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](hmc-lab.com)

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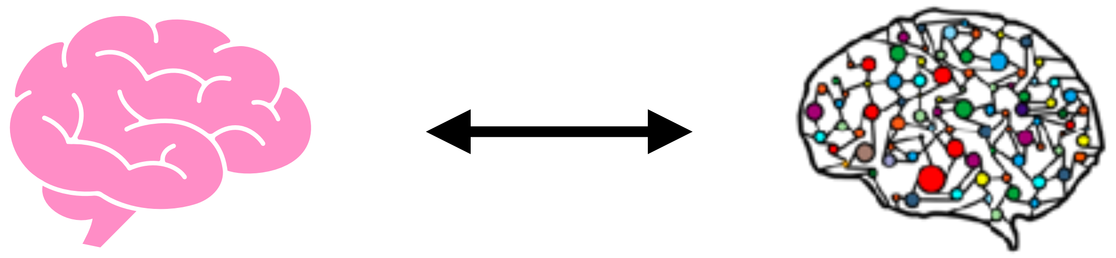
About the HMC Lab

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:

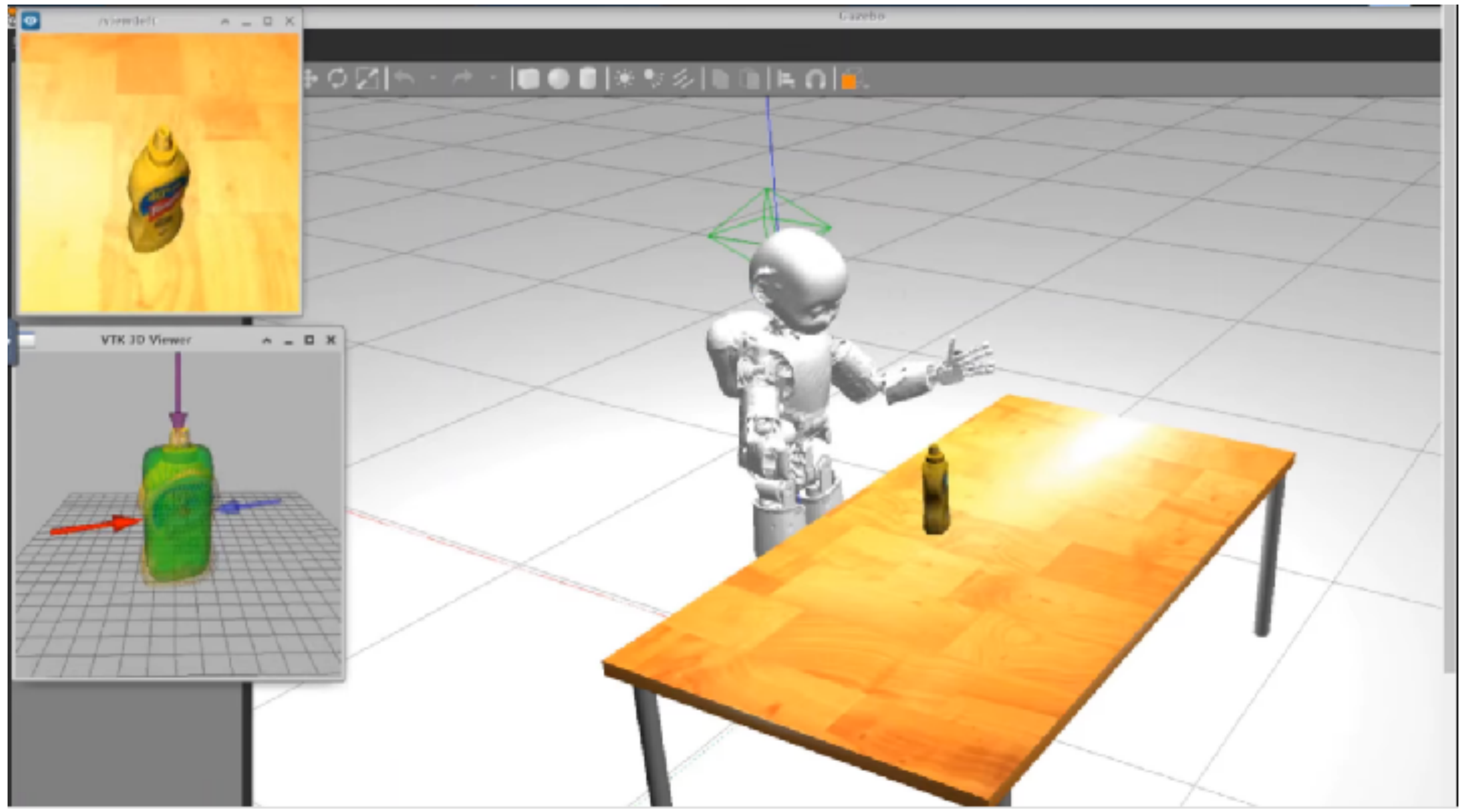
- online experiments (commonly in the form of interactive games)
- computational modeling of behavior (e.g., decisions, search trajectories, and reaction times)
- evolutionary models and simulations
- analyzing large scale real-world datasets
- developmental studies (comparing children and adults)
-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

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

Project 1: Designing a MuJoCo environment for intuitive physical reasoning tasks

Research Question

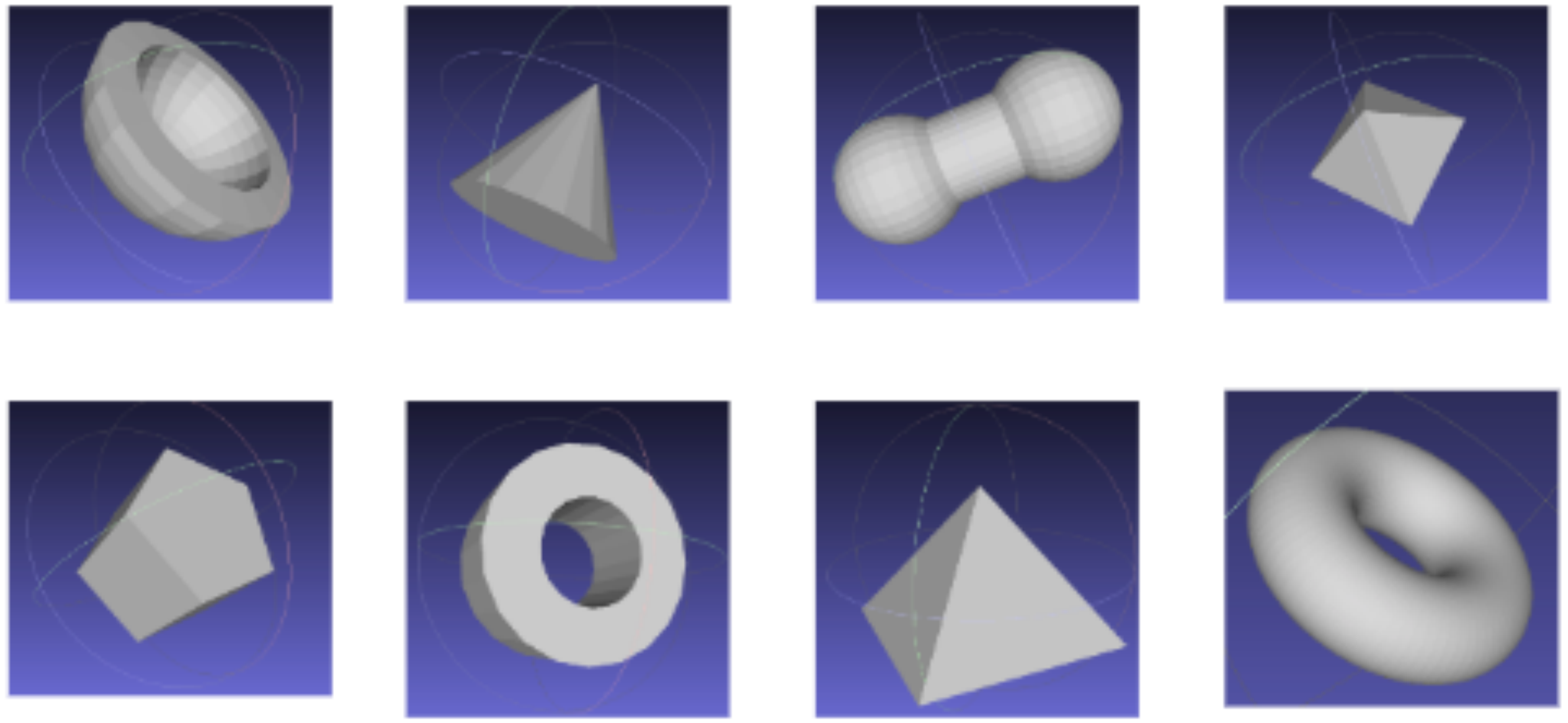
According to Piaget, infants gradually learn to successfully search for hidden objects which points to the lack of *object permanence* as a cognitive concept in newborn's mind (Piaget, 1954). Other physical reasoning concepts like *continuity*, *solidity*, *gravity* and *inertia* also mature later during 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 2: 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.

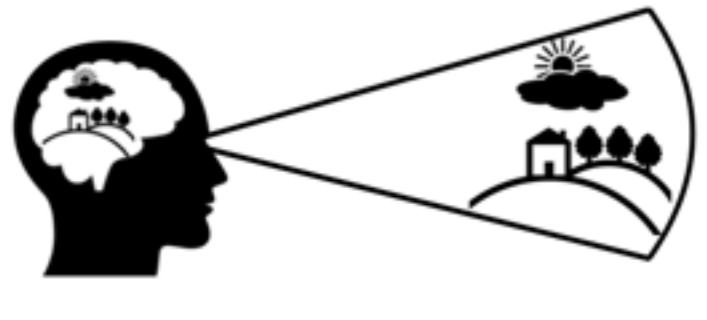
Approach

- 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

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

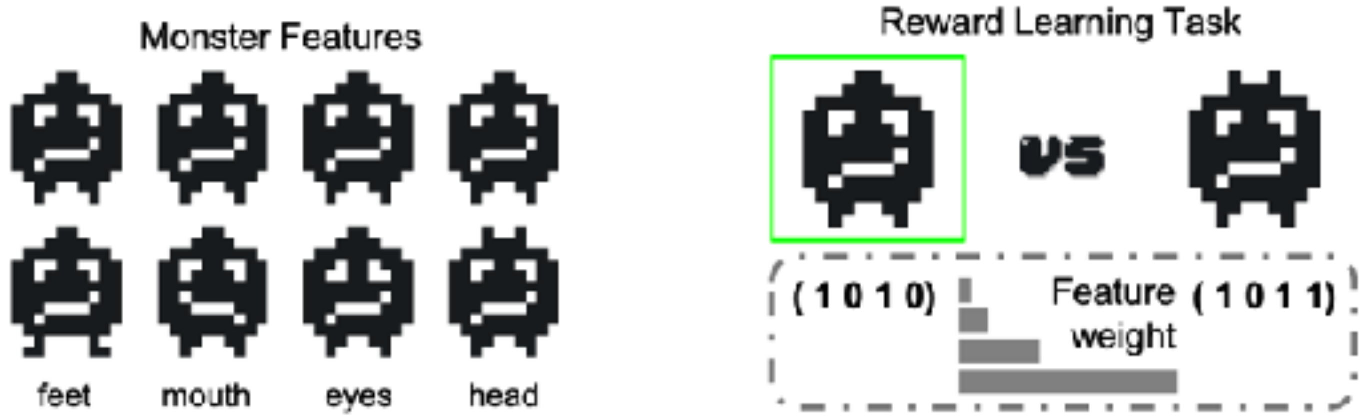
semantic model



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

episodic memory

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



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

Project 3: Neural correlates of reward generalization and exploration

Research Question

How do people integrate observations of reward when they also generalize to similar options?

Approach

- fMRI study planned for early 2025, using a modified version of the Spatially correlated bandit task (**Wu et al., 2018**; **Wu et al., 2020**)
- Relate model predictions and parameters to understand the neural mechanism underlying reward generalization and exploration

Scope

- Learn to design and implement an fMRI experiment based on previous online experiment code (Javascript/HTML)
- Learn to work with computational modeling and fMRI analyses
- Collaboration with MPI Berlin and University of Hamburg

Spatially correlated bandit

7	5	10	22	32	32	28	24	22	26	33
6	11	19	29	38	41	42	40	37	36	40
22	27	30	35	43	50	53	53	51	49	46
45	44	38	36	40	46	47	49	54	55	48
61	55	46	40	37	32	27	31	44	52	44
62	59	57	54	44	27	14	17	33	46	45
53	59	68	71	59	36	17	15	28	45	51
46	57	71	77	67	47	26	18	27	45	56
45	56	65	67	60	46	29	20	27	42	55
51	57	58	53	47	40	30	23	28	40	49
60	62	58	47	39	38	35	31	35	41	46