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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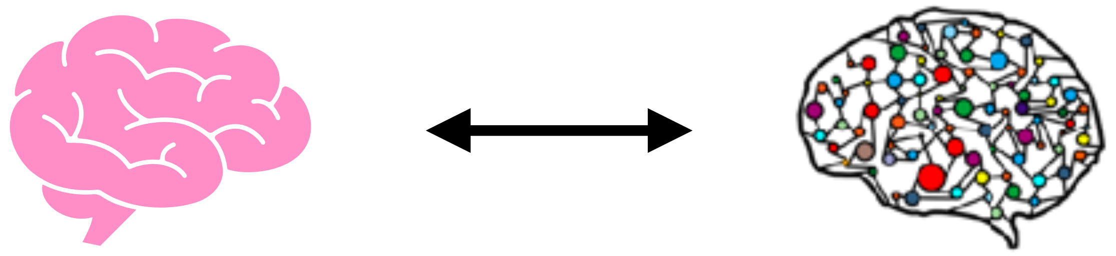
About the HMC Lab

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:

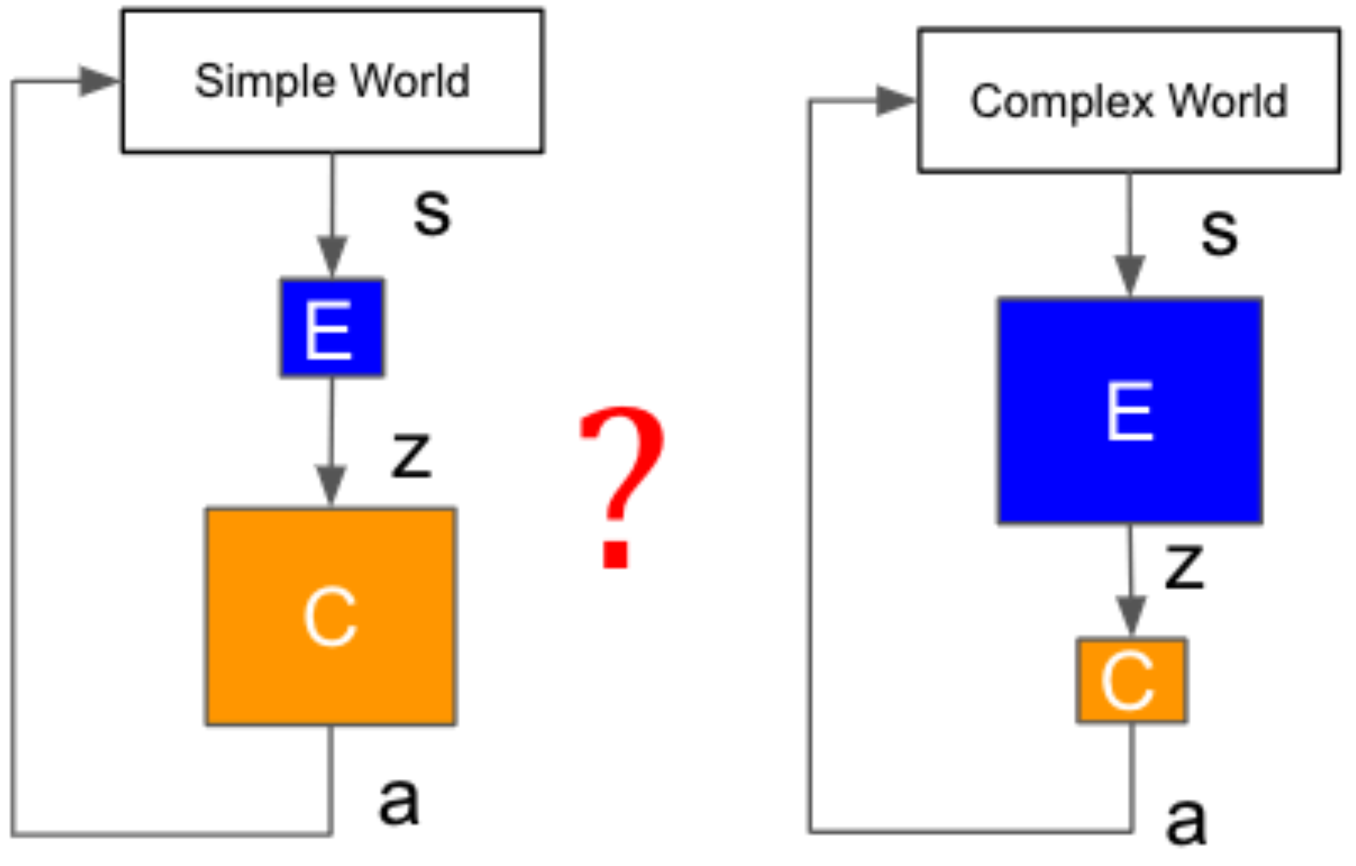
- online experiments (commonly in the form of interactive games)
- lab-based virtual reality experiments
- computational modeling of behavior (e.g., decisions, search trajectories, and reaction times)
- evolutionary models and simulations
- developmental studies (comparing children and adults)
- neuroimaging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

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

Project 1: Taming the cost of control by disentangling complex representations

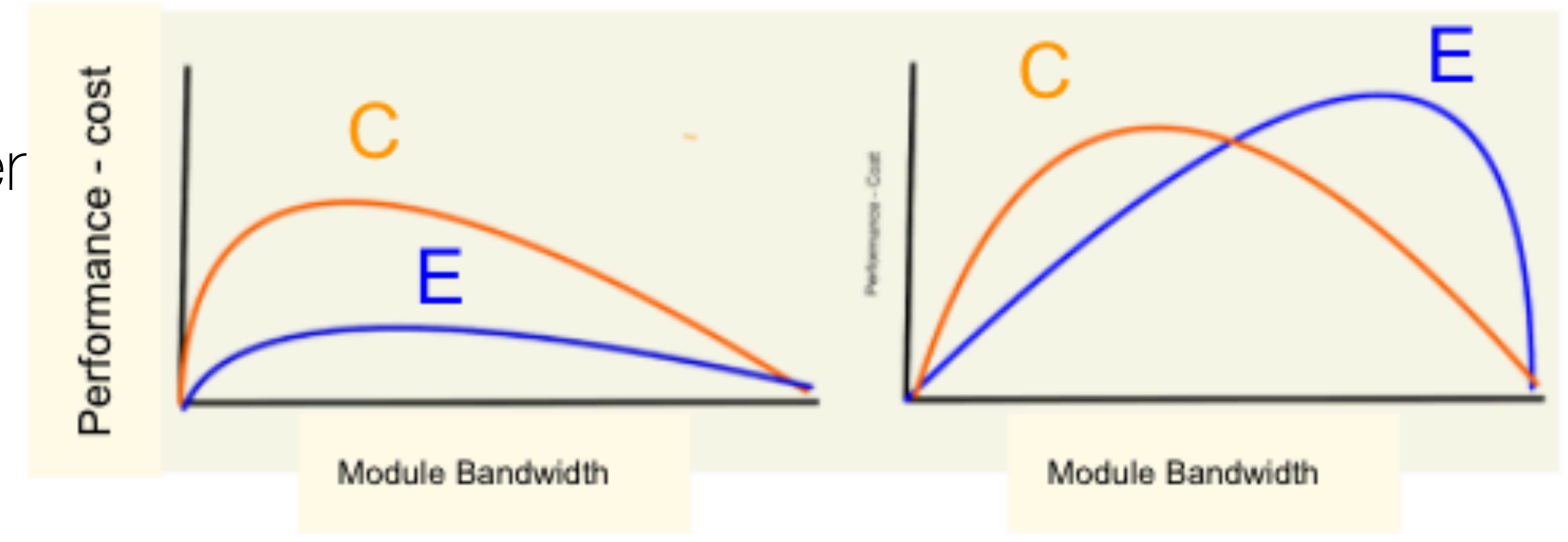
Research Question

How do humans modulate the complexity of their representations and behavioral policies in response to the varying complexity of the world?



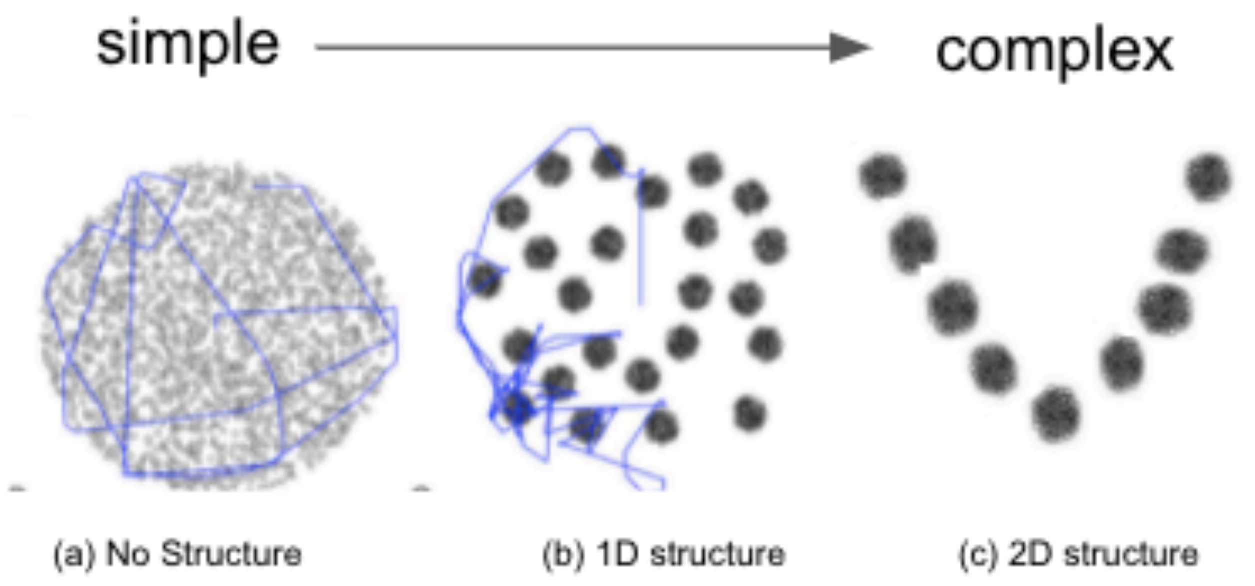
Approach

- Consider a simple learning model where an encoder E compresses input from the environment into a latent representation z, and a controller module C learns a policy mapping z➞a
- An adaptive agent should be able to adapt the representational bandwidth of E and the capacity of C to the complexity of the environment
- What kind of adaptive learning system can facilitate optimal information exchange between the encoder and the controller, to minimize the costs of learning?



Scope

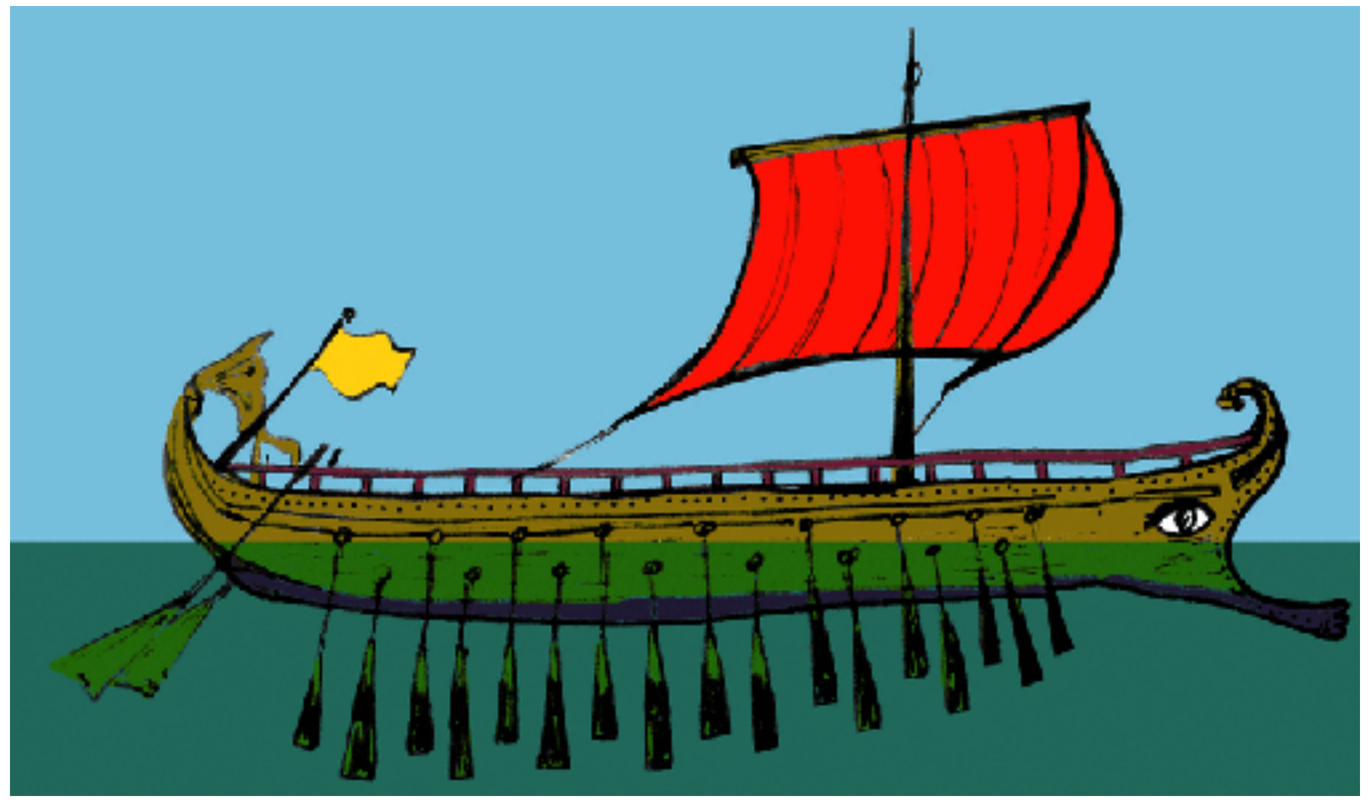
- Design and implement an online web-based experiment (HTML, JavaScript, PHP) to test the predictions of our model
- Work with a PhD student to learn about computational modeling using both evolutionary and classical RL frameworks
- Collaboration with MPI Biological Cybernetics



Project 2: Exploring compositional hypothesis space

Research question

Compositionality enables the *re-use of previous knowledge*, the *creative generation of infinite new solutions* and the the *understanding of complex problems in terms of simpler components*. However, the space of possible hypotheses in a compositional setting are unbounded -- how do people navigate it? Do they navigate it in a *local* way, by changing one piece of the hypothesis at a time?

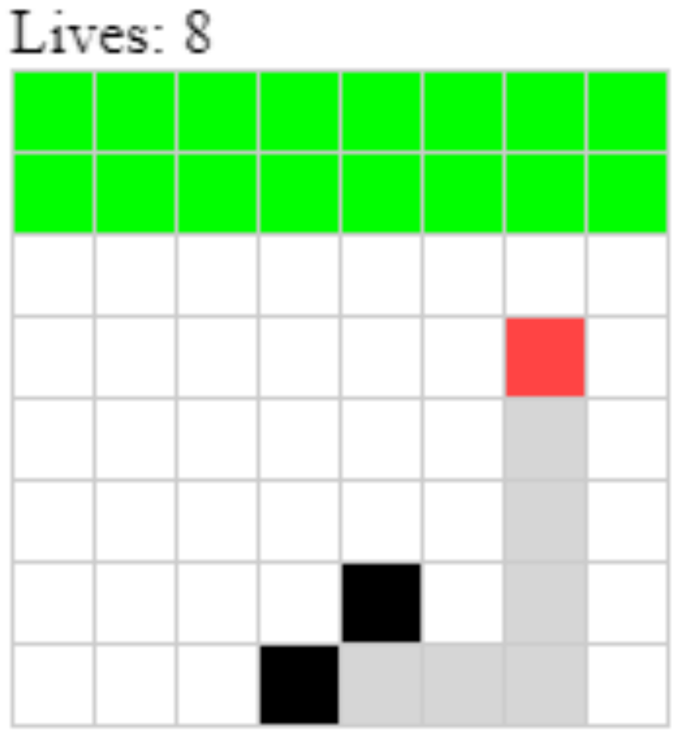


Approach

- Let participant run a Squid Game-like maze that is governed by rules that are unbeknownst to them but drawn from a compositional grammar
- Inspect the patterns of responses to understand how people generate hypotheses about the underlying compositional structure

Scope

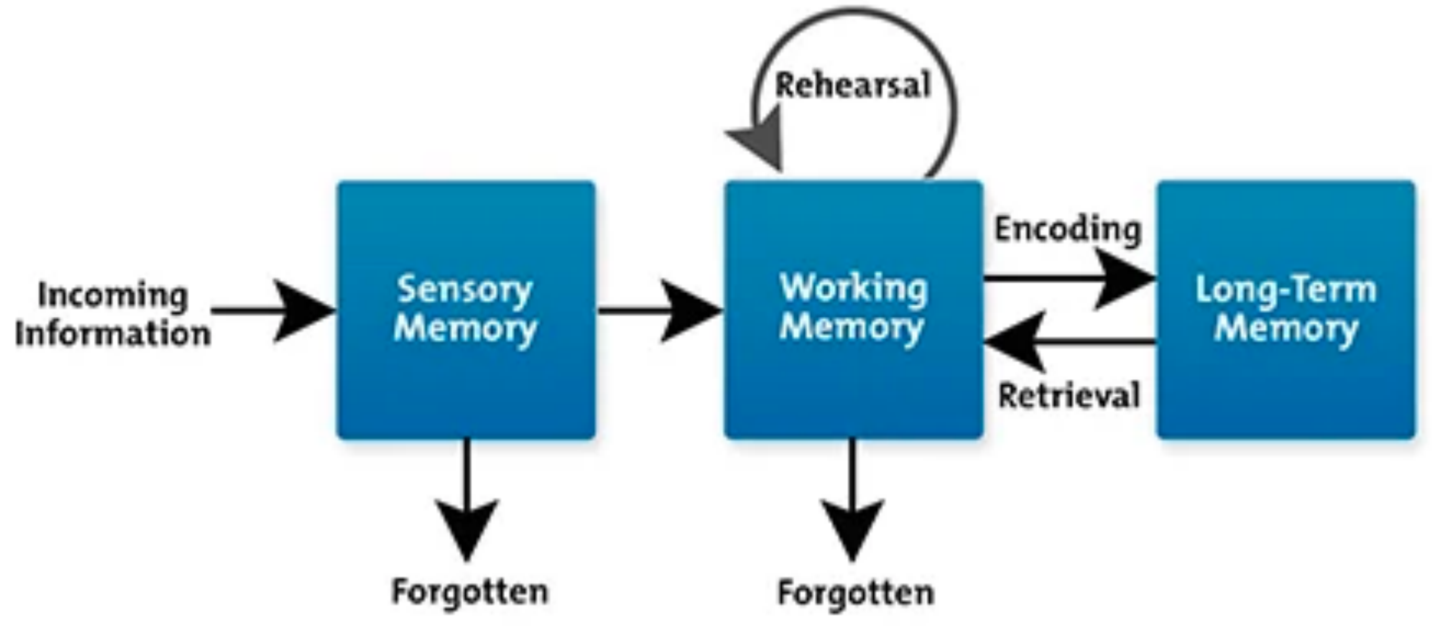
- Design and implement an online web-based experiment (HTML, Javascript, PHP)
- Develop a compositional grammar for sequence generation
- Analyze data and test algorithms for hypotheses generation (e.g. Markov Chain Monte Carlo) and structure discovery (e.g. Successor Representation)
- In collaboration with the MPI Biological Cybernetics



Project 3: Understanding human memory and forgetting using computational modeling

Research question

It was generally assumed that freshly acquired memories are initially in a dynamic, fluid state for a short period of time, after which the memory is consolidated or removed. Yet there are many current debates in the field about the exact mechanisms that govern the temporal dynamics of memories.

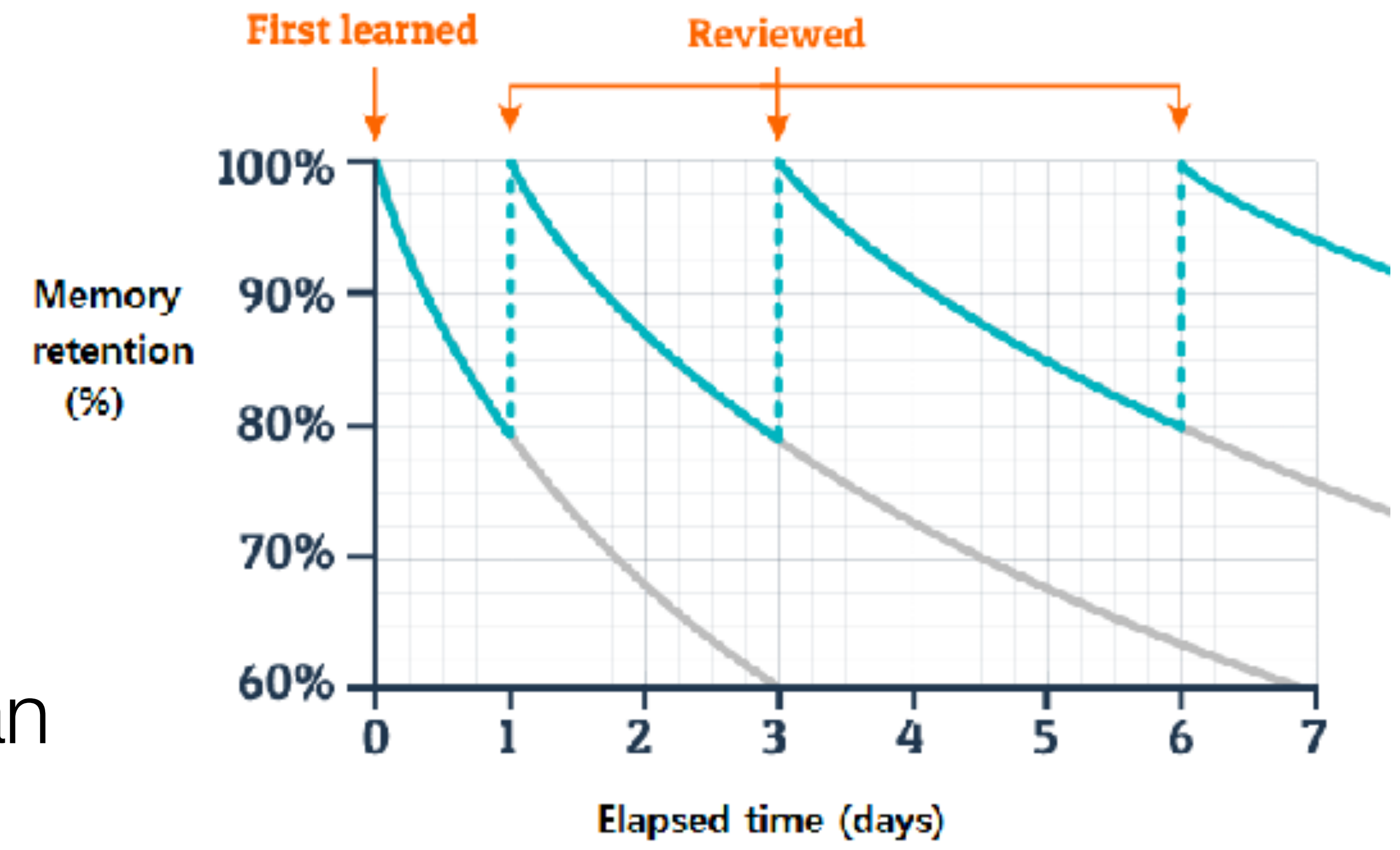


In this project, you will

1. **Develop a deeper understanding of the mechanism of human memory**. What empirical support is there for different memory systems (e.g., working memory, long-term memory, etc…)? What are the theoretical implications of these distinctions?

2. **Conceptualize the link between memory and forgetting**. What causes forgetting, and how is it different for distinct different memory systems? How does repetition help avoid forgetting?

3. **Develop computational models and experiments**. How to design models of human memory that combine rehearsal and retrieval?



This project is in collaboration with the ML Collab

Project 4: Neural correlates of reward generalization and exploration

Research Question

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

Approach

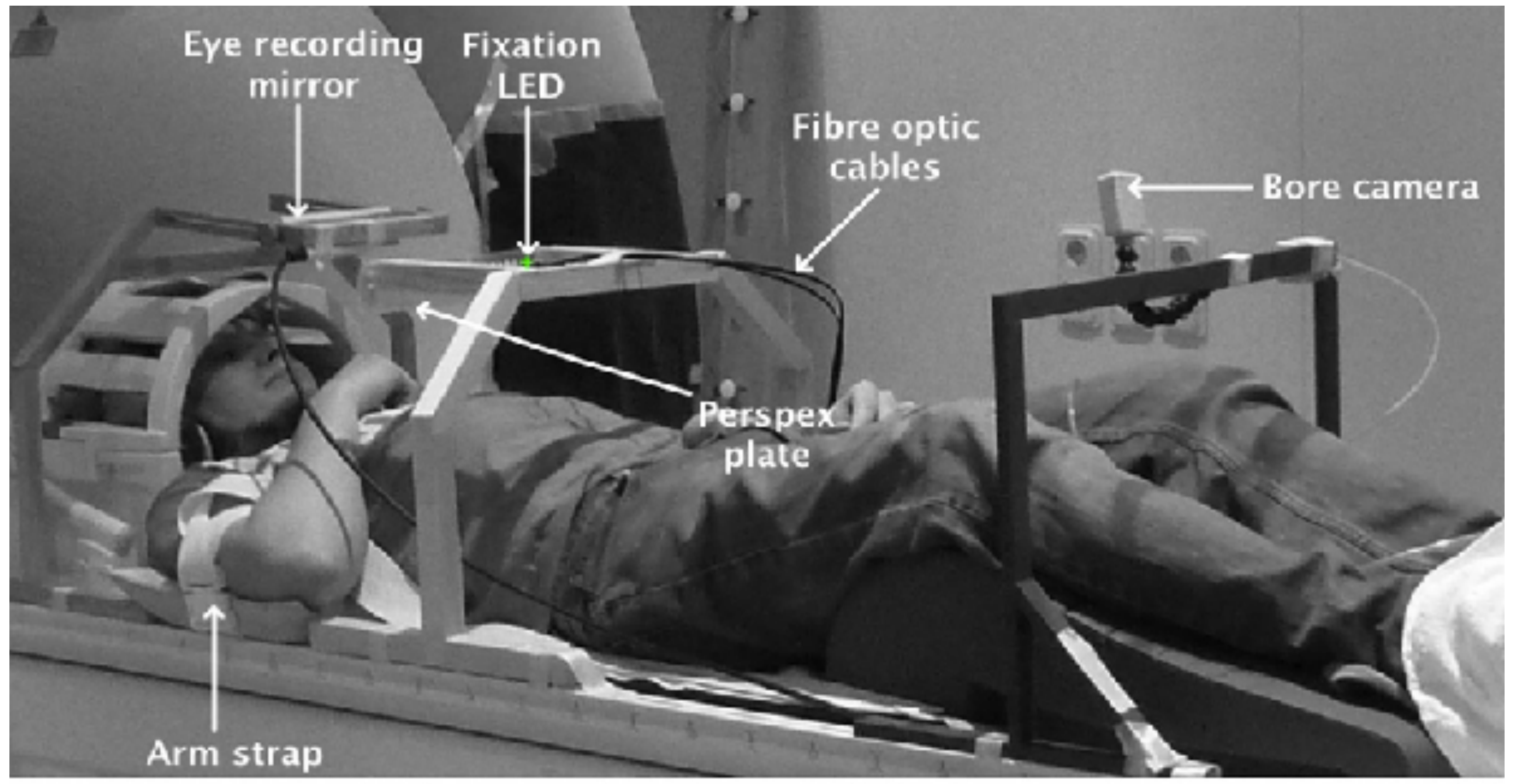
- Simultaneous fMRI and eye-tracking study planned for late 2022, using a modified version of the Spatially correlated bandit task
- Use eye-tracking to improve our process-level understanding of previous computational models (**Wu et al., 2018**; **Wu et al., 2020**)
- Relate model predictions and parameters 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 the analysis of eye-tracking data
- Collaboration with University Hospital Tübingen and MPI Berlin

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



Project 5: Propose your own project!

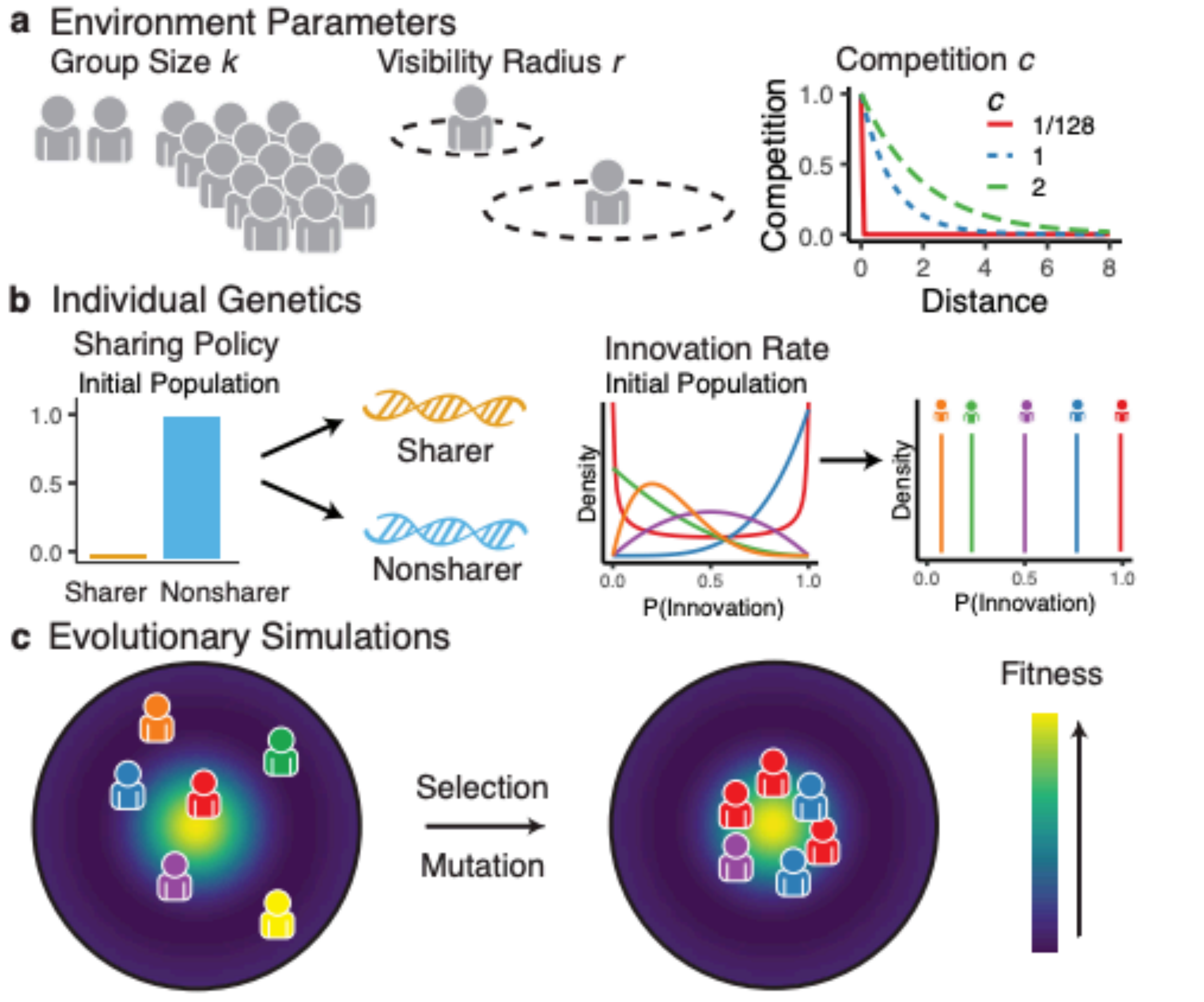
- Take the reigns and propose your own research project! To make things feasible within the rotation period or for a thesis, here are some suggestions of projects with existing data/code that could be built upon:

- **How does cooperation arise in competitive environments?** Through a series of agent-based and evolutionary simulations, we found that unconditional sharing of information can be beneficial, even in the absence of traditional reciprocity or reputation-based mechanisms. Many open questions, new environments, and learning mechanisms that can be tested

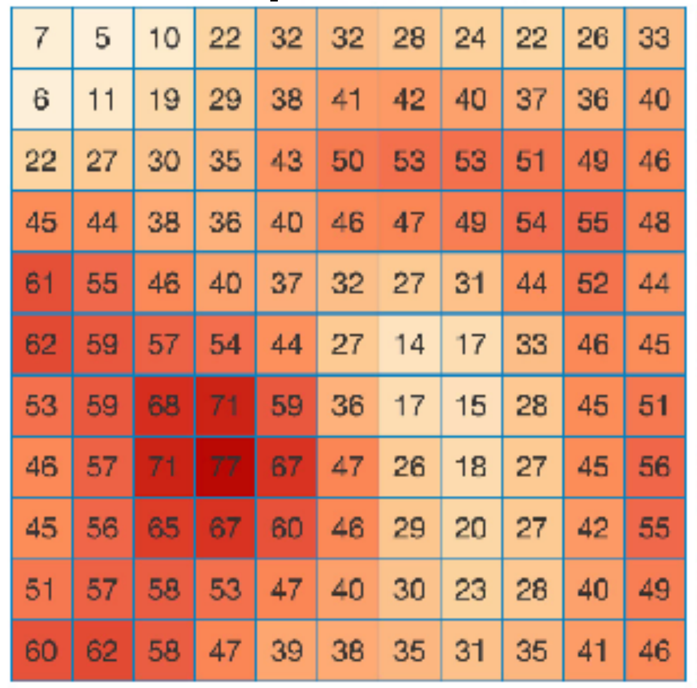
- **Why do people systematically under-generalize? Why are people systematically biased towards performing local search?** These are unexplained questions from a series of previous papers studying the search for rewards in spatially structured (Wu et al., 2018) and conceptually structured (Wu et al., 2020), and graph-structured environments (Wu et al., 2021). All the code and data are publicly available (1, 2, 3)

- **Note**: proposing your own project requires a high level of independent thinking and ability to craft an interesting and obtainable research question

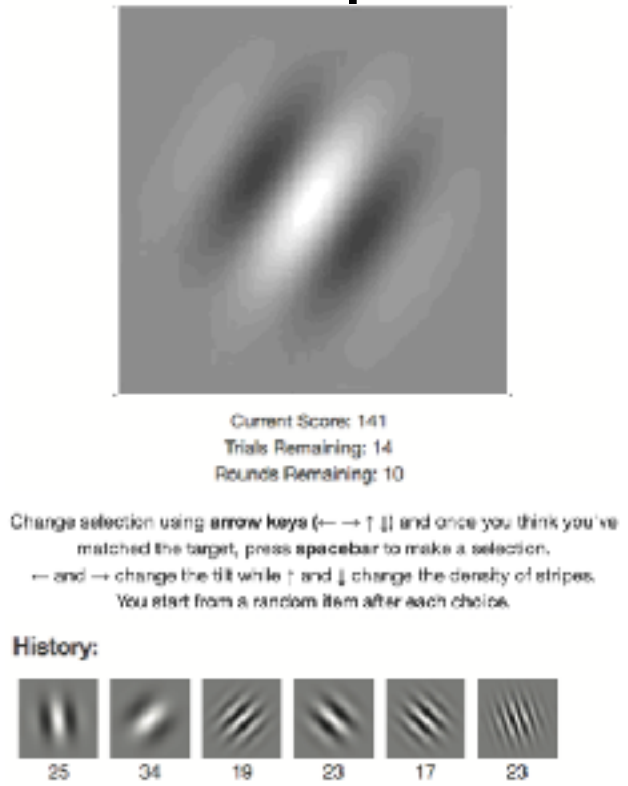
Evolutionary simulations



Spatial



Conceptual



Graph-structured