e.g., observational learning vs. explicit pedagogy) and which task dimensions are most sensitive to pedagogy (e.g, opaque vs. transparent causal structure)

Scope

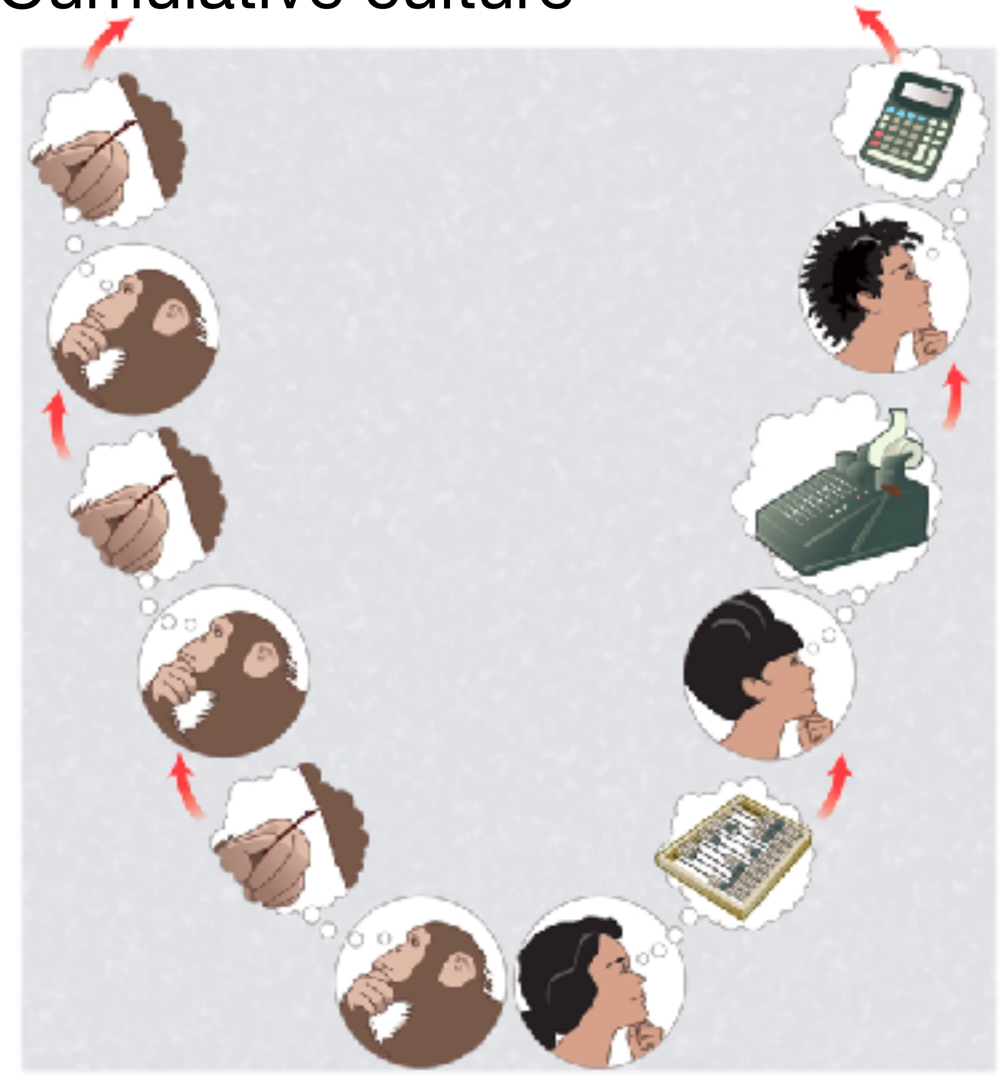
- Learn to design and implement an online experiment based on previous online experiment code (experience with Javascript/HTML/PHP highly recommended)
- Analyze data and perform statistical analyses (experience with Python/R encouraged)
- Collaboration with MIT and Deepmind

Tool use in animals and humans



Allen*, Smith*, & Tenenbuam (PNAS 2020)

Cumulative culture

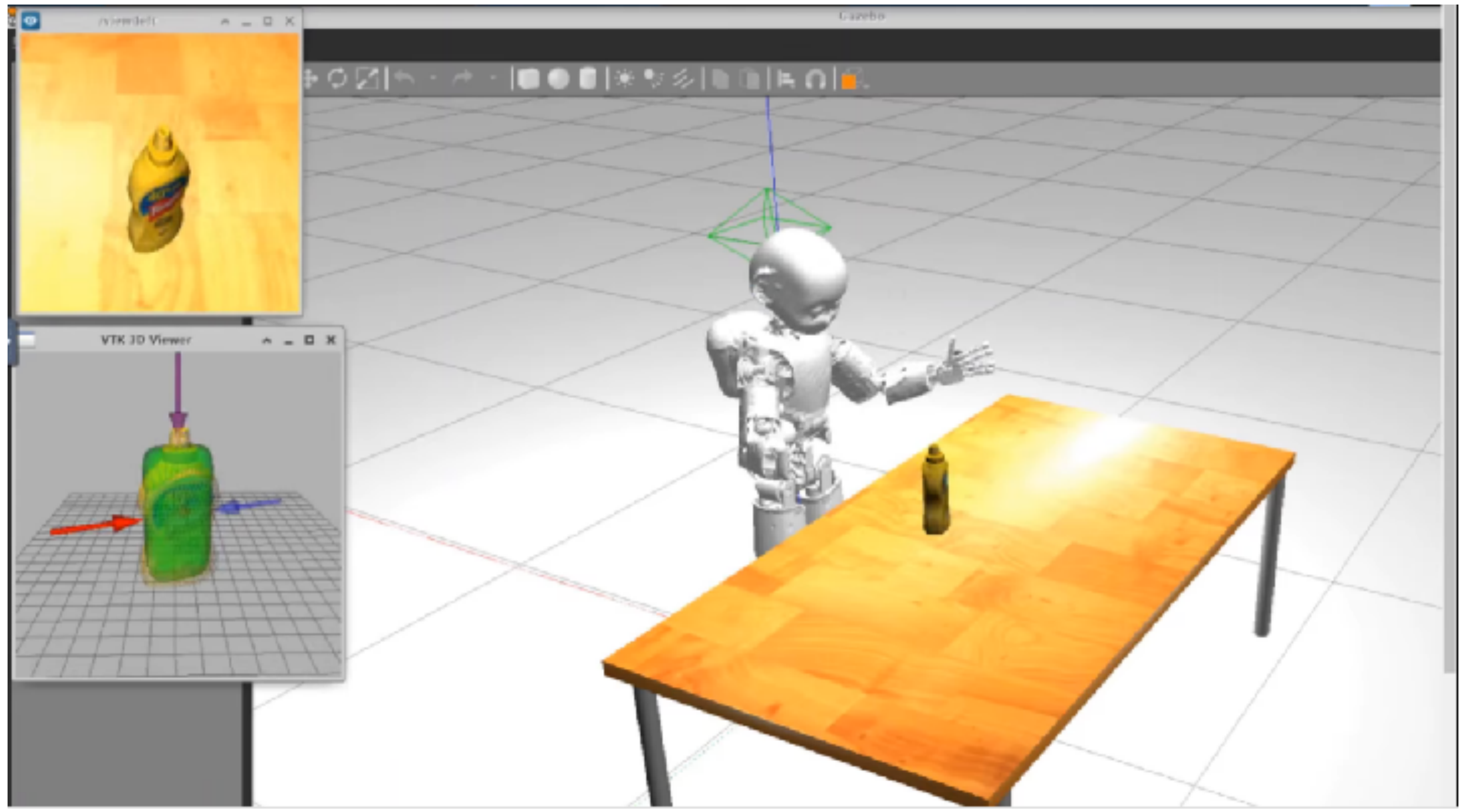


Kurzban & Barrett (Sci, 2012)

Project 3: Designing a MuJoCo environment for intuitive physical reasoning tasks

Research Question

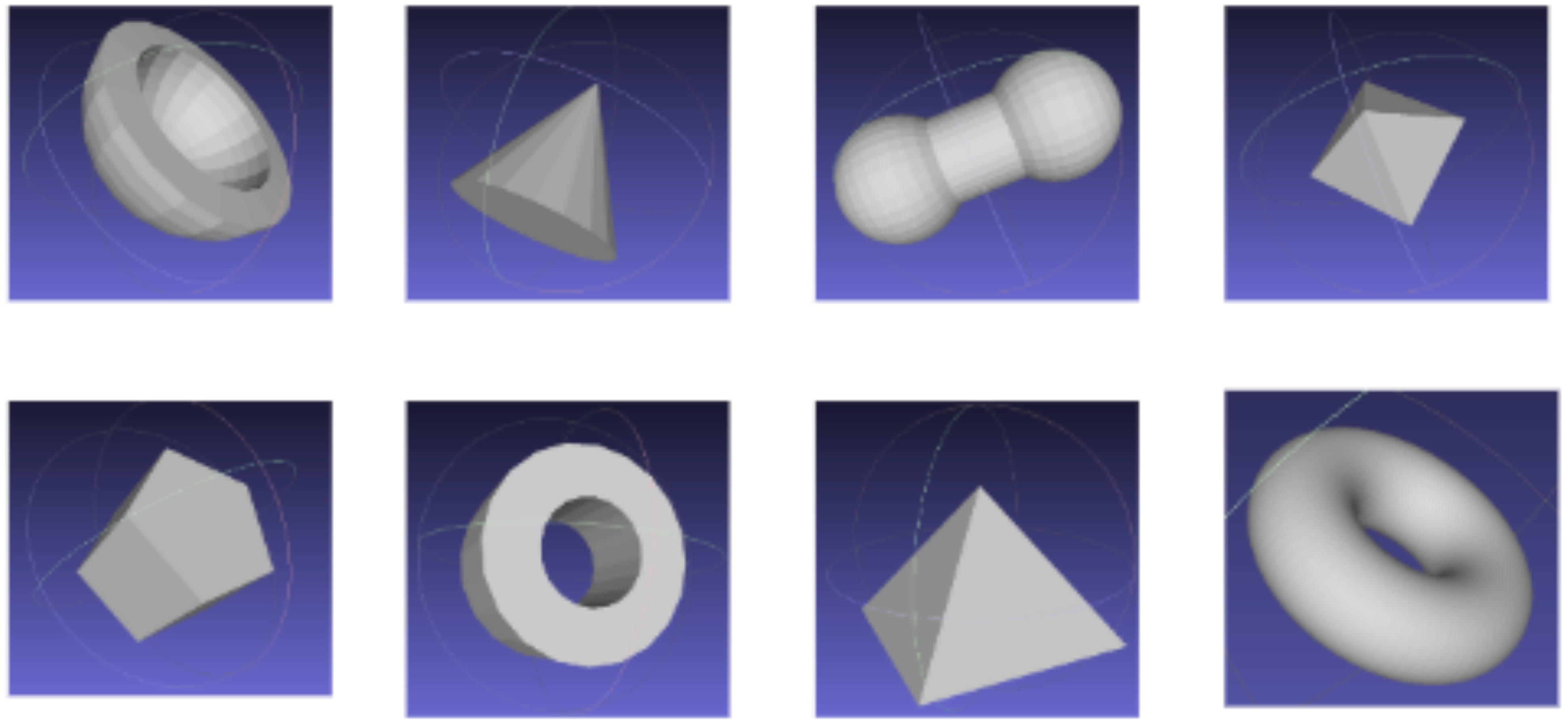
According to Piaget, infants gradually learn to successfully search for hidden objects which points to the lack of *object permanence* as a cognitive concept in newborn's mind (Piaget, 1954). Other physical reasoning concepts like *continuity*, *solidity*, *gravity* and *inertia* also mature later during infant's cognitive development (Spelke et al., 1992). Smith and Gasser claim these reasoning abilities emerge in the interaction of an agent with an environment (Smith & Gasser, 2005). Taking inspiration from cognitive development literature, several attempts have been made to replicate intuitive physics reasoning in machines (Chang et al., 2017, Piloto et al., 2022, Agrawal et al., 2016, Smith et al., 2019). But none of these attempts have incorporated the idea from Smith and Gasser that intuitive physics understanding emerges from agent-environment interactions of the embodied agents. To implement this in practice, a simulated playground is necessary for the machine to interact in. The goal of this project is to build such an environment.



https://github.com/robotology/icub-gazebo-grasping-sandbox

Approach

- Improve upon the existing MuJoCo environment
- Add a curriculum of tasks with different objects for the iCub robot to interact with in the simulation
- Create an OpenAI gym environment from the MuJoCo environment



Kachergis et al. (2021)

Scope

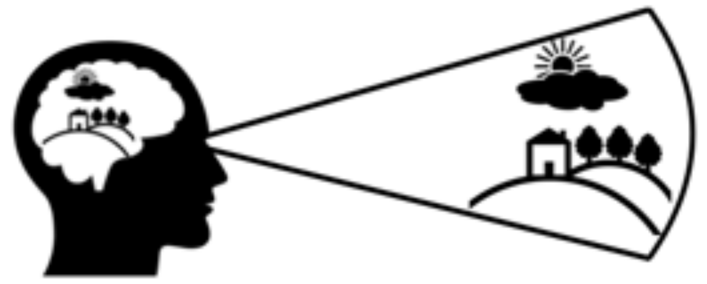
- This is meant as a lab rotation project
- Learn to code MuJoCo environments and turn them into an OpenAI gym environment
- Time permitting, the environments can be tested with existing neural network architectures

Project 4: Episodic and model based control

Research question

Humans construct internal models to predict the consequences of possible actions. However in a newly encountered environment, limited experience can make it unfeasible to fit a parametric model. Therefore in the early stages of learning, relying on experiences directly may be more efficient (Lengyel & Dayan, 2009). It has been hypothesised that this constitutes a normative rationale for two complementary learning systems, one that constructs a parametric model (typically associated with the neocortex) and a non-parametric one (typically associated with episodic memory and hippocampal regions) (Kumaran et al, 2016, Nagy & Orban, 2006). We are interested in how the brain arbitrates between these two controllers as well as better understanding the computational trade-offs that they make.

semantic model



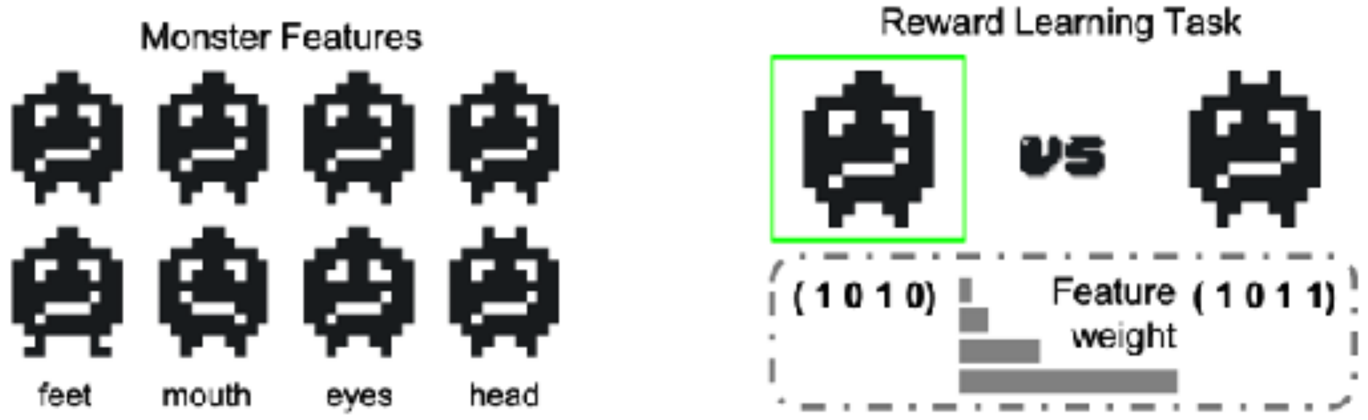
$$p(x, z, \theta \,|\, \mathcal{D})$$

episodic memory

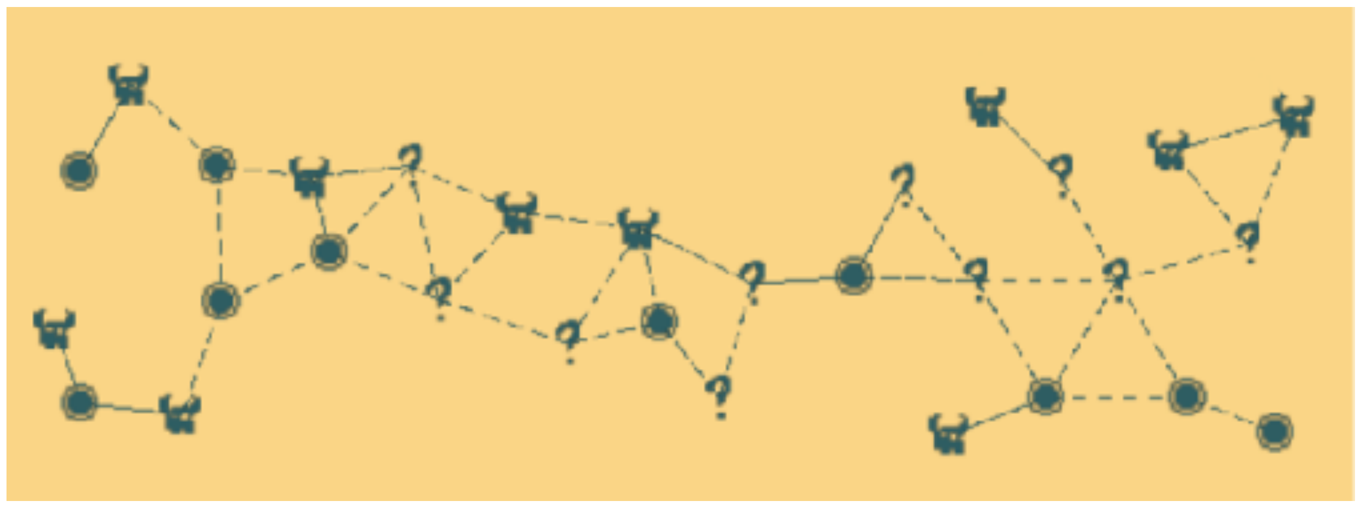
$$\{x_t\} \subset \mathcal{D}$$

Approach

- Explore the interaction between parametric and non-parametric learning systems in a behavioural experiment, building on the setting of Xiong, Moneta, Banyai, & Wu, 2023
- Investigate how the contents of episodic memory are selected, specifically whether they are optimised to support the construction of the model
- We use a reinforcement learning framework and bayesian methods for computational modelling



Xiong, Moneta, Banyai, & Wu (CCN 2023)



Scope

- Implement an online experiment (experience with Javascript/HTML/PHP will be required)
- Option to construct computational models and analyse data (Python knowledge useful)
- Project in collaboration with MPI for Biological Cybernetics

Project 5: Applying social learning models to real world data

Research question

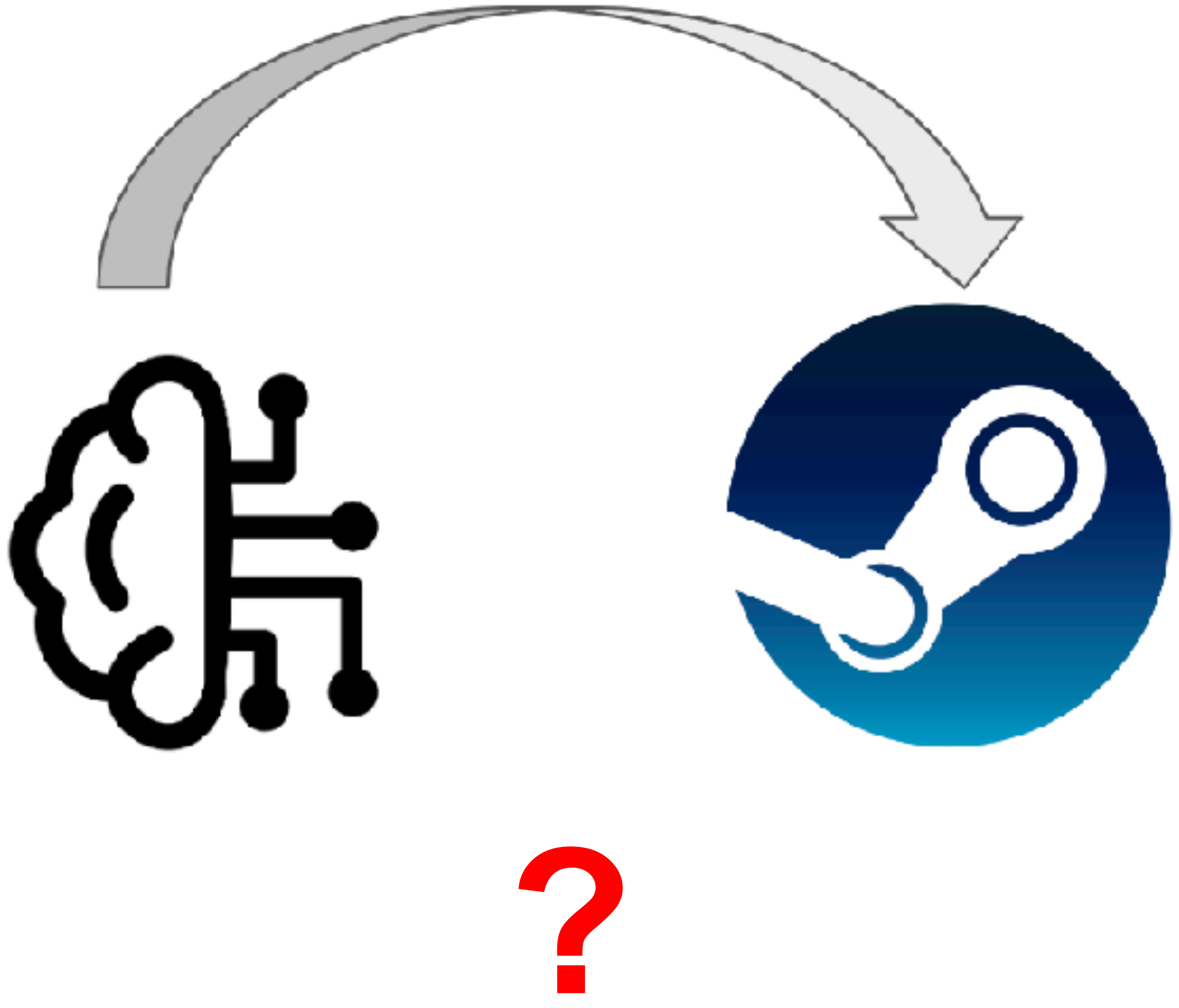
There are many ways to formalize human social learning through computational models (e.g., Baker et al., 2017, Najar et al, 2020, Toyokawa, Whalen & Lala, 2019, Witt et al., 2024). These models are generally established based on data from controlled experiments (but see Analytis et al., 2024 for an exception and inspiration). How well do these models apply to naturalistic, real-world data? Let's find out by analyzing Steam data of video-game reviews!

Approach:

- Web scraping
- Computational modelling

Scope:

- Scrape and wrangle large, sparse datasets
- Use NLP to extract information from reviews
- Apply established computational models to naturalistic data
- Refine established models, or create your own!



EARLIEST START DATE IS JULY 2024!