Bridging the gap between different levels of analysis

Work in Progress

Summer 2021

Understanding brain-body-environment systems

Brain only.

One task (often no task).

Open loop (input-output)

Brain-centric analysis.

BBE systems.

Multiple tasks.

Closed loop.

Behavior-inclusive analysis.

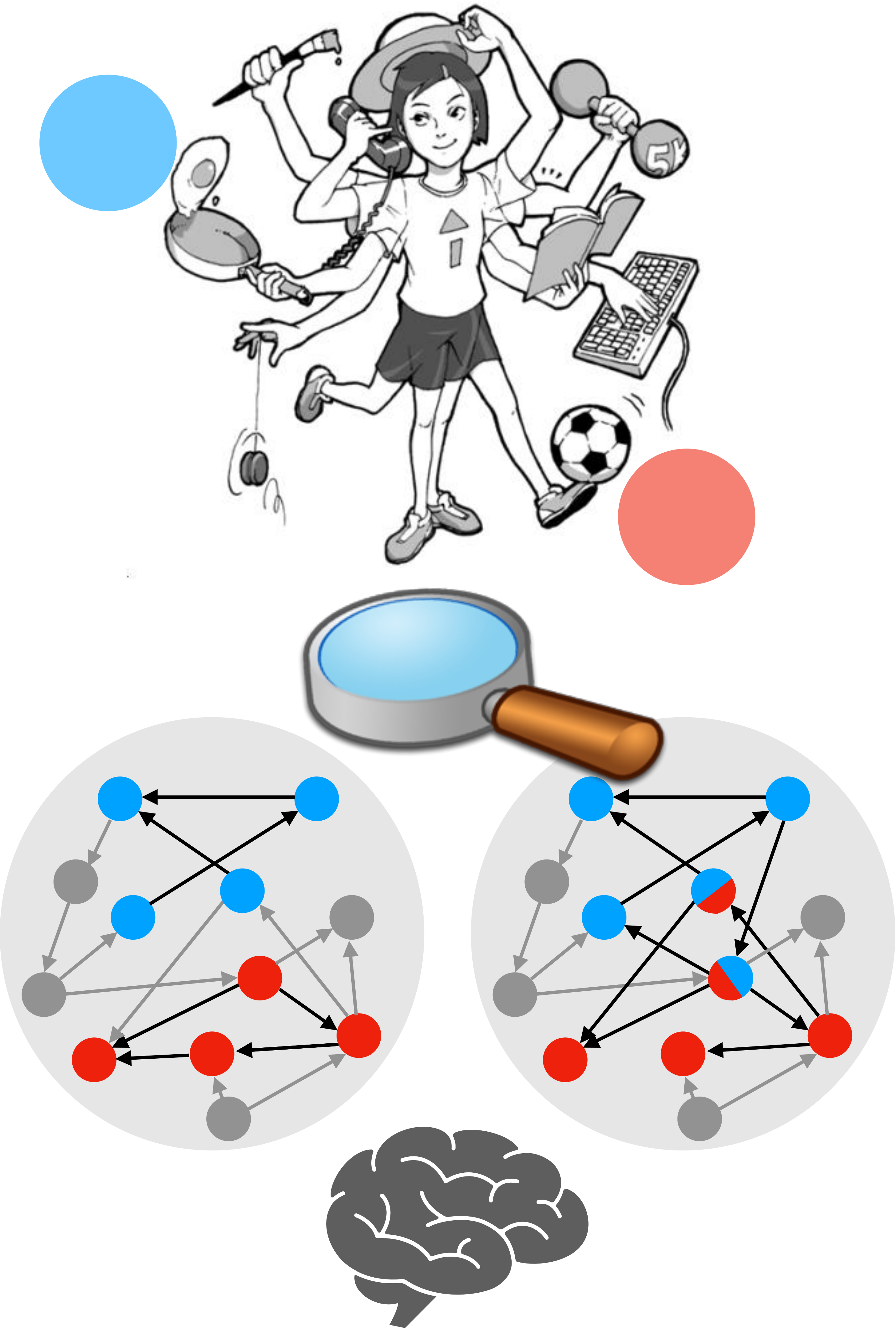
Illustrations by Shun Iwasawa in Pfeifer (2001)

Motivating questions

When a BBE system can perform multiple behaviors, how are its resources shared or specialized for each task?

And how does this resource allocation depend on:

- Similarity between tasks.
- Cognitive complexity of tasks.
- Degree of embodiment of tasks.
- Size of the neural circuit. Neural network architecture.
- Neural model. Synaptic plasticity. Neuromodulation.
- Shared/specialized sensory/motor periphery.
- Training regime.
- Presence of noise.
- Individual variability.



The many different levels and tools of analysis

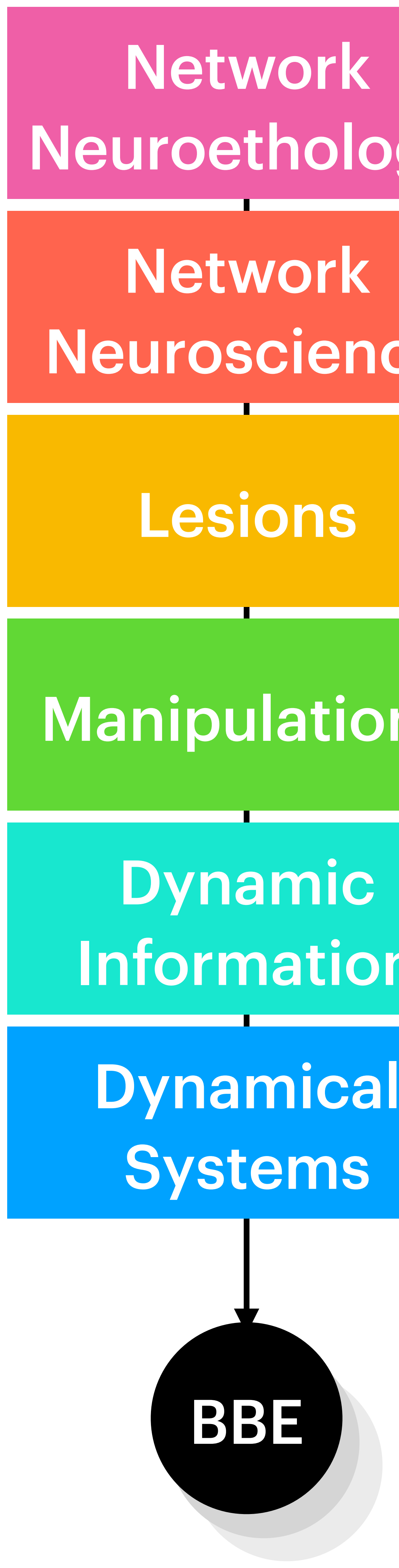
To operationalize the role and involvement of each component of the system in the task.

Broad goal: Develop a toy model of a brain body environment system and analyze it using many different tools of analysis at different levels of description.

Then use these to build intuition about which aspects of the story at each level are consistent and/or explained by aspects of the story at a different level.

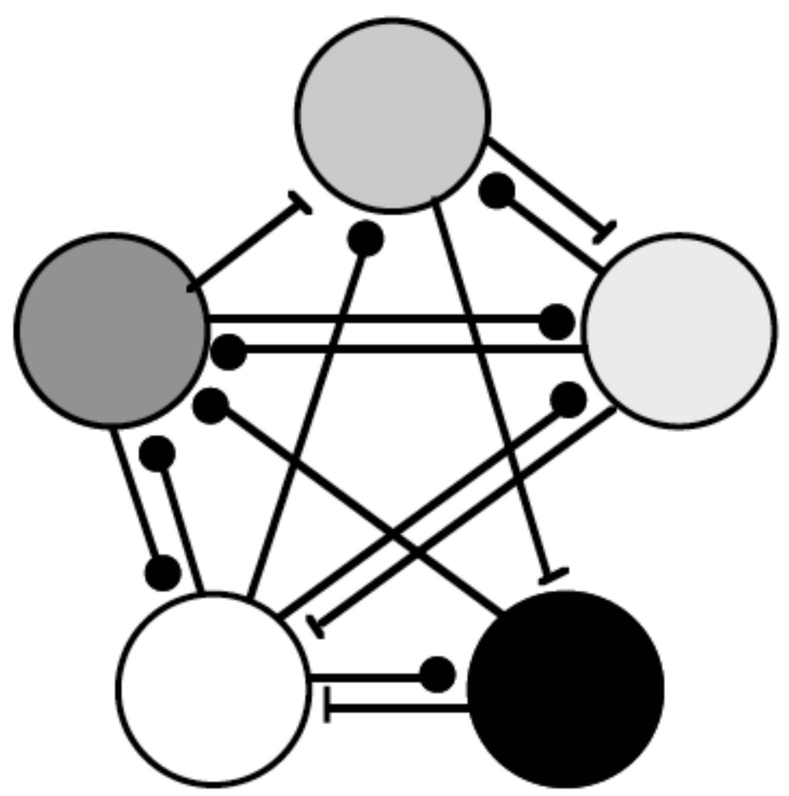
Once the story is worked out for one agent, the lessons can be compared/tested on a second agent.

Are there some aspects of the story that are altogether missed at the higher levels that are present at the lower levels? Can the lower level be used to explain the phenomena at the higher levels? Conversely, are there some aspects of the story that are gained at higher levels? For example, once the analysis is applied across not a single individuals but an ensemble of solutions — potentially the degeneracy at the lower levels of explanation are integrated at the higher levels of explanation.

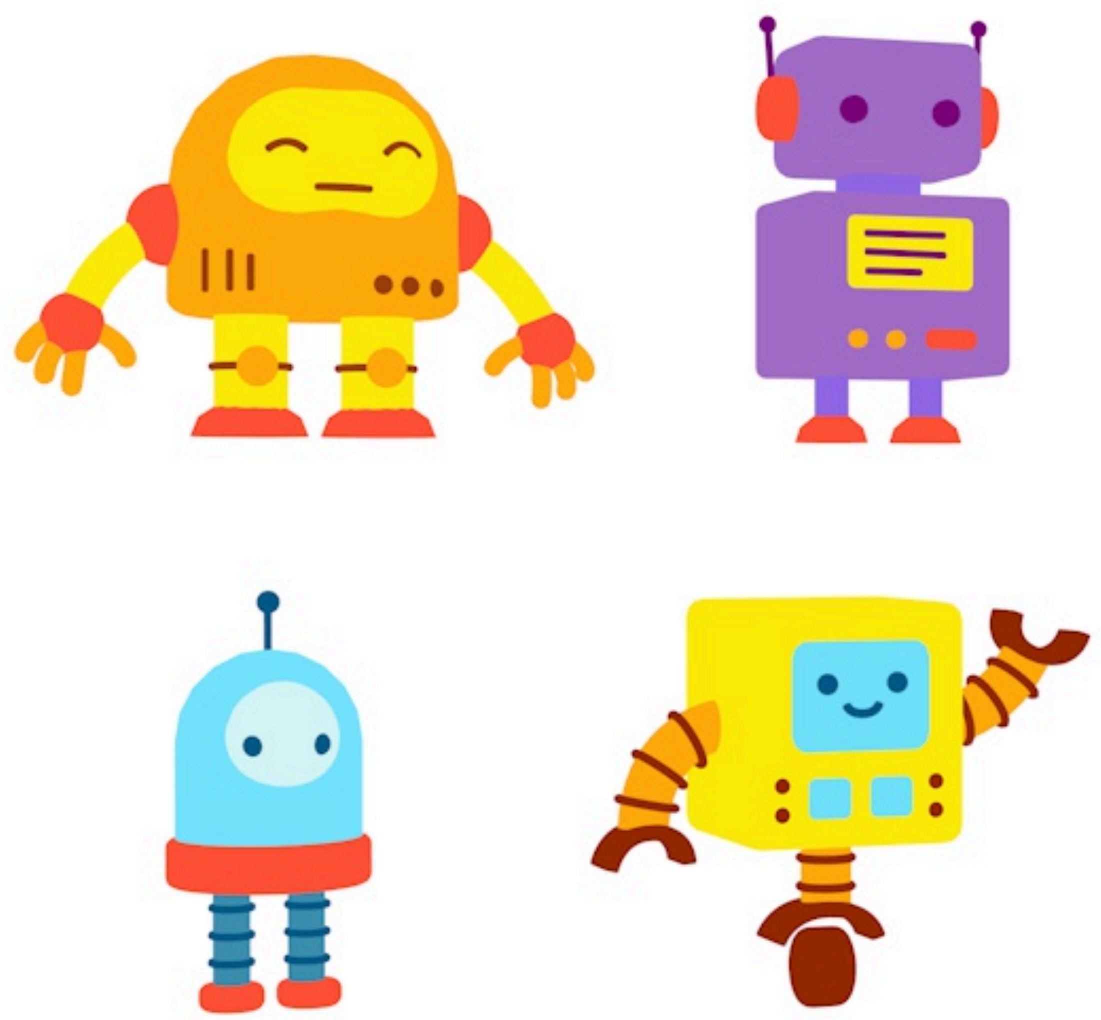


Computational Neuroethology Approach

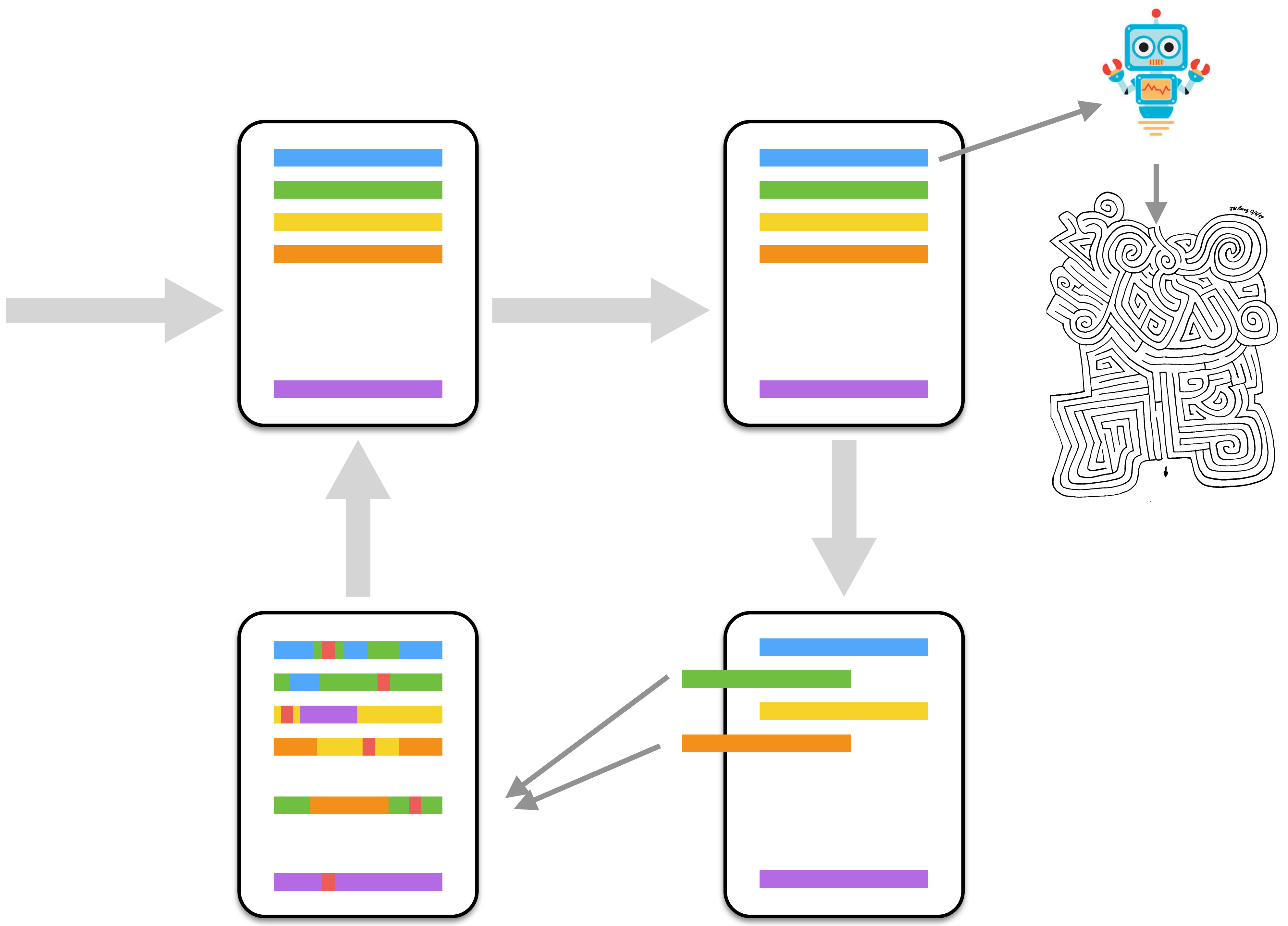
Evolution and analysis of simple but complete and tractable BBE system



Brain



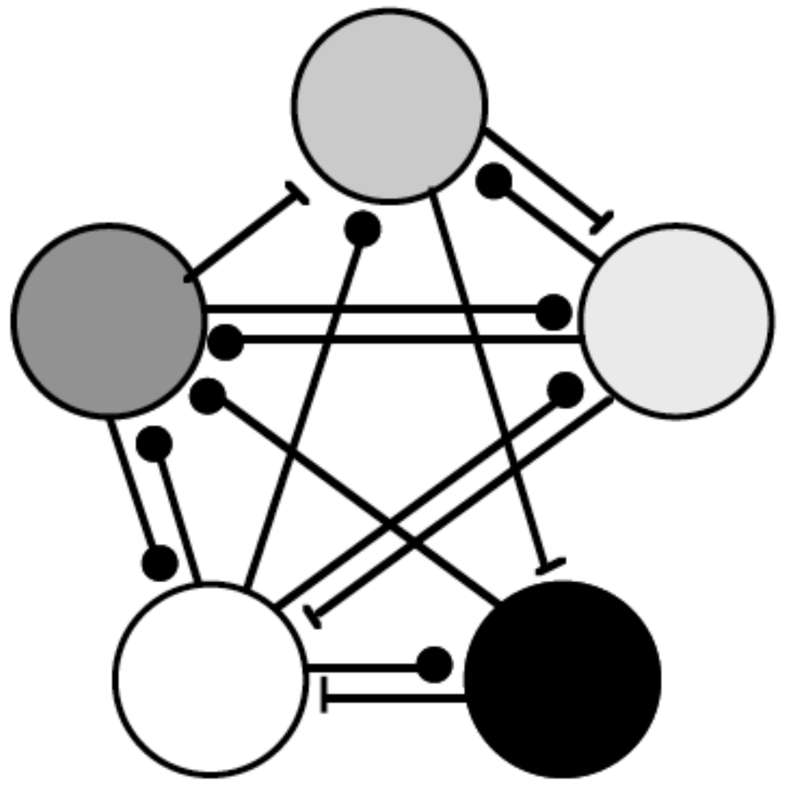
Body-Env



Train

Picking your brain

An interconnected set of nonlinear interacting dynamic components.



Rate of change of the neuron/ node state

Leaky component

Summed input from all presynaptic neurons

Transfer function (typically a sigmoid)

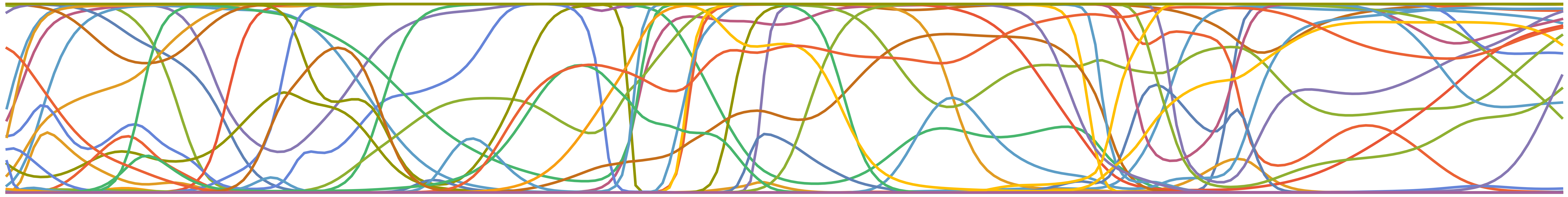
$$\dot{y}_i = \frac{1}{\tau_i}\left(-y_i + \sum_{j=1}^{N} w_{ji}\,\sigma\left(y_j + \theta_j\right) + I_i\right)$$

External input

Time-constant

Weight

Bias



Micro-circuits at the level of individual neurons

Macro-circuits at the level of brain regions

302 | 8693

100,000 | ~10^6

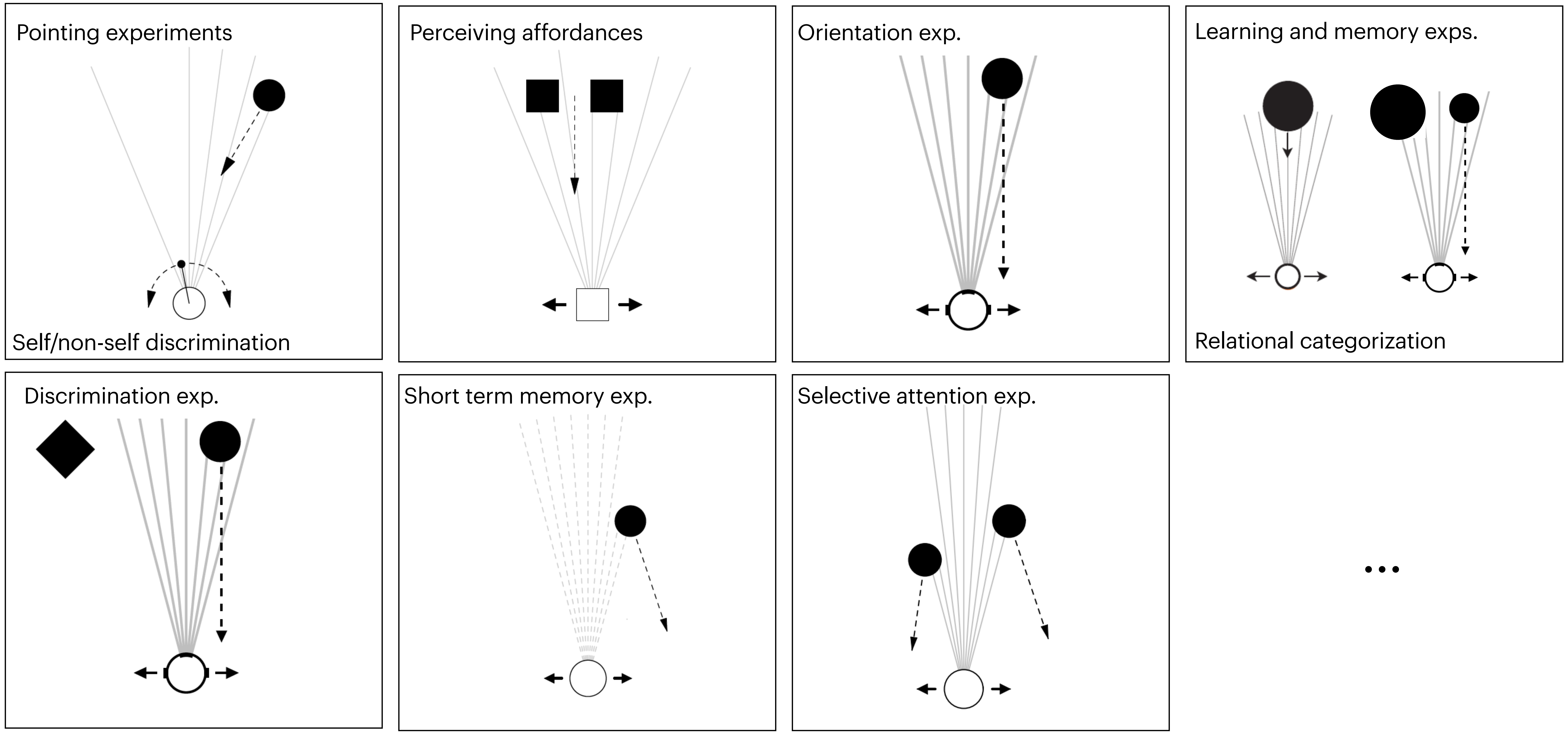
250,000 | ~10^7

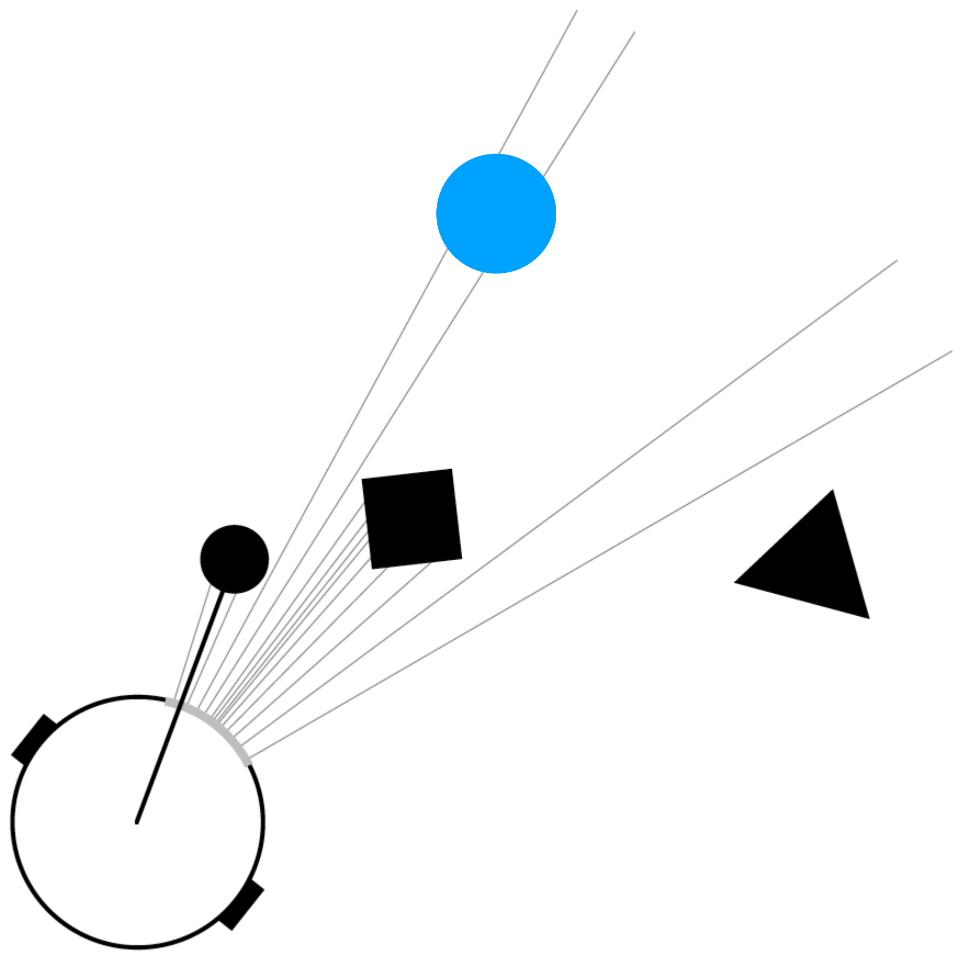
71,000,000 | ~10^{12}

~10^{10} | ~10^{14}

Task ecology

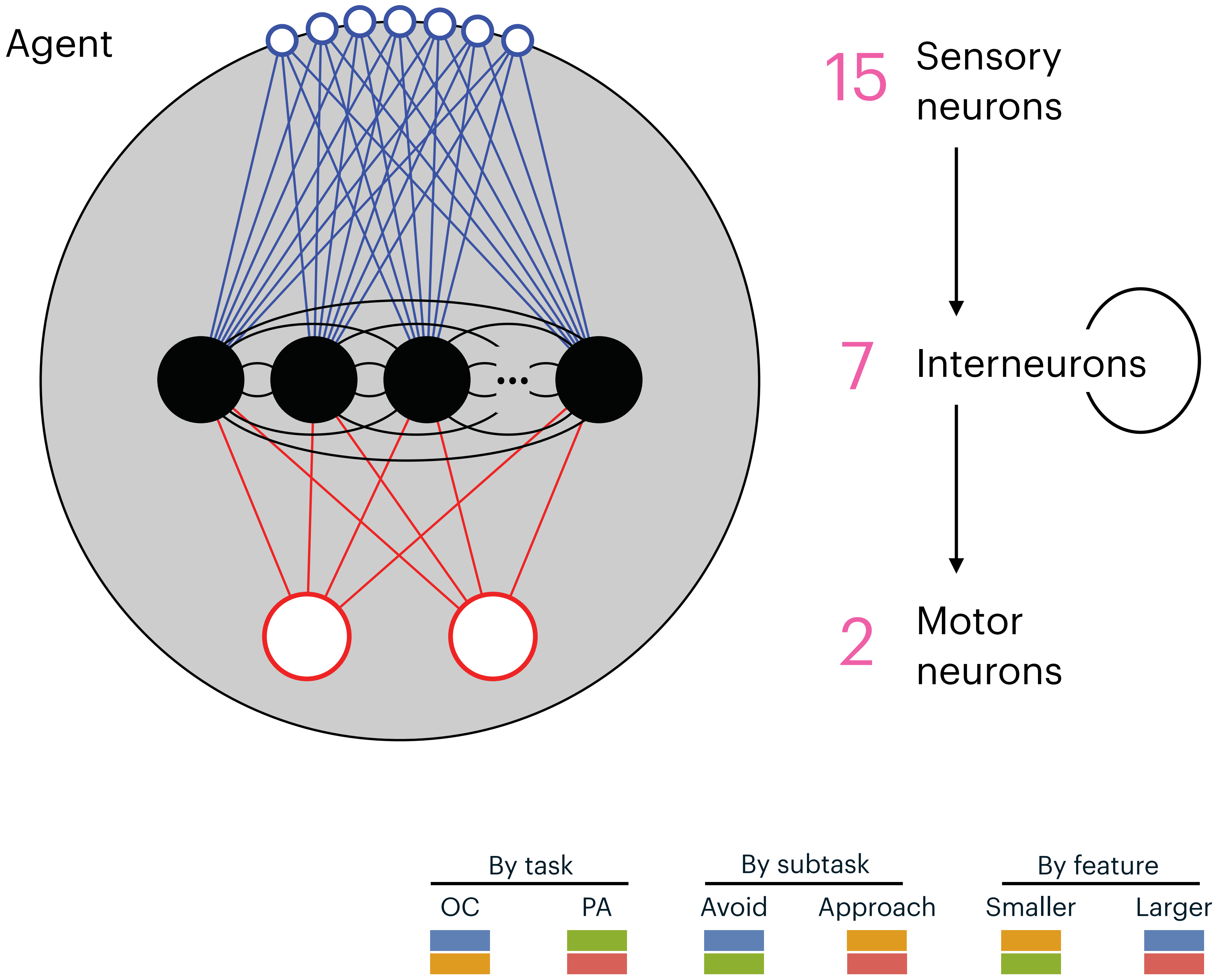
Existing ones and possible extensions.

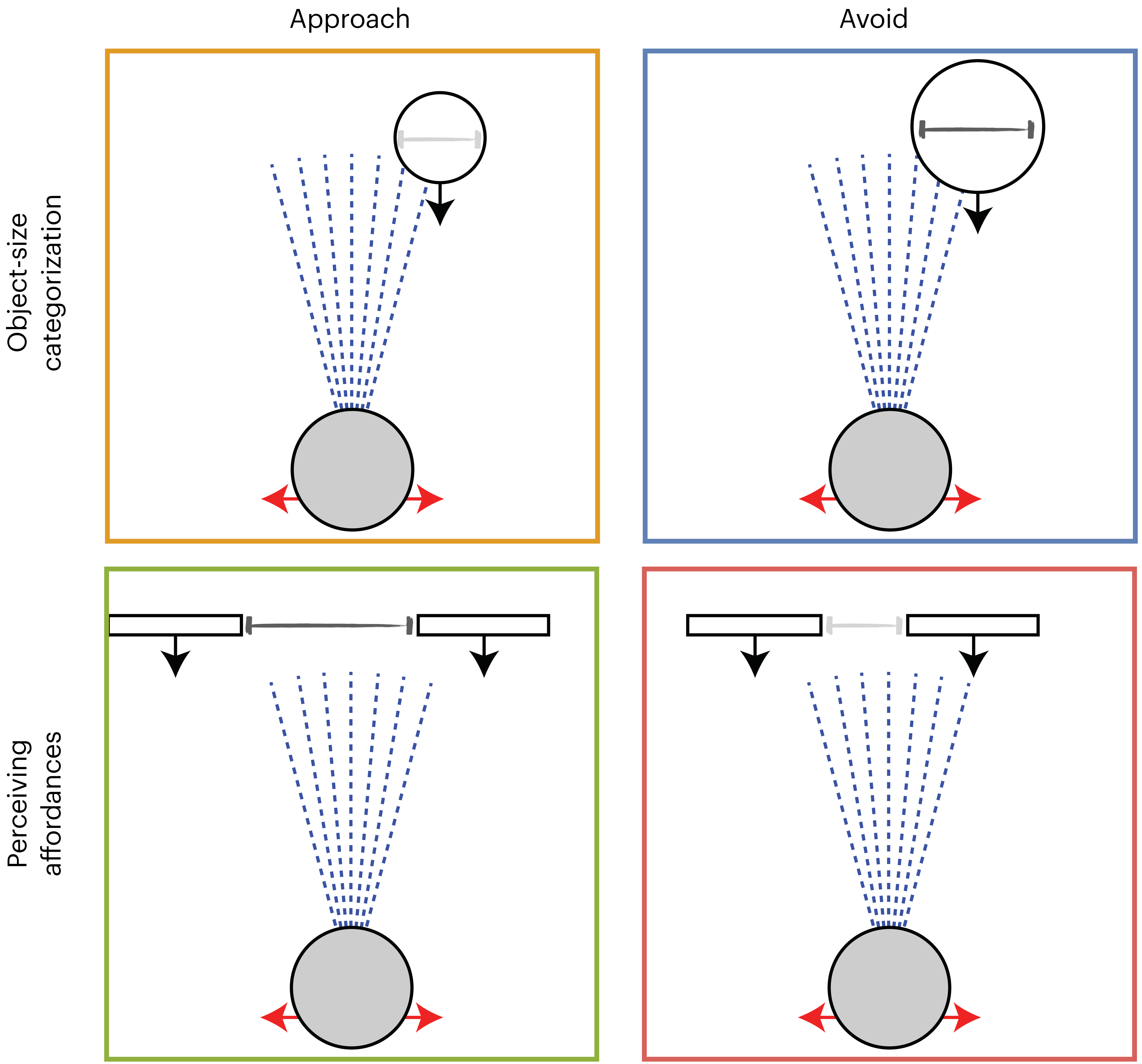




I'm running these in C++, but Madhavun has been developing an OpenAI Gym Python version of these that include real-time rendering.

Starting simple: Two highly interrelated tasks

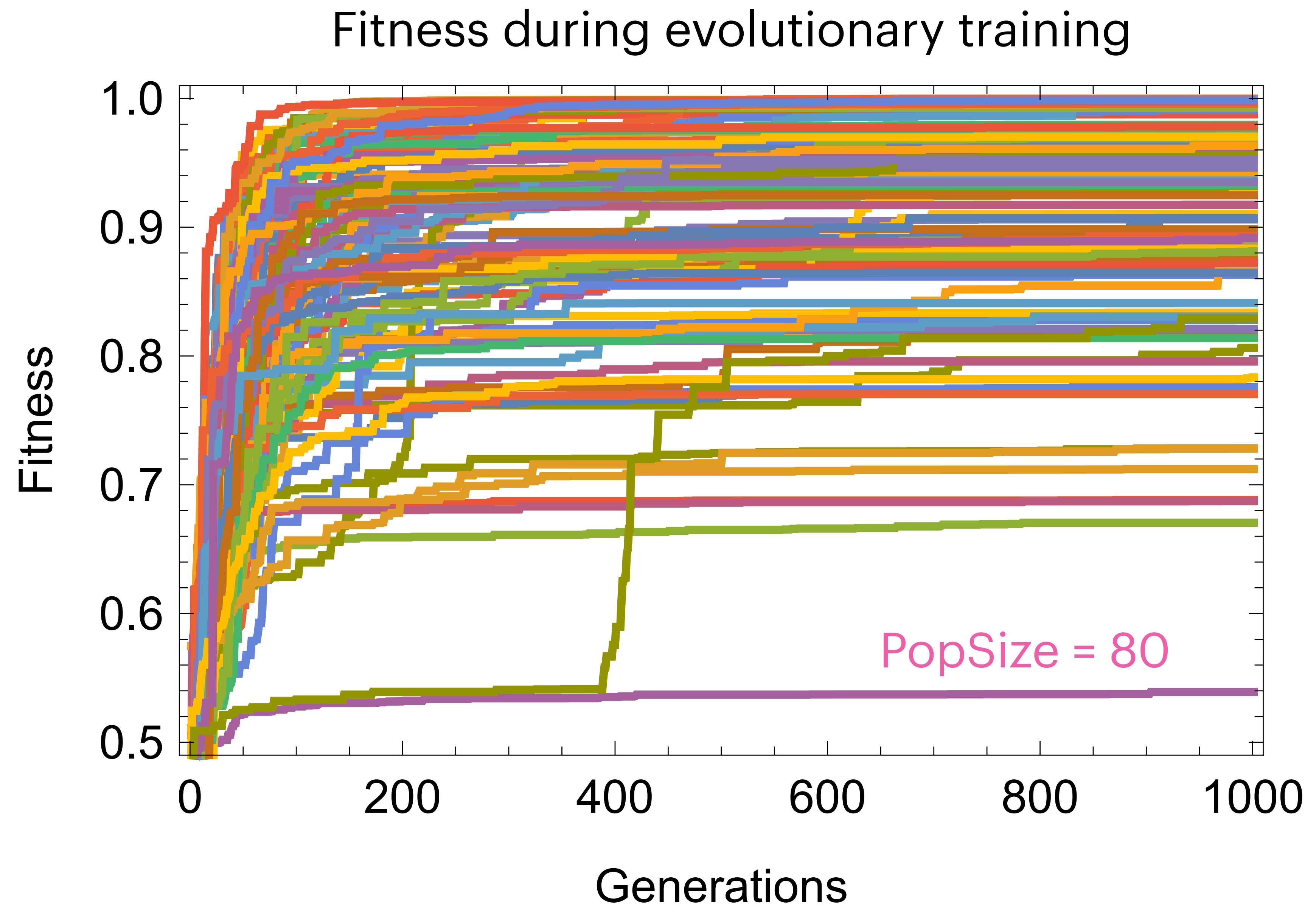


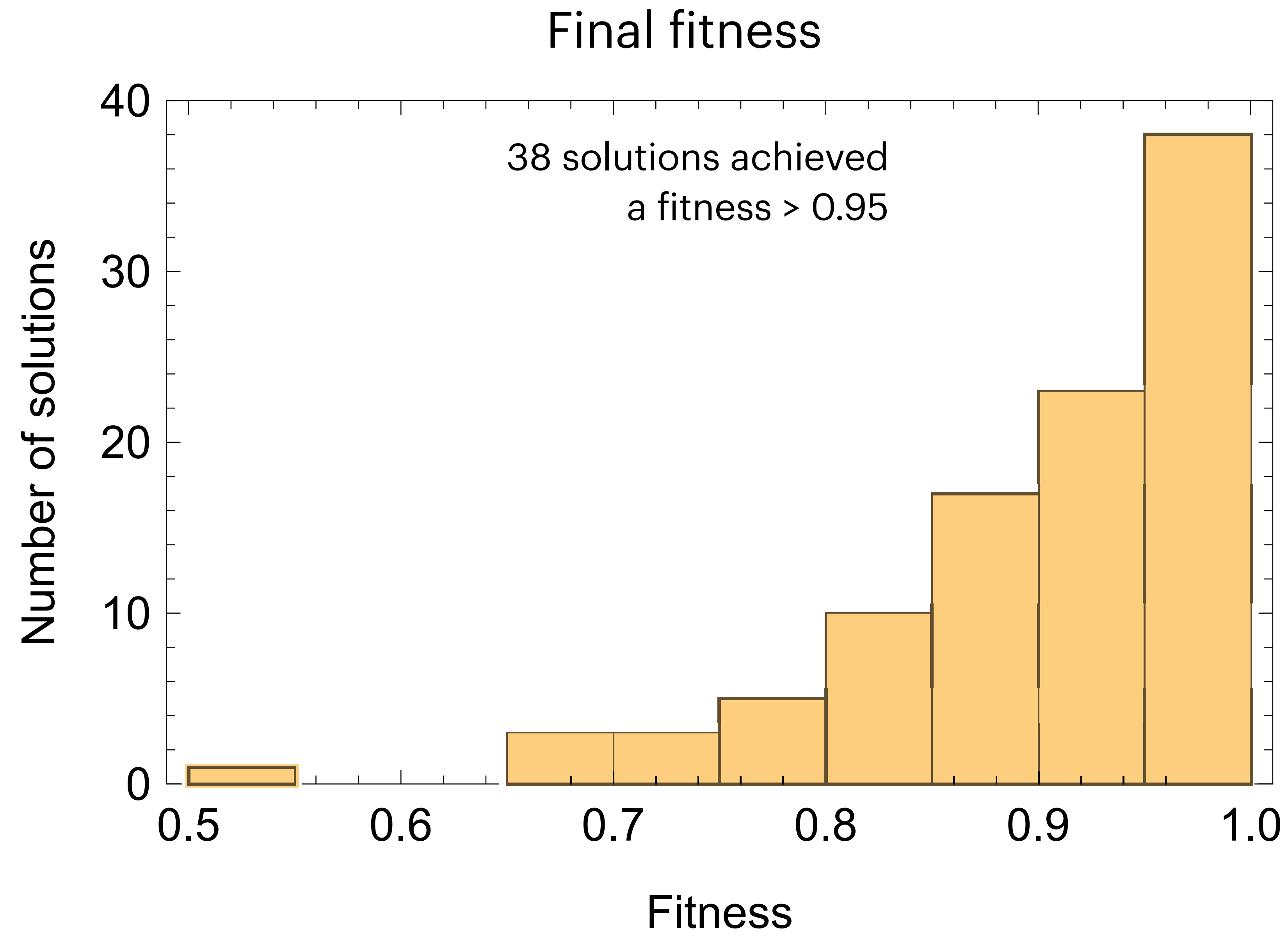


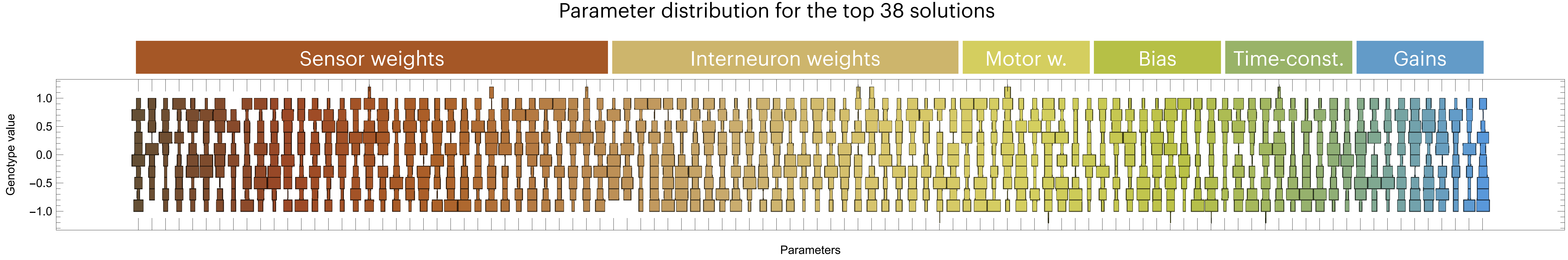
Feature: Relative size of the object or gap: Smaller or Larger.

Evolutionary Runs

Obtaining samples for study

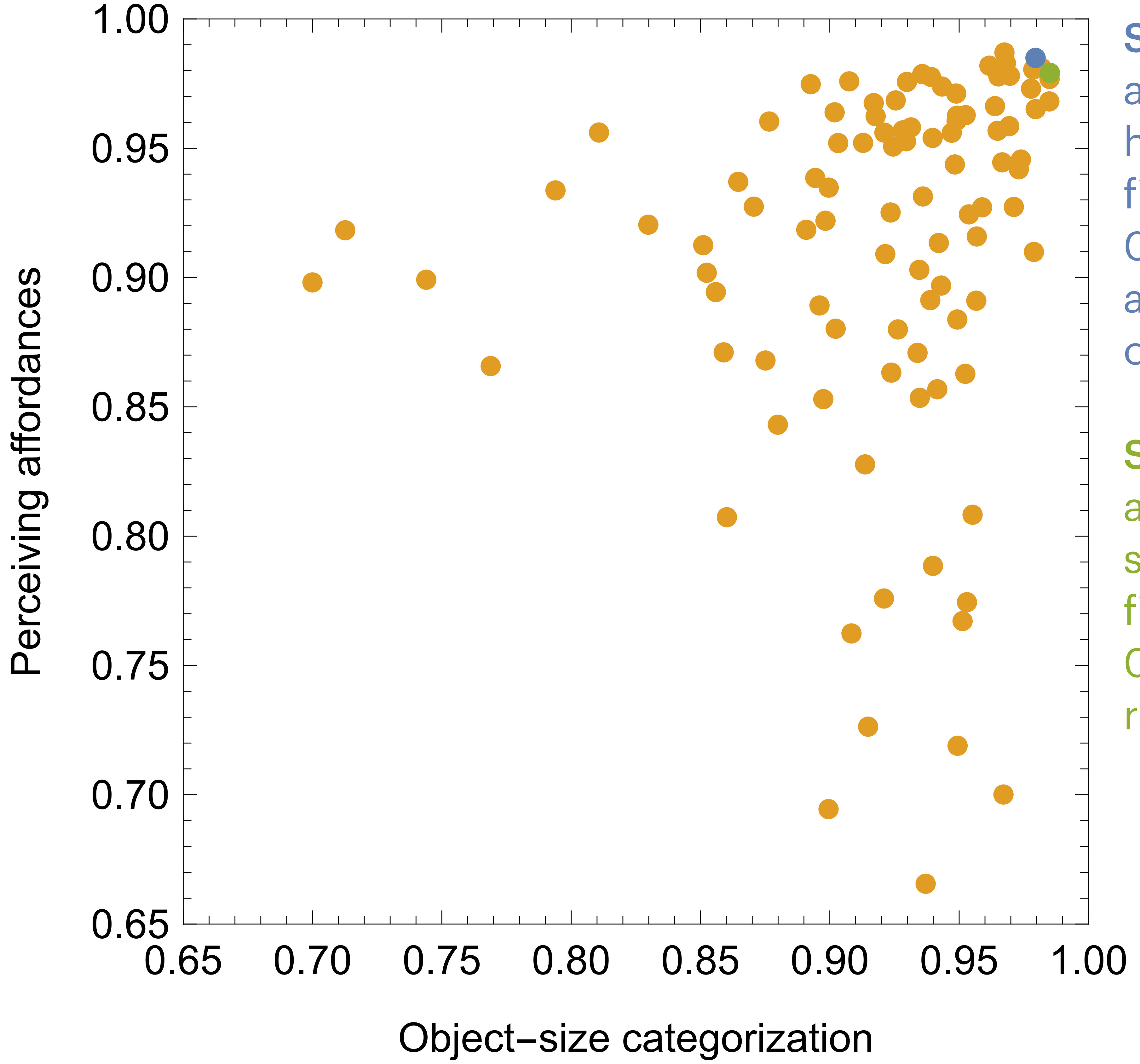






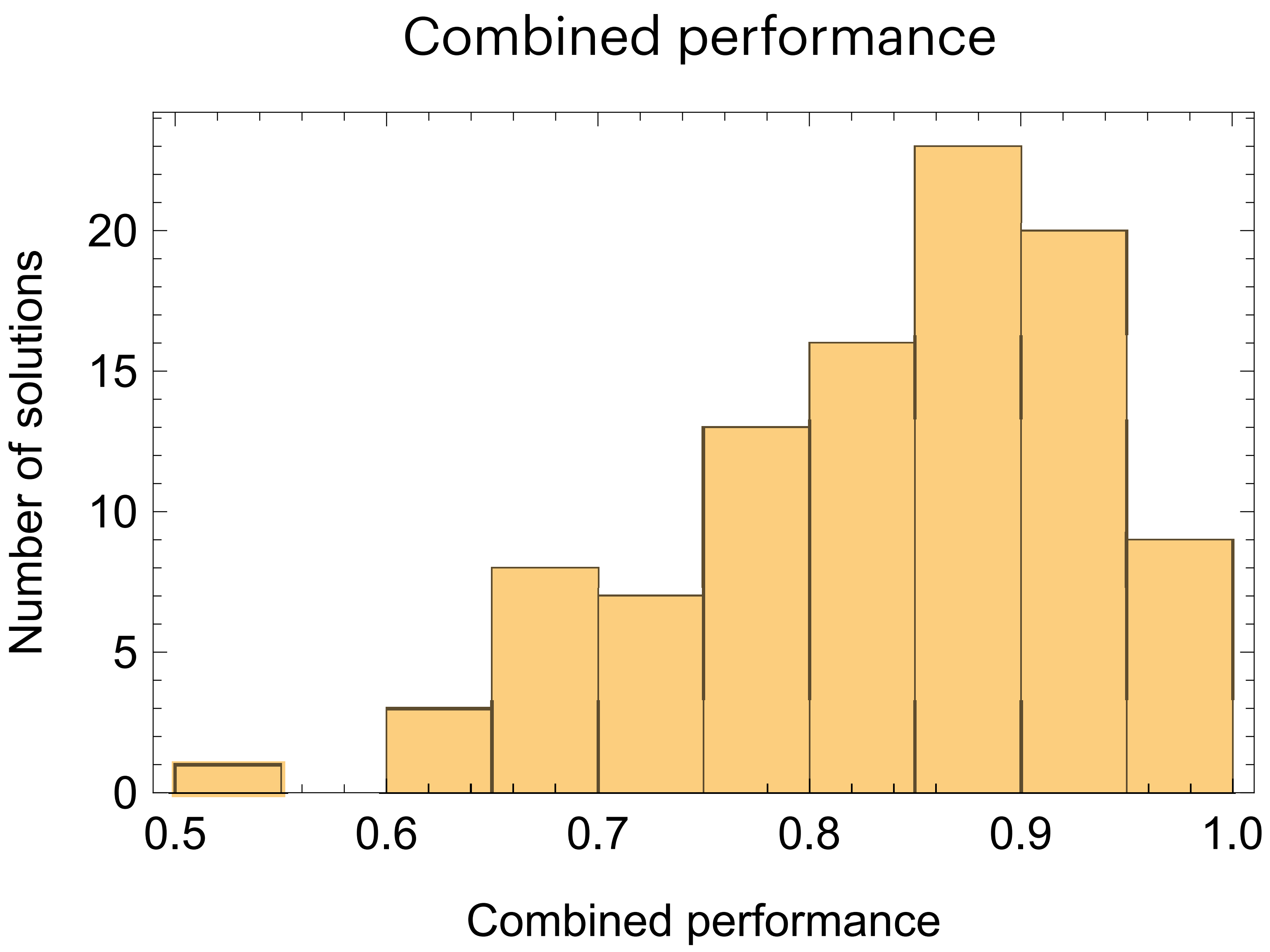
Robustness analysis

Performance of the ensemble in each task individually



Solution #86 achieved the highest combined fitness: 0.9647 (with 0.9795 in one task and 0.9849 in the other).

Solution #1 achieved nearly the same combined fitness: 0.9645 (with 0.9850 and 0.9790, respectively).

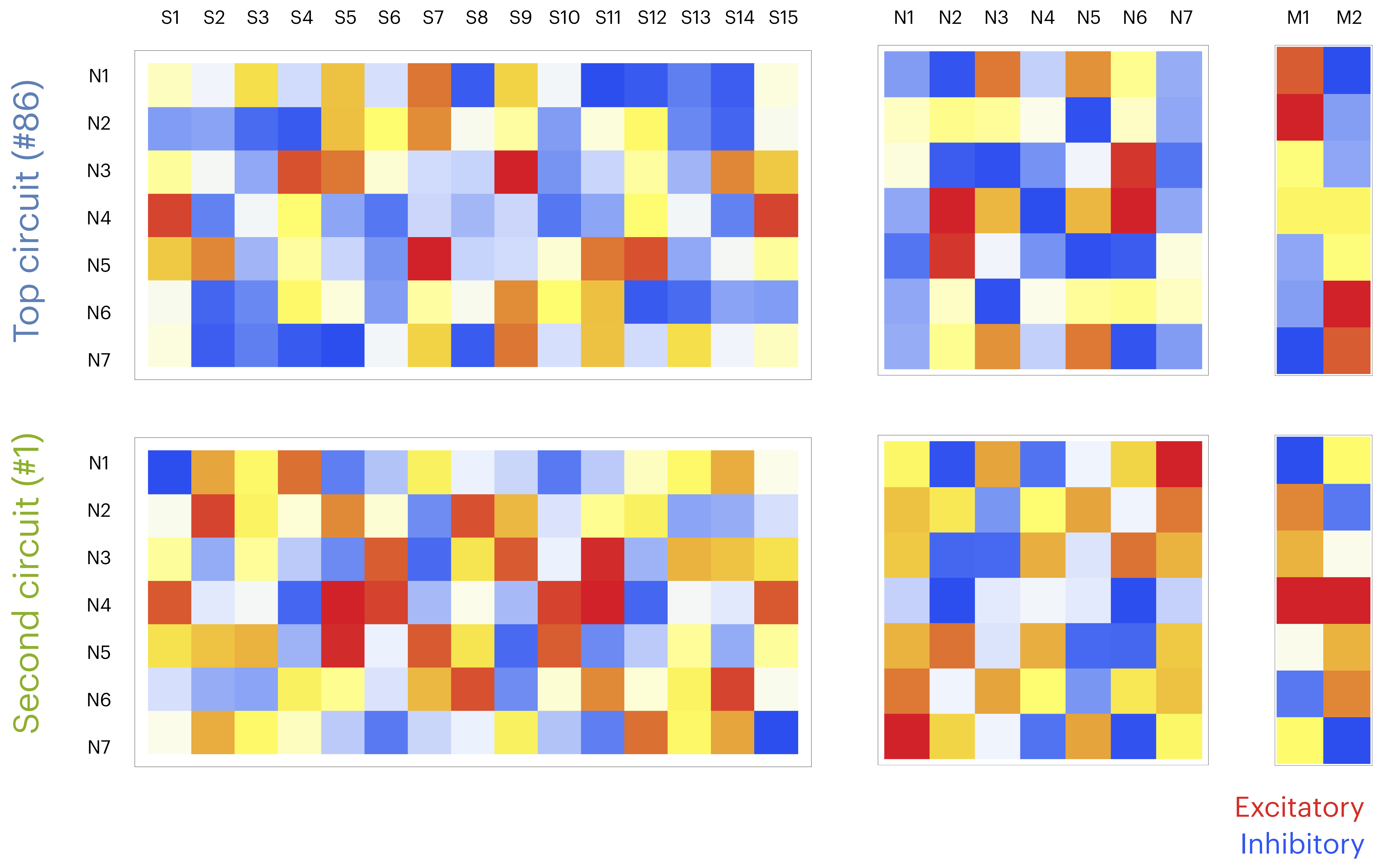


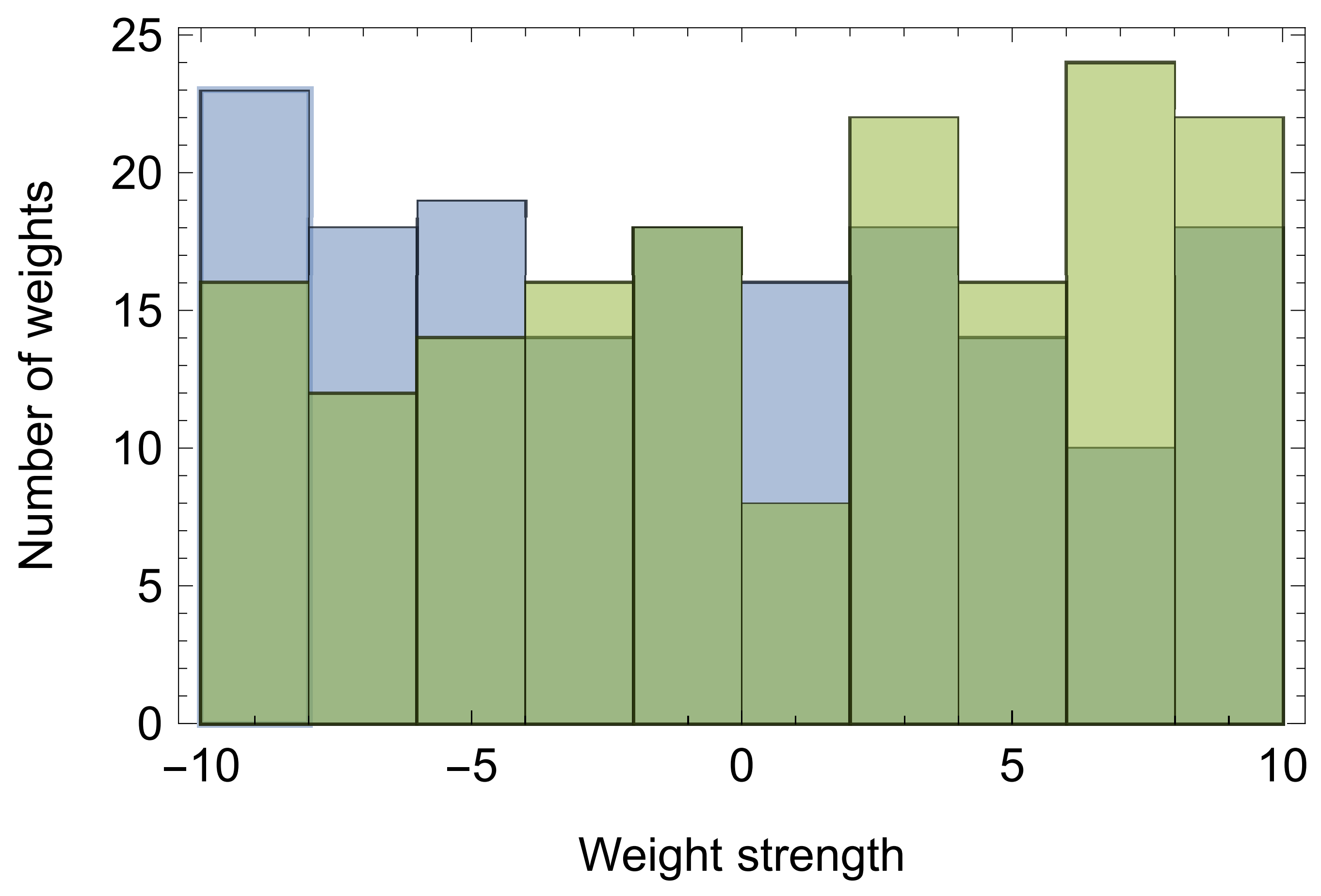
Two key changes with respect to the original fitness evaluation:

(a) dt = 0.1 during training; dt = 0.01 during robustness analysis.

(b) Object size range {20,40,1} and and starting position {1,5,1} during training for 100 trials; Size {20,40,0.05}, Pos {1,5,0.01}, 200,000 trials.

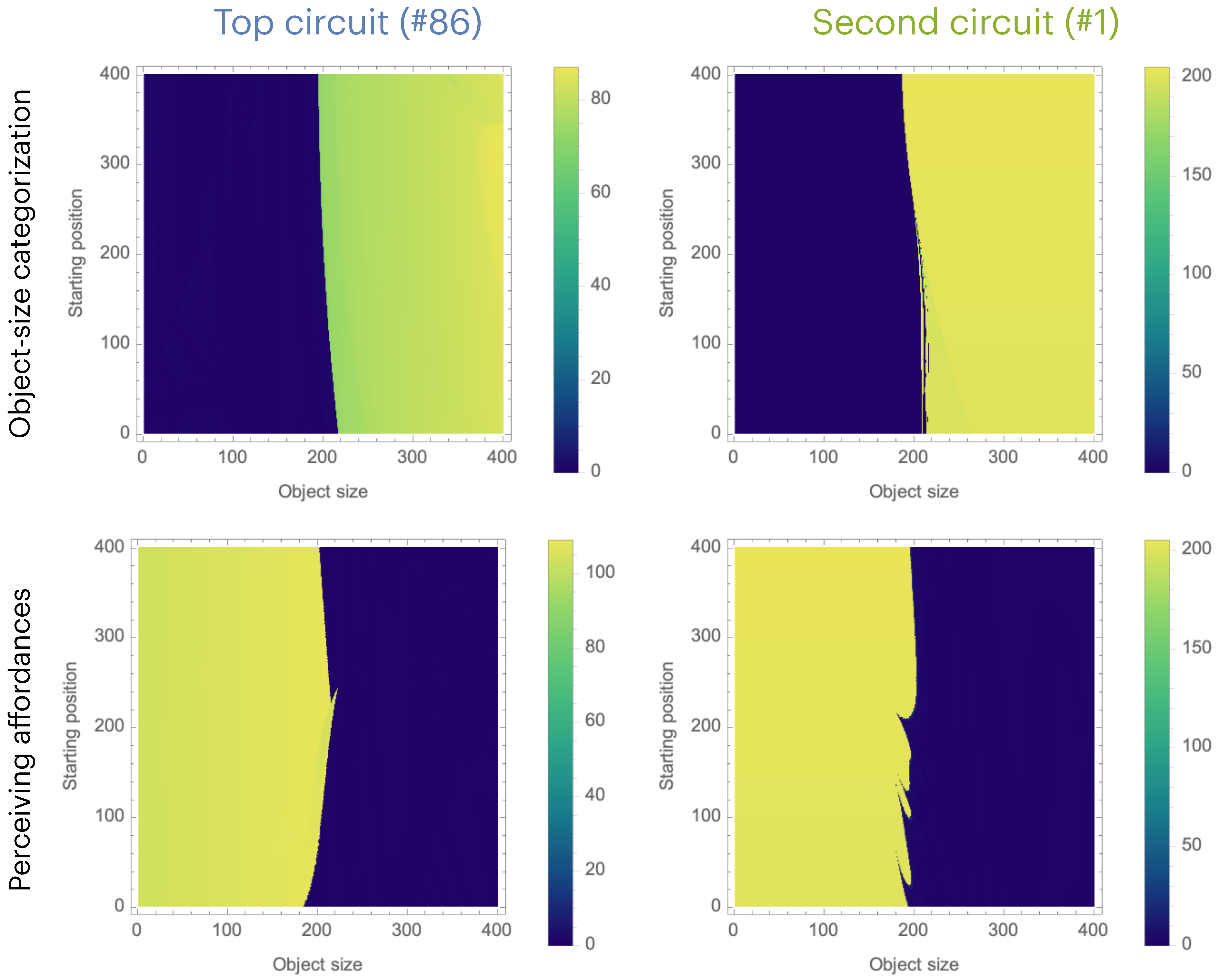
Connectomes of the best two solutions





Generalization

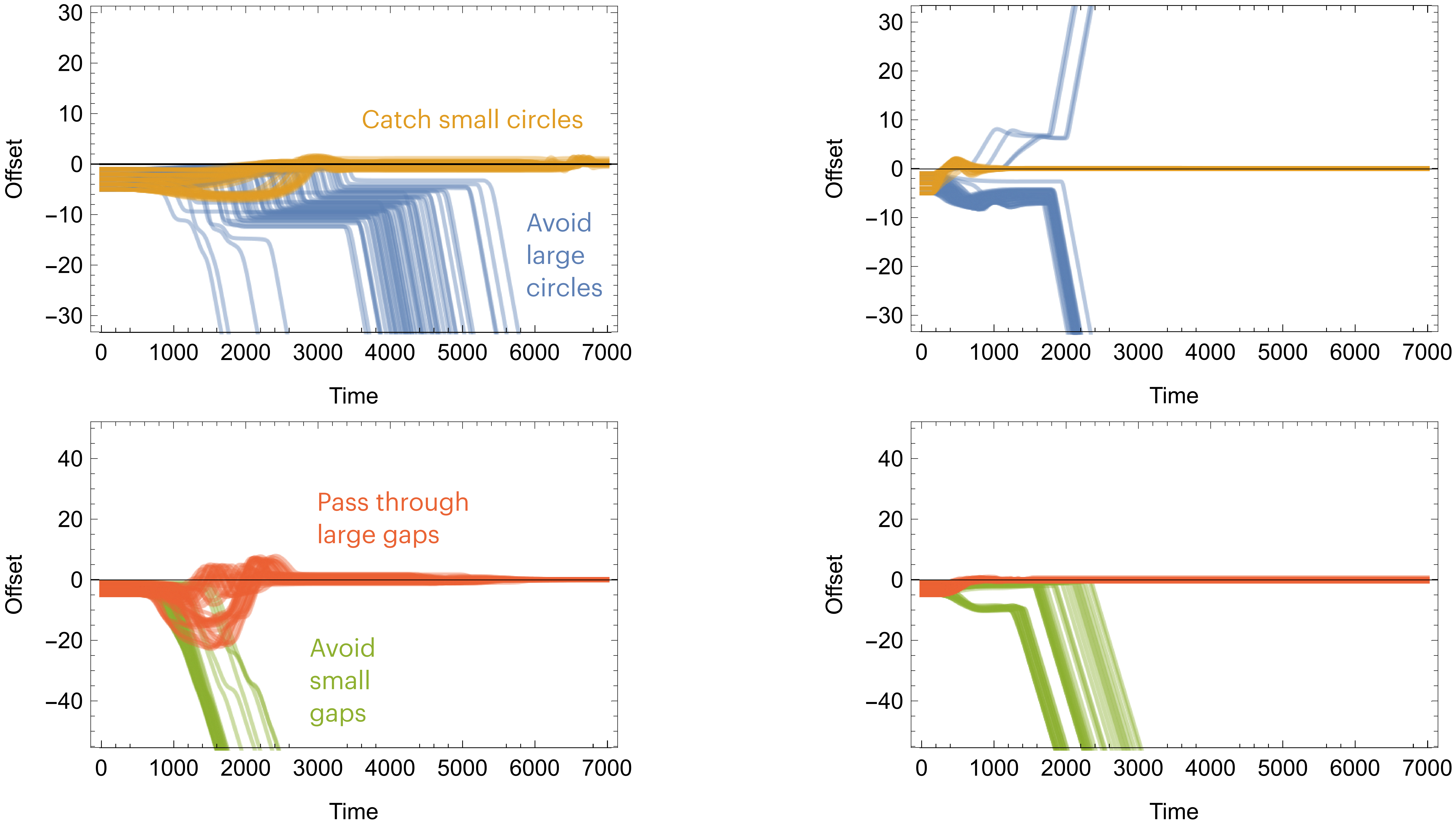
Performance map across different conditions for best two neural circuits

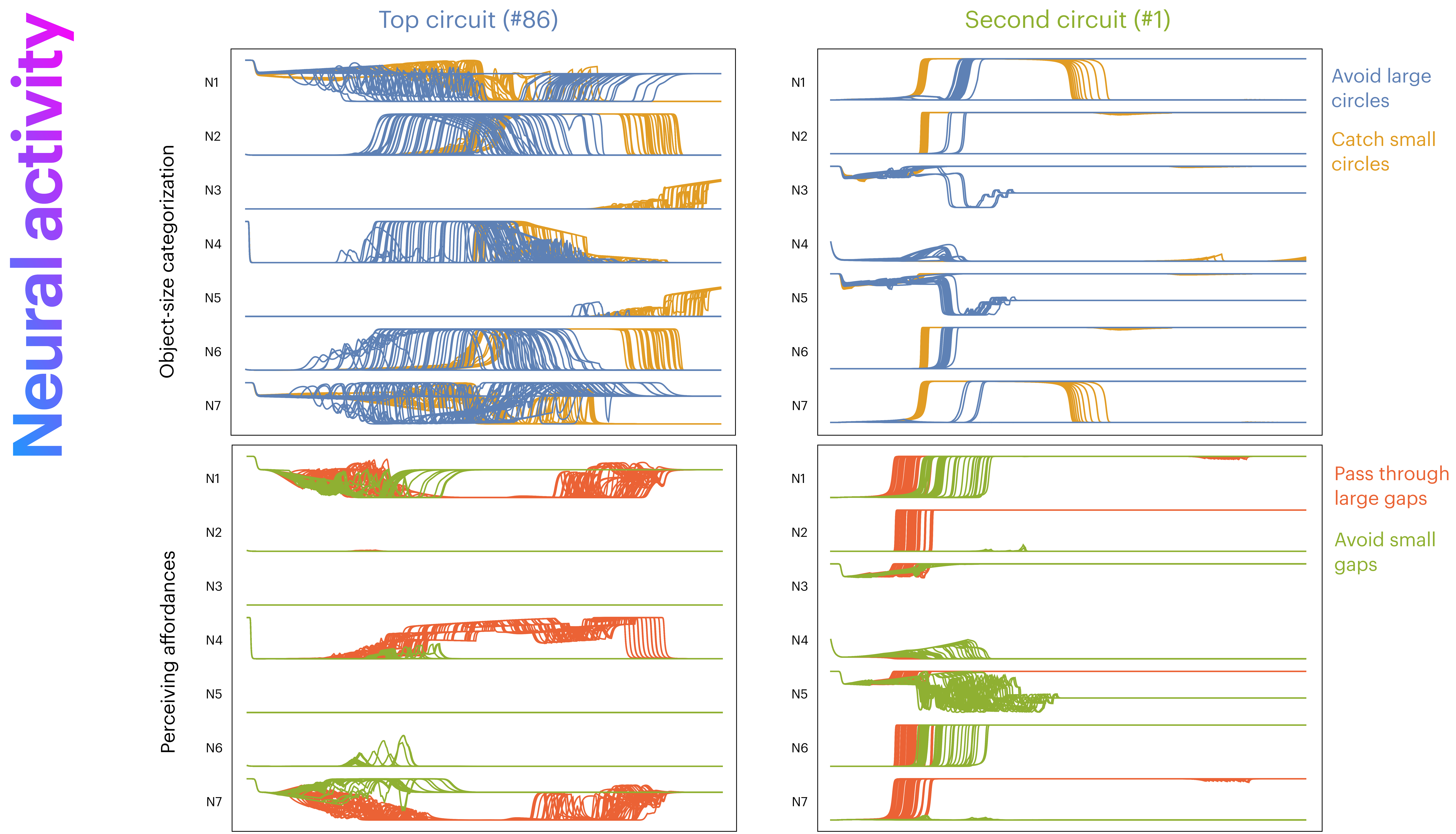


Behavior

Top circuit (#86)

Second circuit (#1)





Neural activity
Top circuit (#86)
Second circuit (#1)
Object-size categorization
Perceiving affordances
N1
N2
N3
N4
N5
N6
N7
Avoid large circles
Catch small circles
Pass through large gaps
Avoid small gaps

Analyses

Neural Variance Story

Information Theoretic Story

Functional Connectivity Story

Edge-centric Functional Connectivity Story

Synaptic Lesion Analysis Story