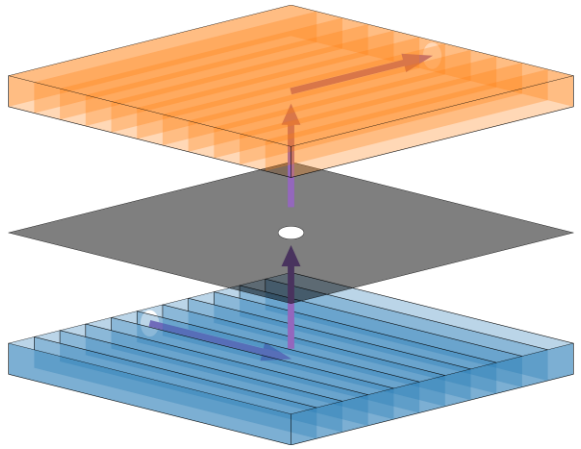
Mice in the Manhattan Maze:

Rapid learning, flexible routing and generalization,

with and without cortex

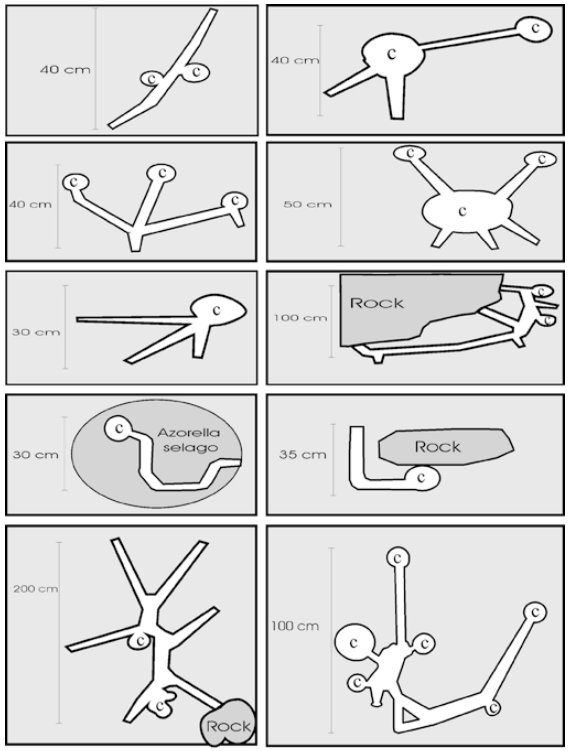


Aug. 9th CCN 2024

Jieyu Zheng, PhD. Candidate, Meister Lab, California Institute of Technology

A Complex Navigation Task for Cognitive flexibility

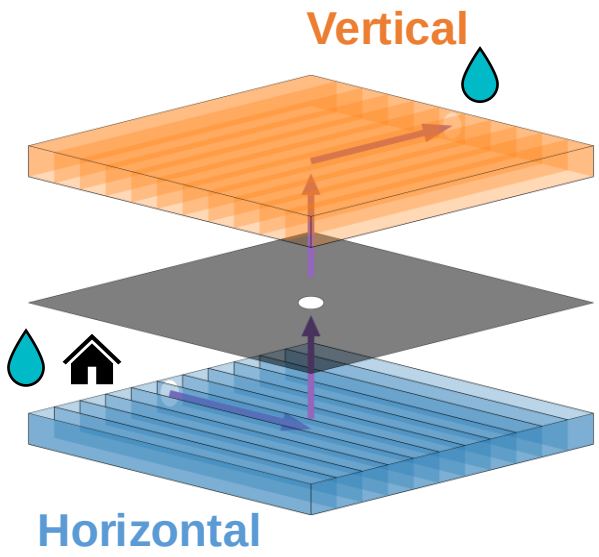
Vera Domingues/Hopi Hoekstra



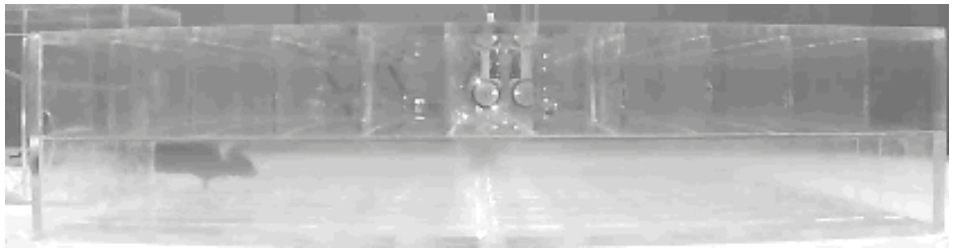
Avenant, 2002

David Rumsey

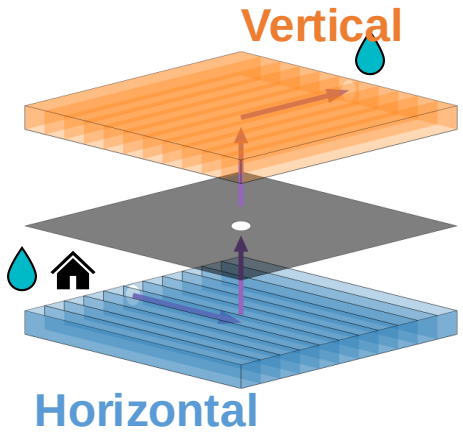
The Manhattan Maze

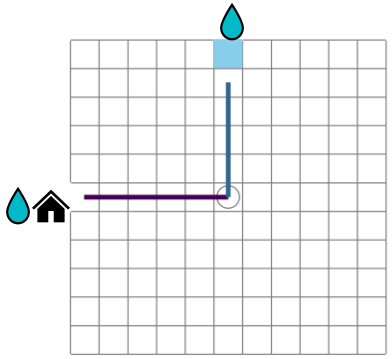


Side View (x2 speed)

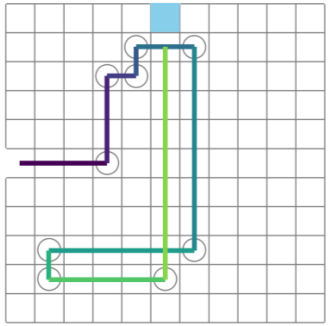


The Manhattan Maze design

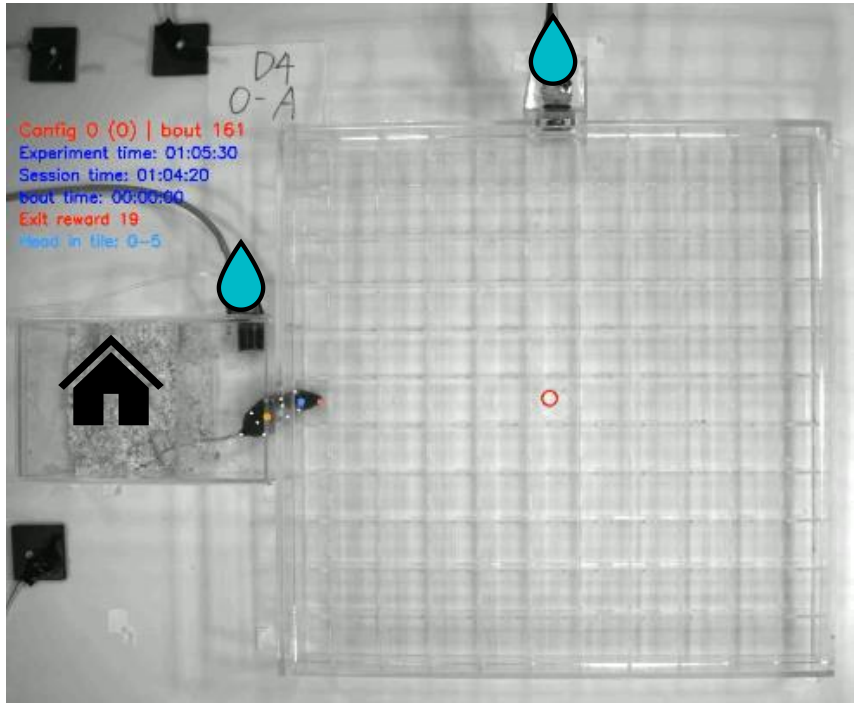


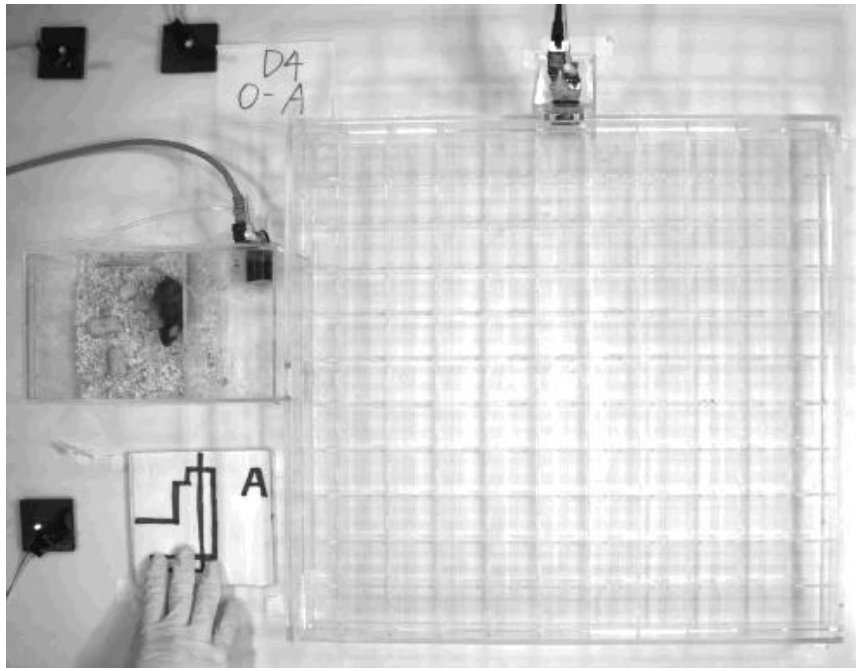


1-hole Mask O



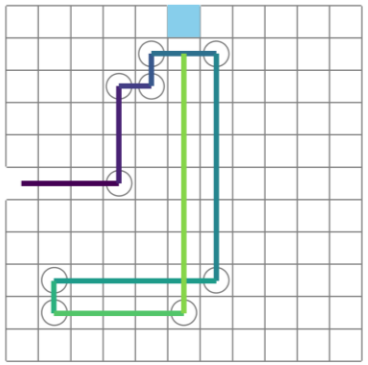
9-hole Mask A



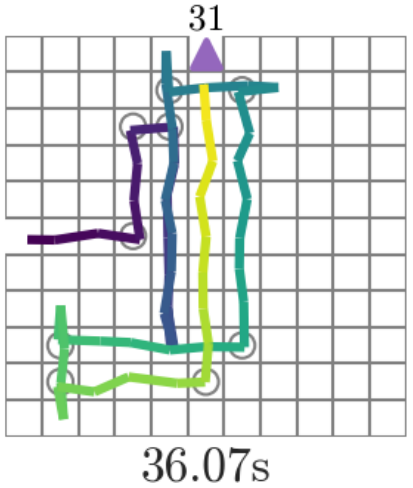


Easy Reconfiguration

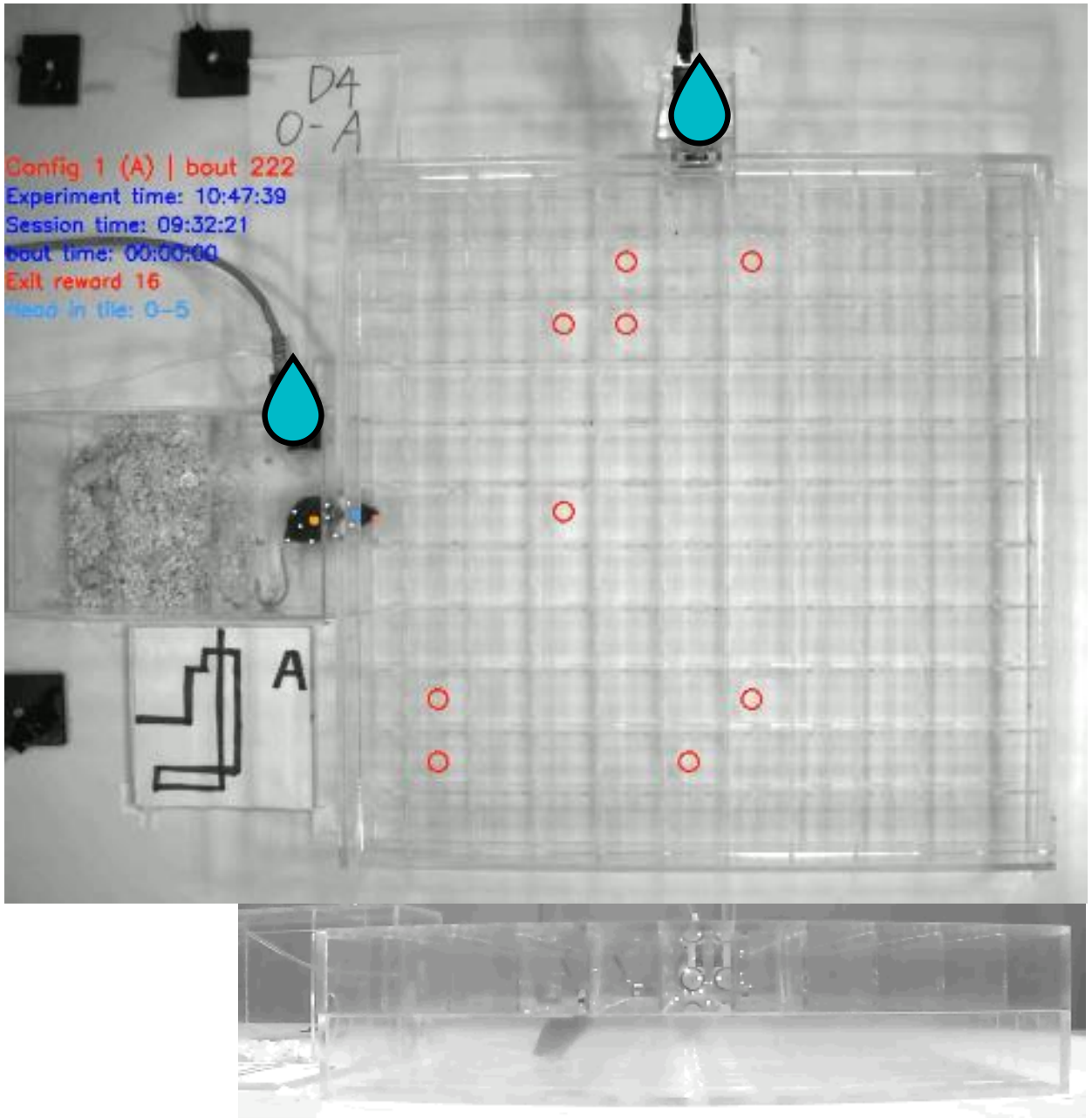
Learning a 9-hole mask



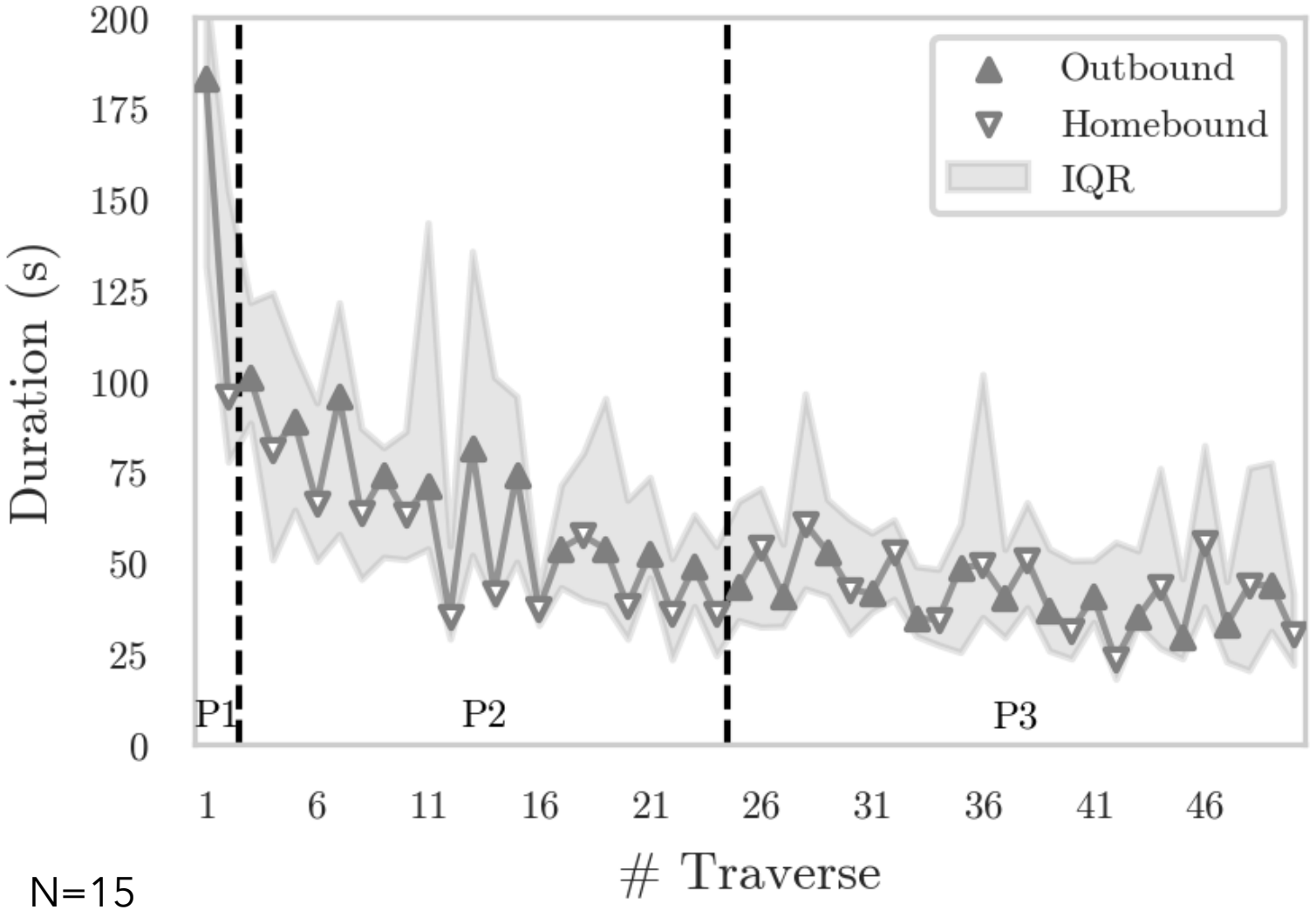
Optimal solution



Mouse Trajectory



Day 1: Rapid learning in Mask A

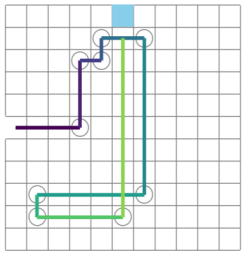


N=15

(A trip from one port to the other)

- Phase 1: 2x improvement by the first homebound traverse

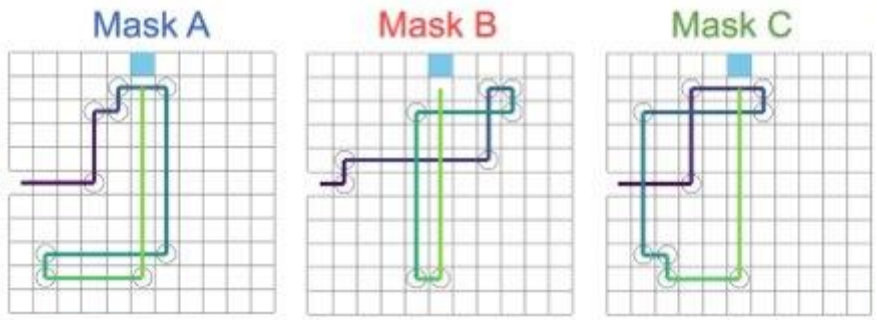
Day2 : Three masks introduced

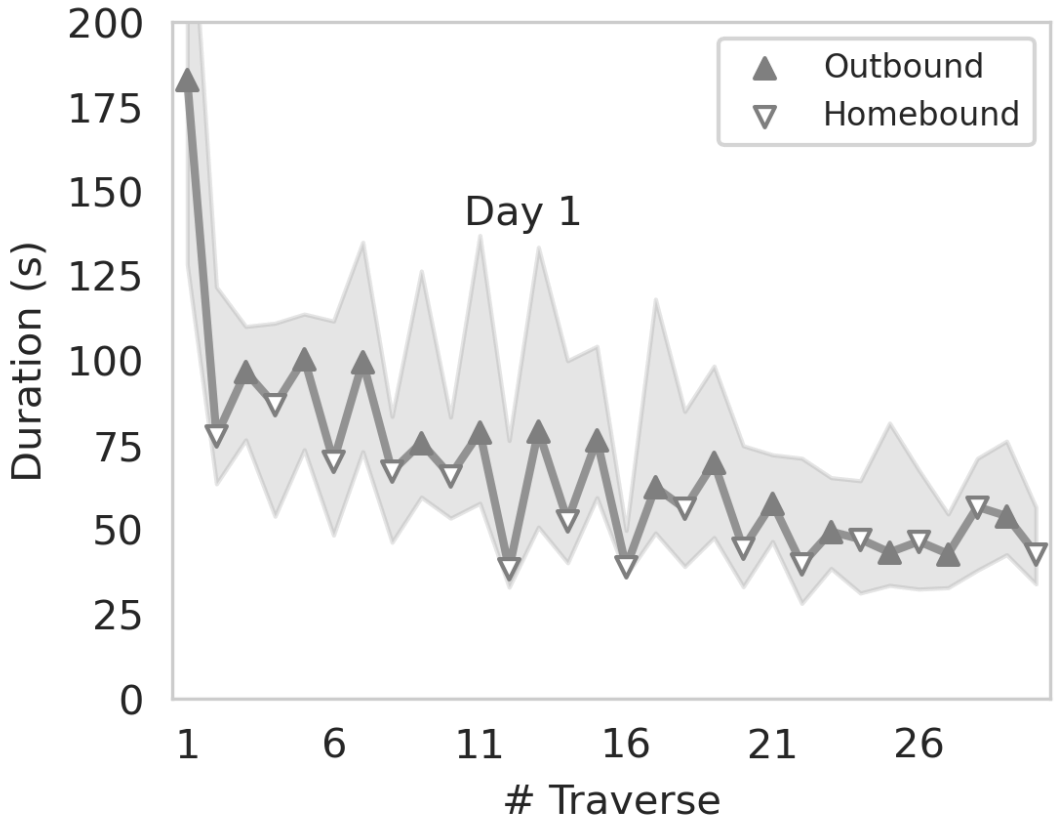


Day 1 Mask A

Day 2

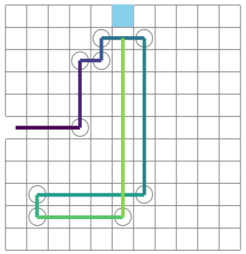
Old-Day1 New Mask 1 New Mask 2





Overnight memory

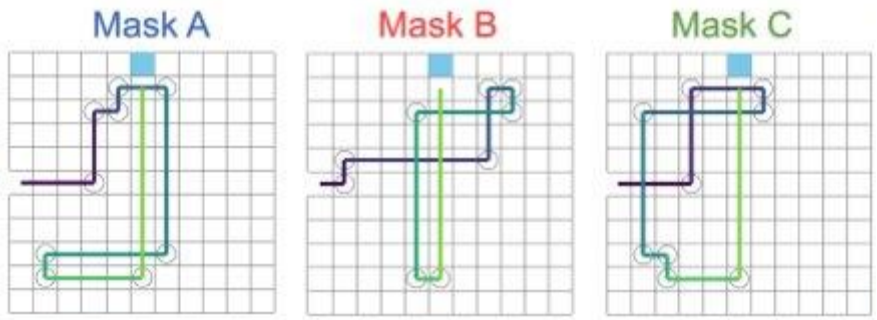
Day2 : Three masks introduced

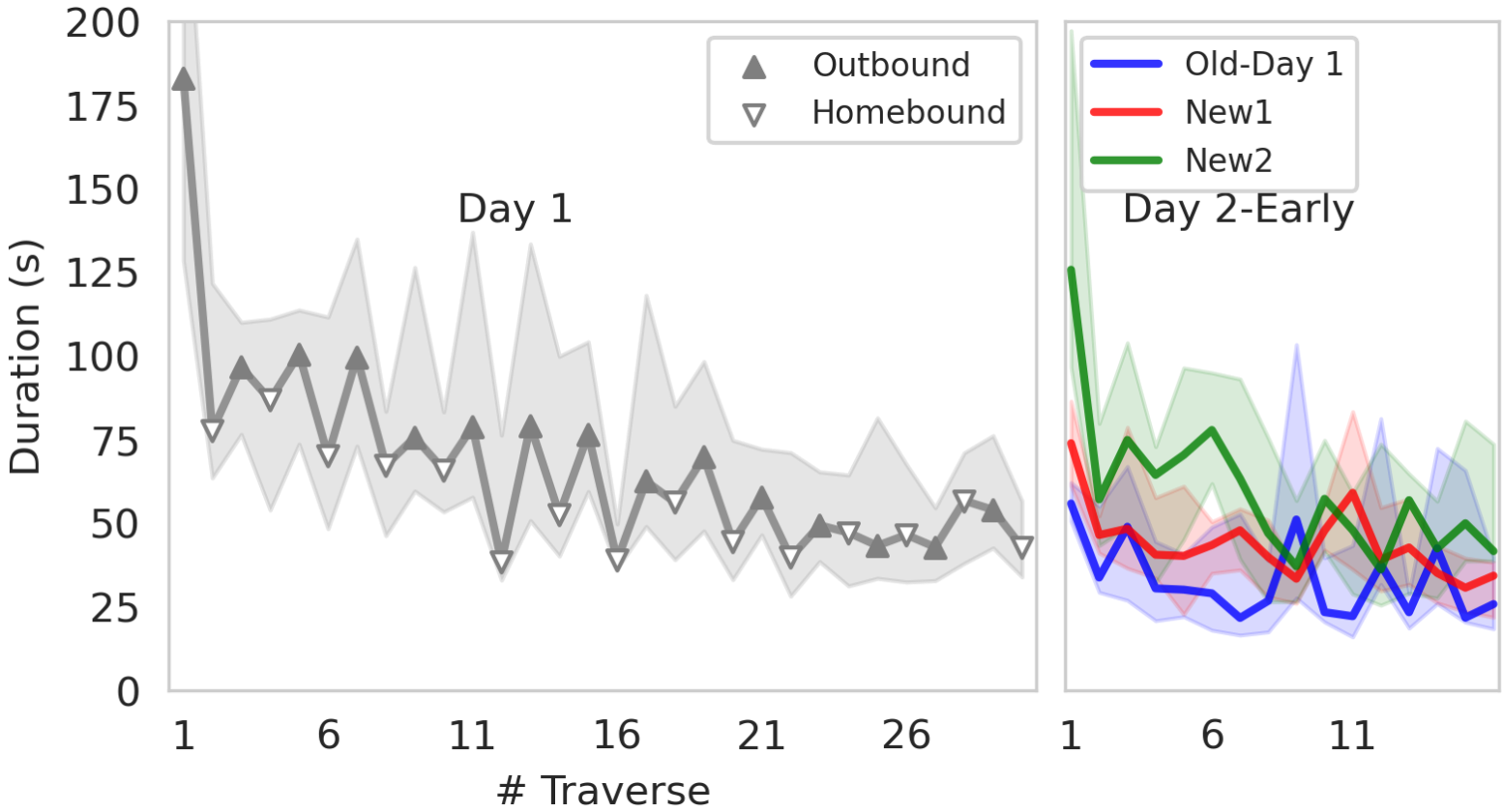


Day 1 Mask A

Day 2

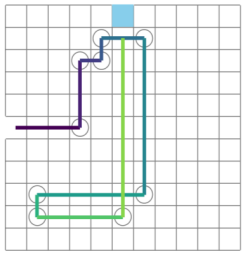
Old-Day1 New Mask 1 New Mask 2



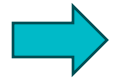


Meta-learning /generalization

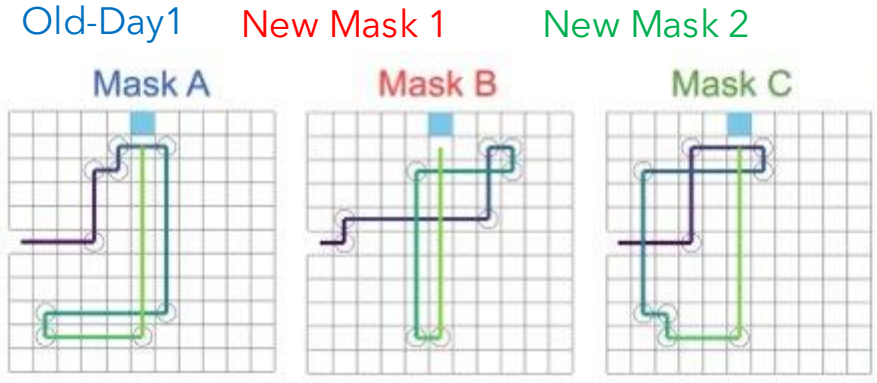
Day2 : Generalization and Memory

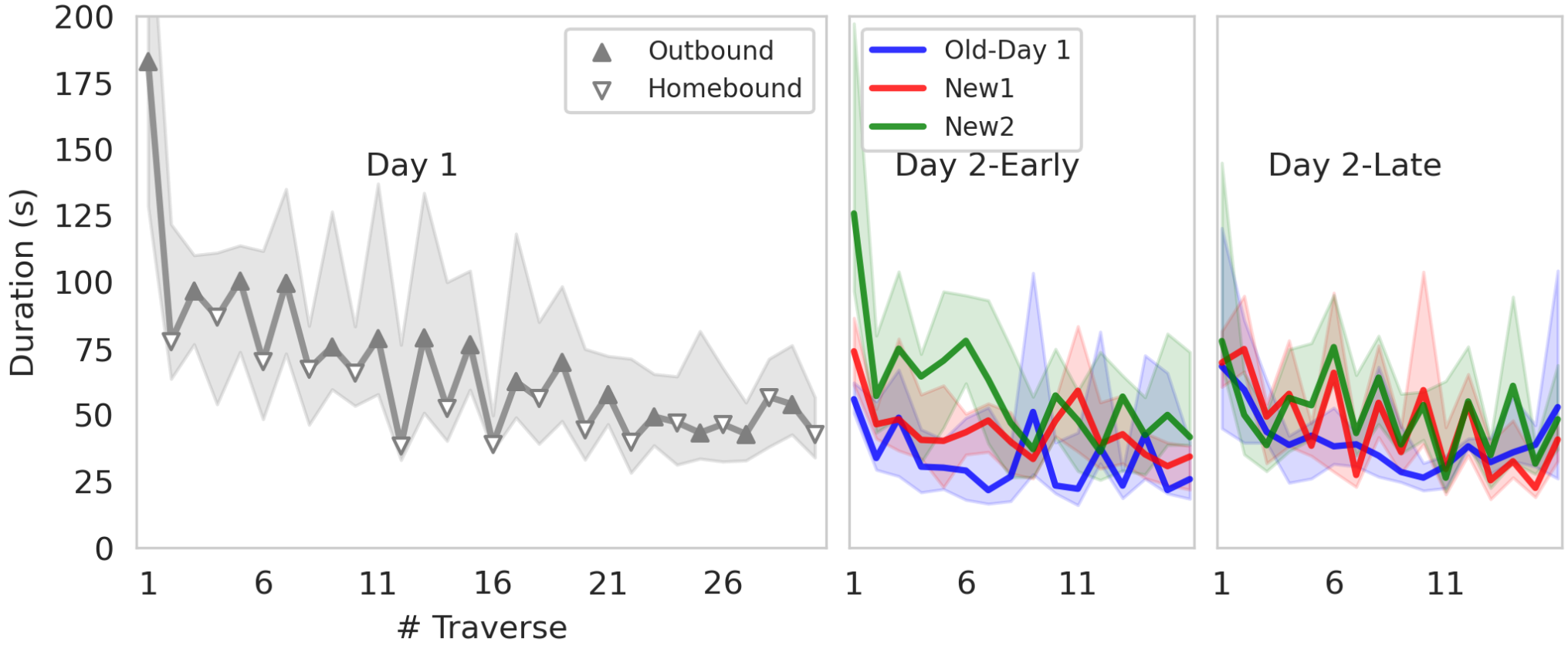


Day 1 Mask A



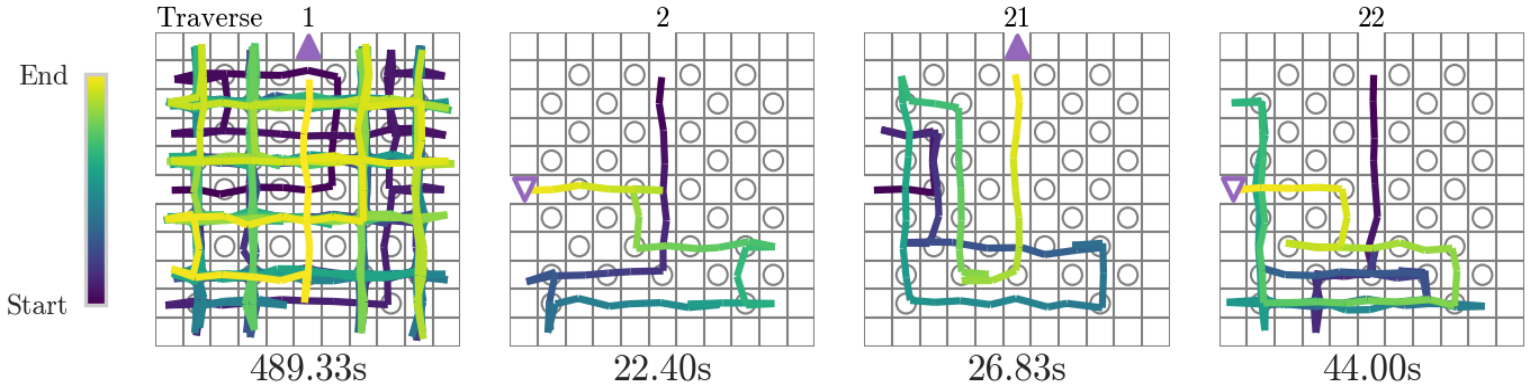
Day 2

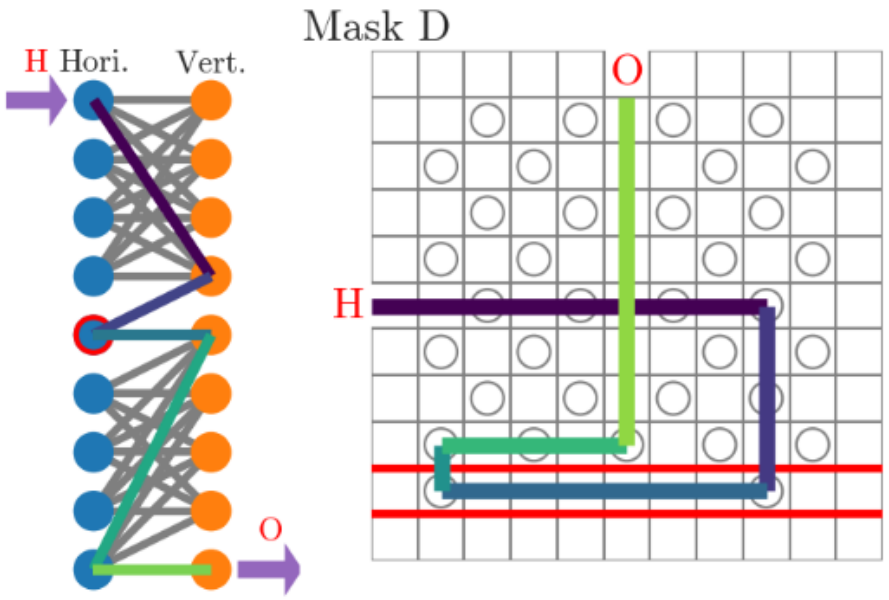


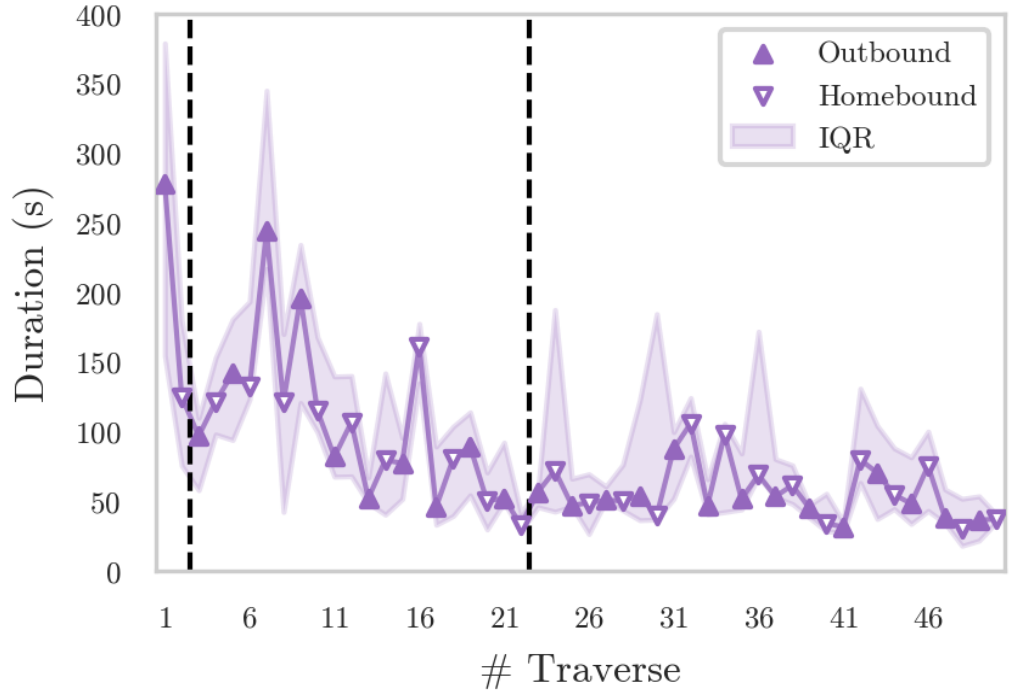


Flexible routing in a complex Mask

Two all-to-all connected areas with a bottleneck
- Many loops
- Redundant paths





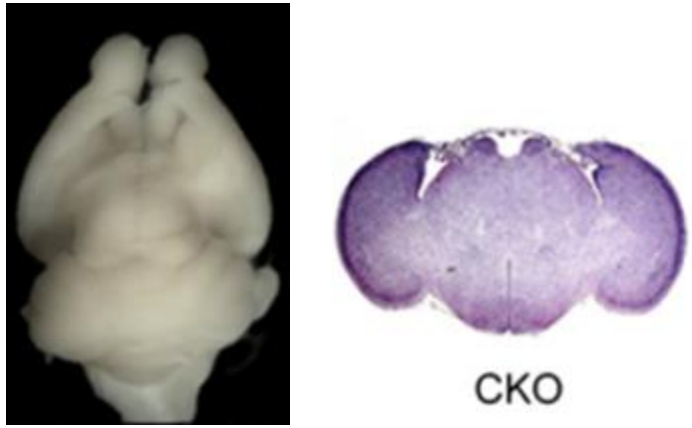


The role of cortex

What is the role of mouse cortex in complex cognitive tasks like the Manhattan Maze?

Structural Mutant: Emx1-Cre^{+} x Pals 1 flox/flox, born **without neocortex or hippocampus**

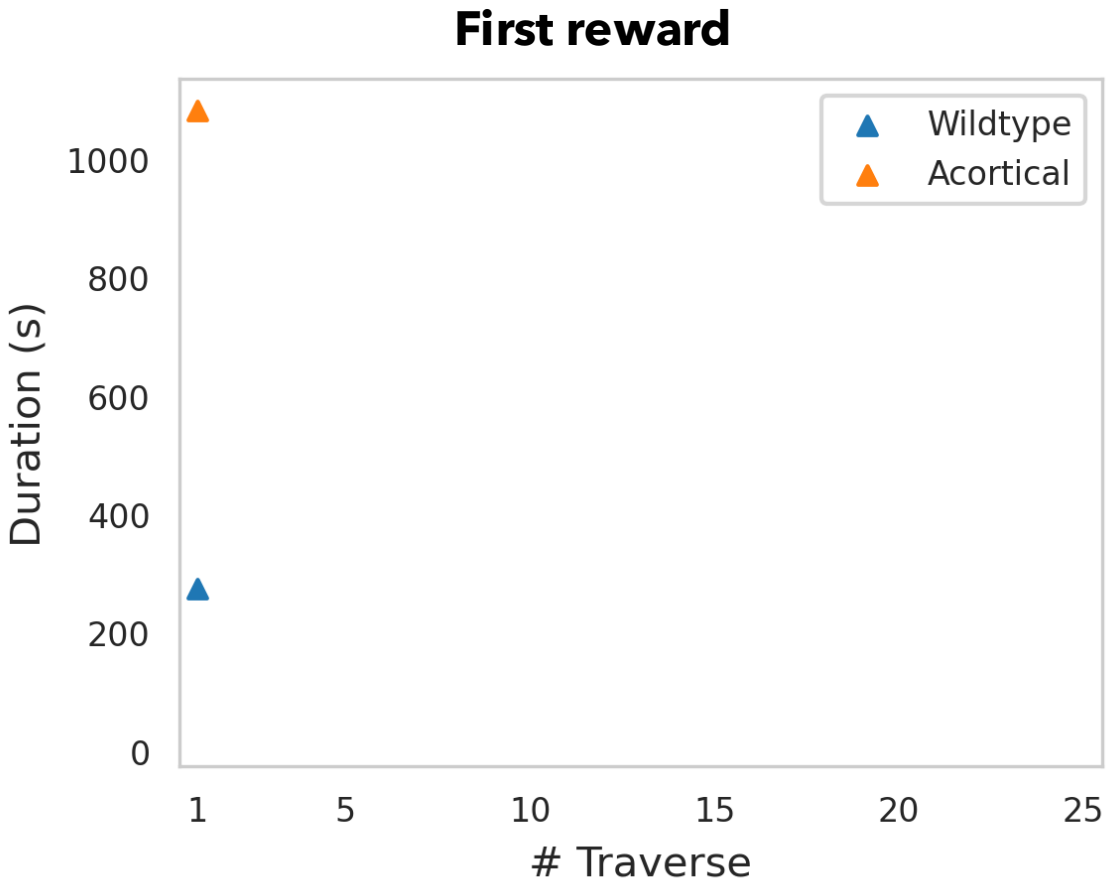
C57BL6/J Wildtype



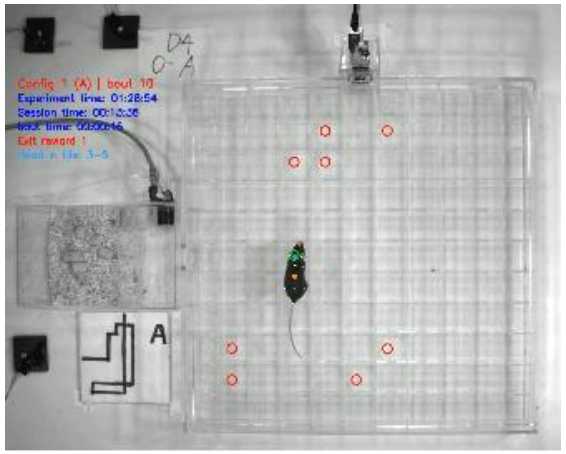
Emx1-Cre+ x Pals1 flox/flox

Kim et Walsh, 2010

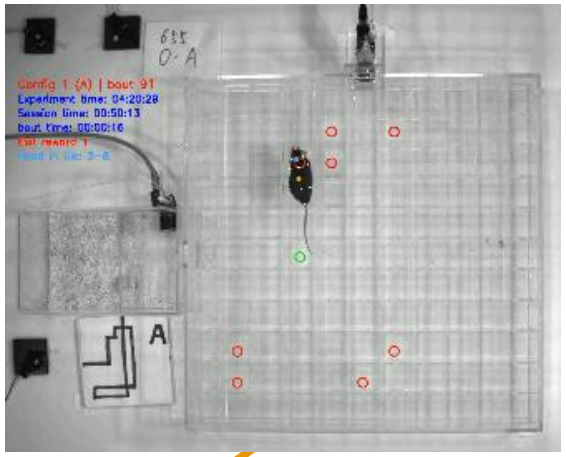
Acortical mouse took 3x time to solve the first mask



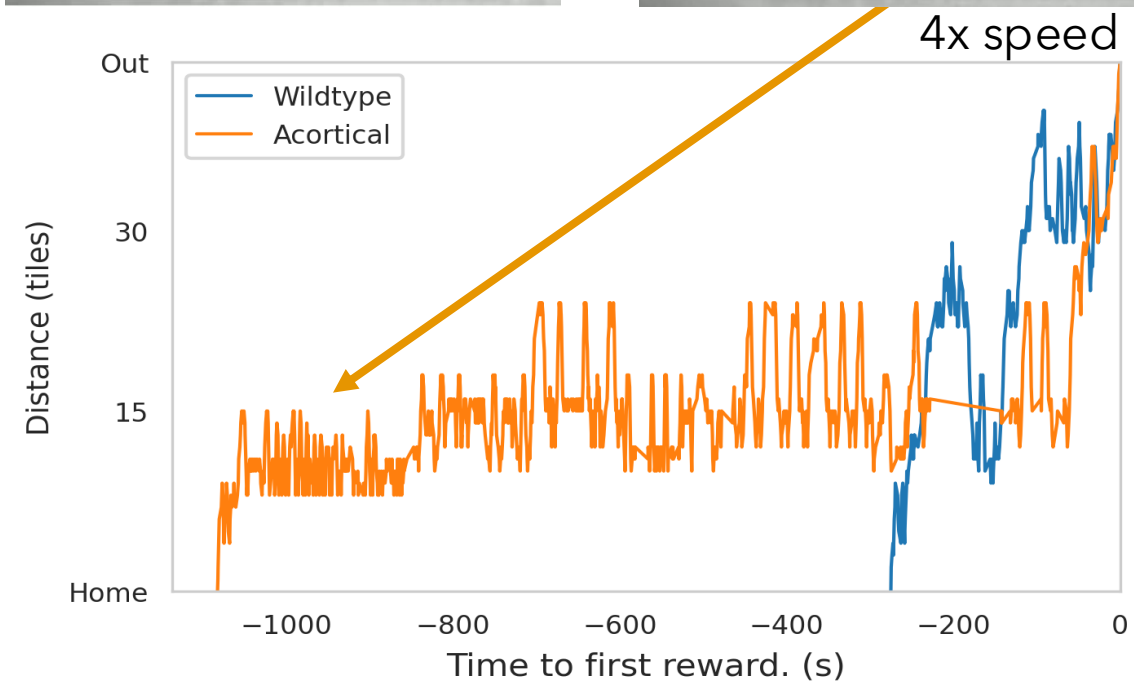
Wildtype



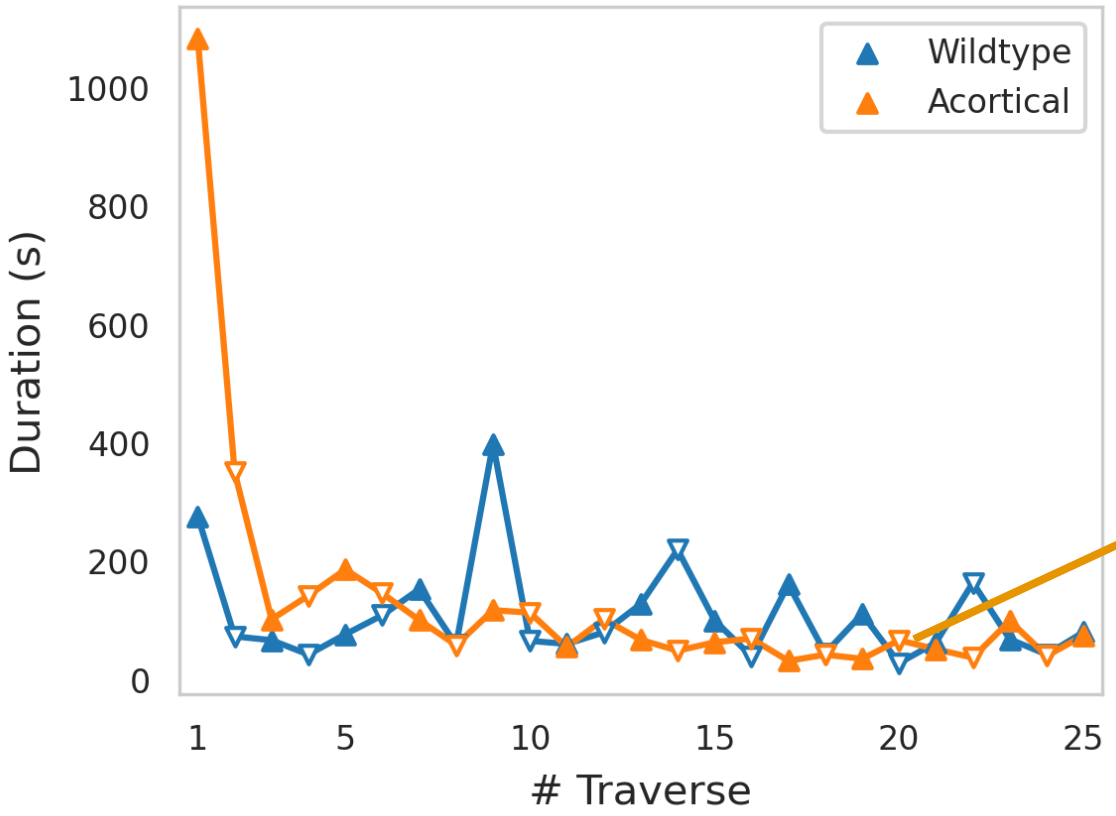
Acortical

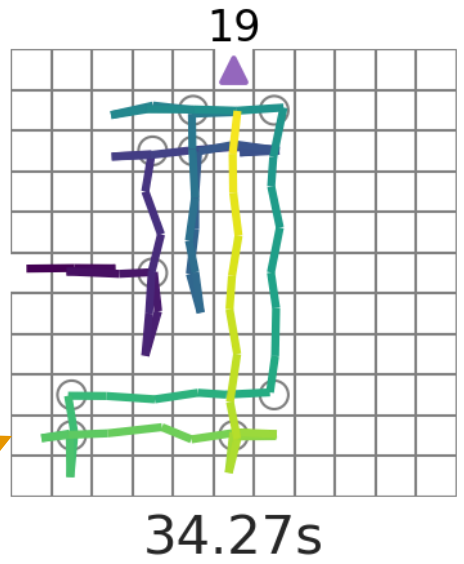


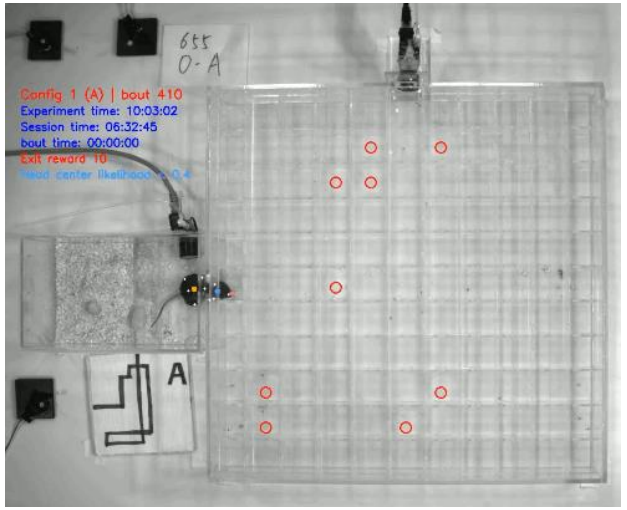
4x speed



Acortical mouse learning the first mask

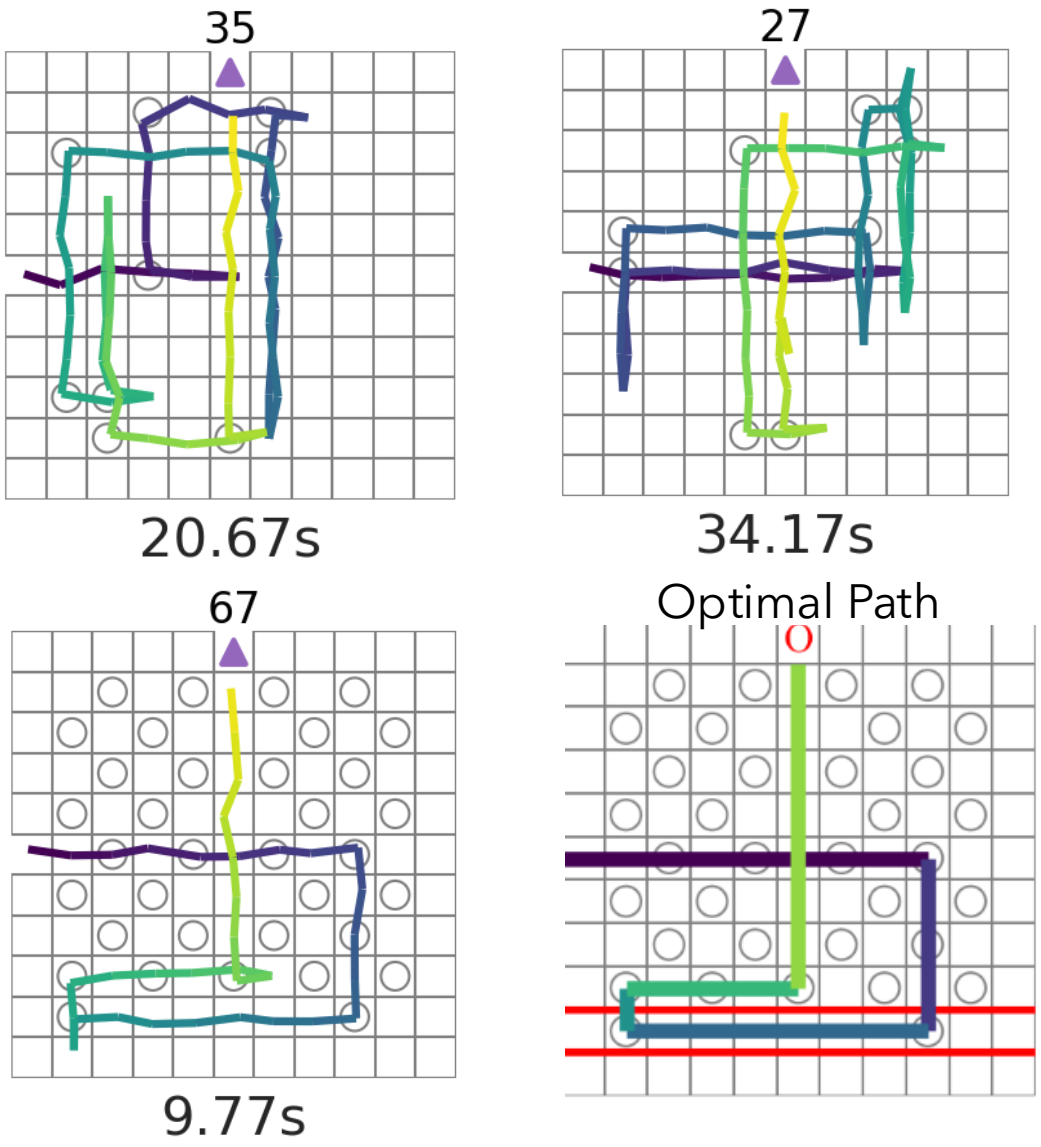


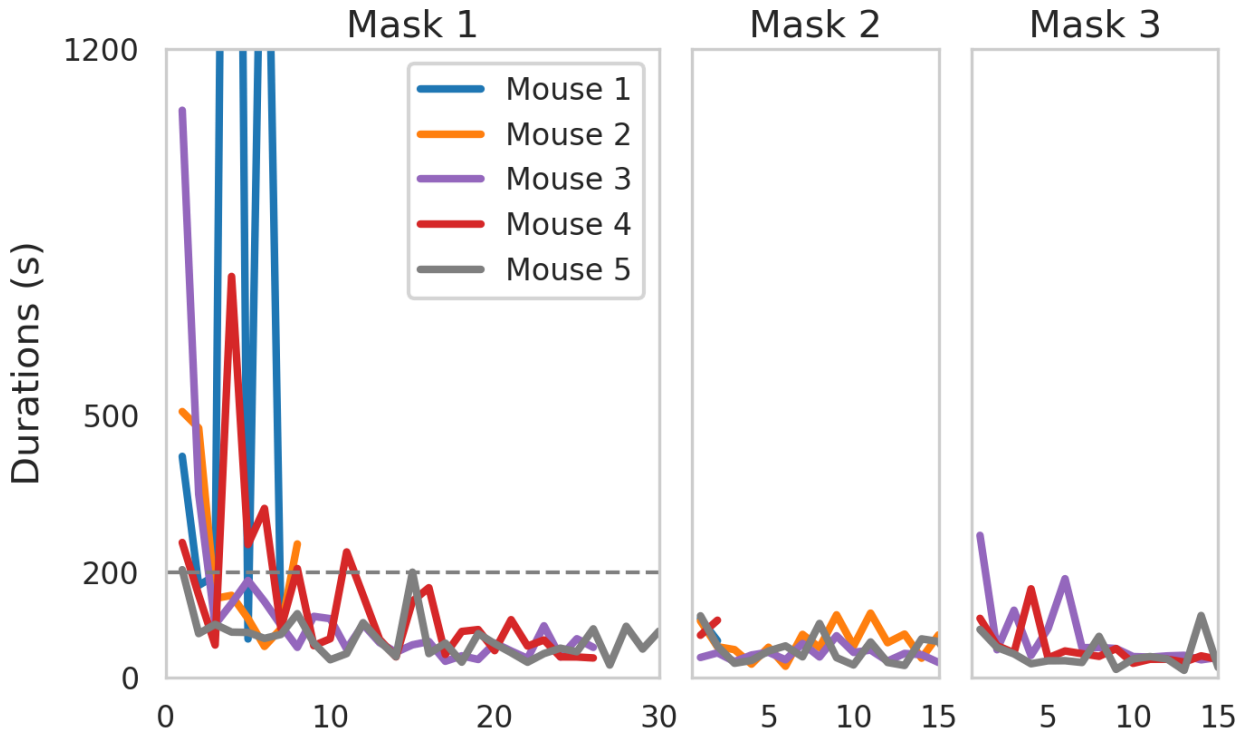




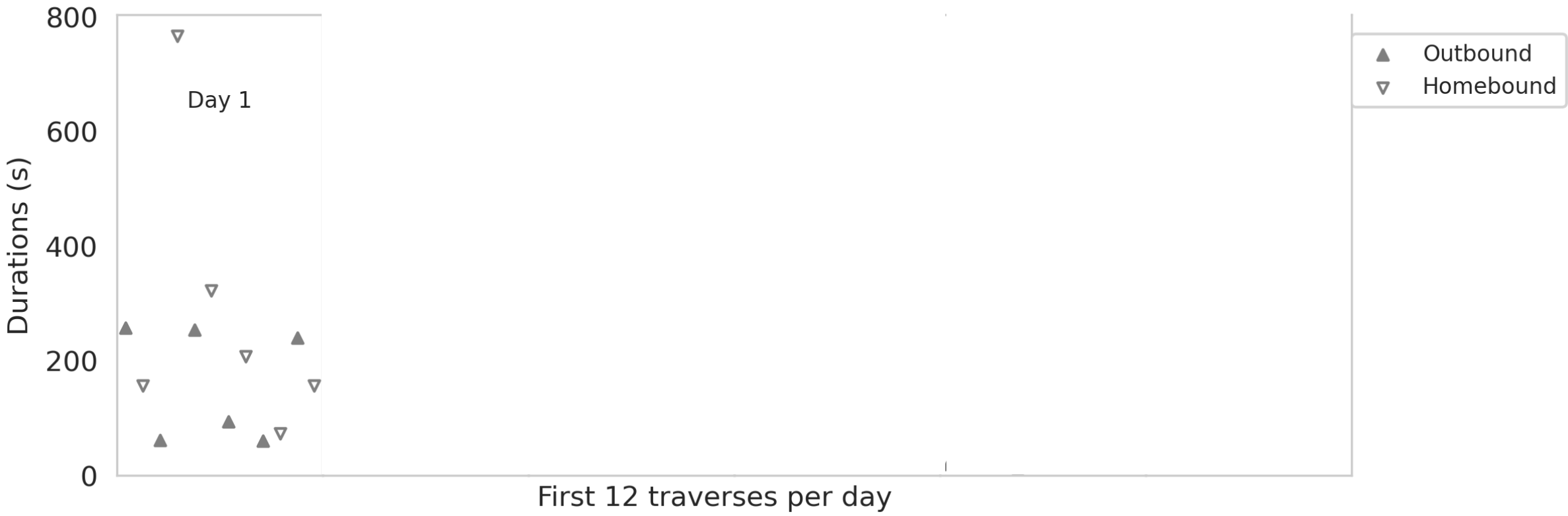
4x speed

Learning multiple masks





Long-term memory in an acortical mouse



Summary

- Rapid learning (1 map of **9** decisions):
  - First homing: **2x difference**
  - ~20 rewards (10x round trips) to reach optimal: **5x difference**

- Overnight memory in early Day 2: starting with **the same** performance as late Day 1

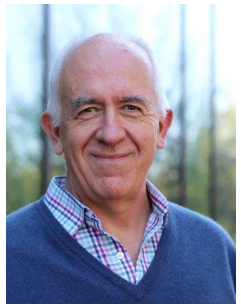
- Accelerated learning over 2 days: **2 new maps**

- Acortical mice:
  - **3x** longer for the first traverse
  - Preserves rapid learning, generalization and long-term memory

Acknowledgement

- The Manhattan Maze:
  - **Markus Meister, Pietro Perona**
  - **Rogério Guimarães**
  - Jen Hu, Anwesha Das
- The Acortical Mice: **Zeynep Turan**
- Meister Lab at Caltech:
  - Daniel Deng
  - Yingxi Jin
  - Zeyu Jing
  - Leo Li
  - Dan Pollak
  - Jiang Wu

Markus Meister



Pietro Perona

Scan for the slides and poster:

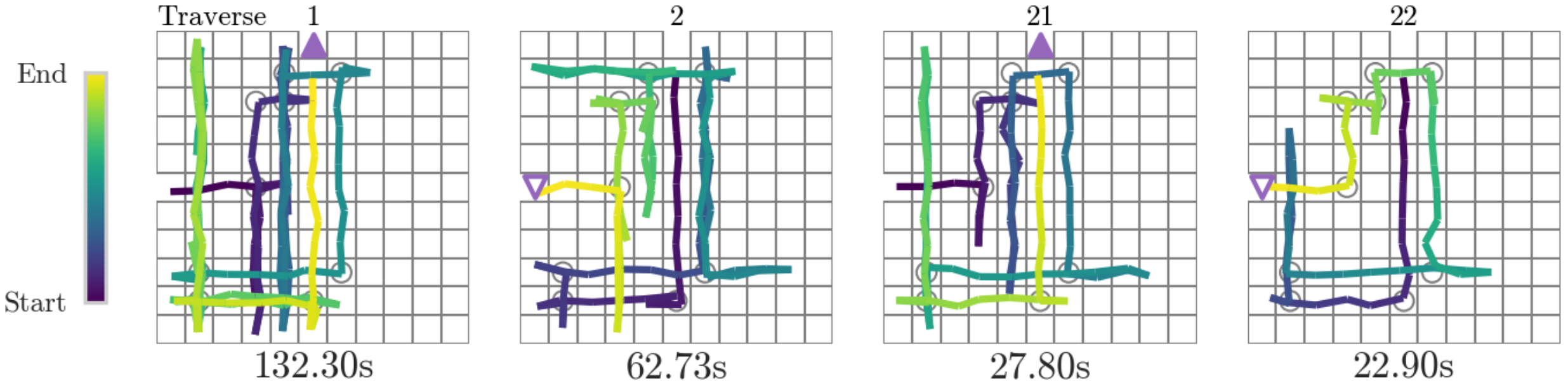
Rogério Guimarães

Zeynep Turan

These projects were funded by Simons Collaboration on the Global Brain (SCGB 543015 and 543025).

Supplementary materials

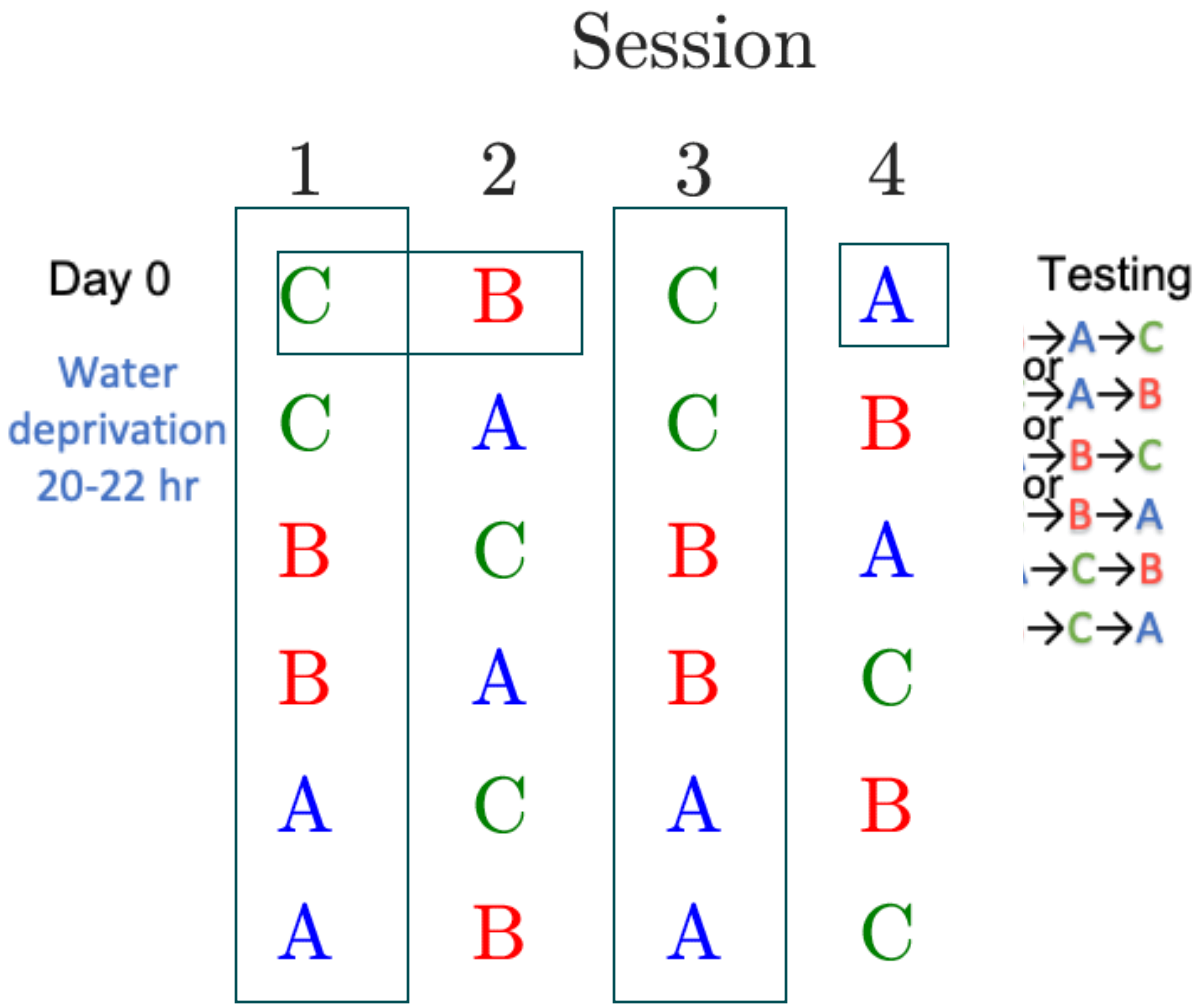
Rapid learning by one wildtype mouse in Mask A



x2

x5-6

Day 2 – experiment plan



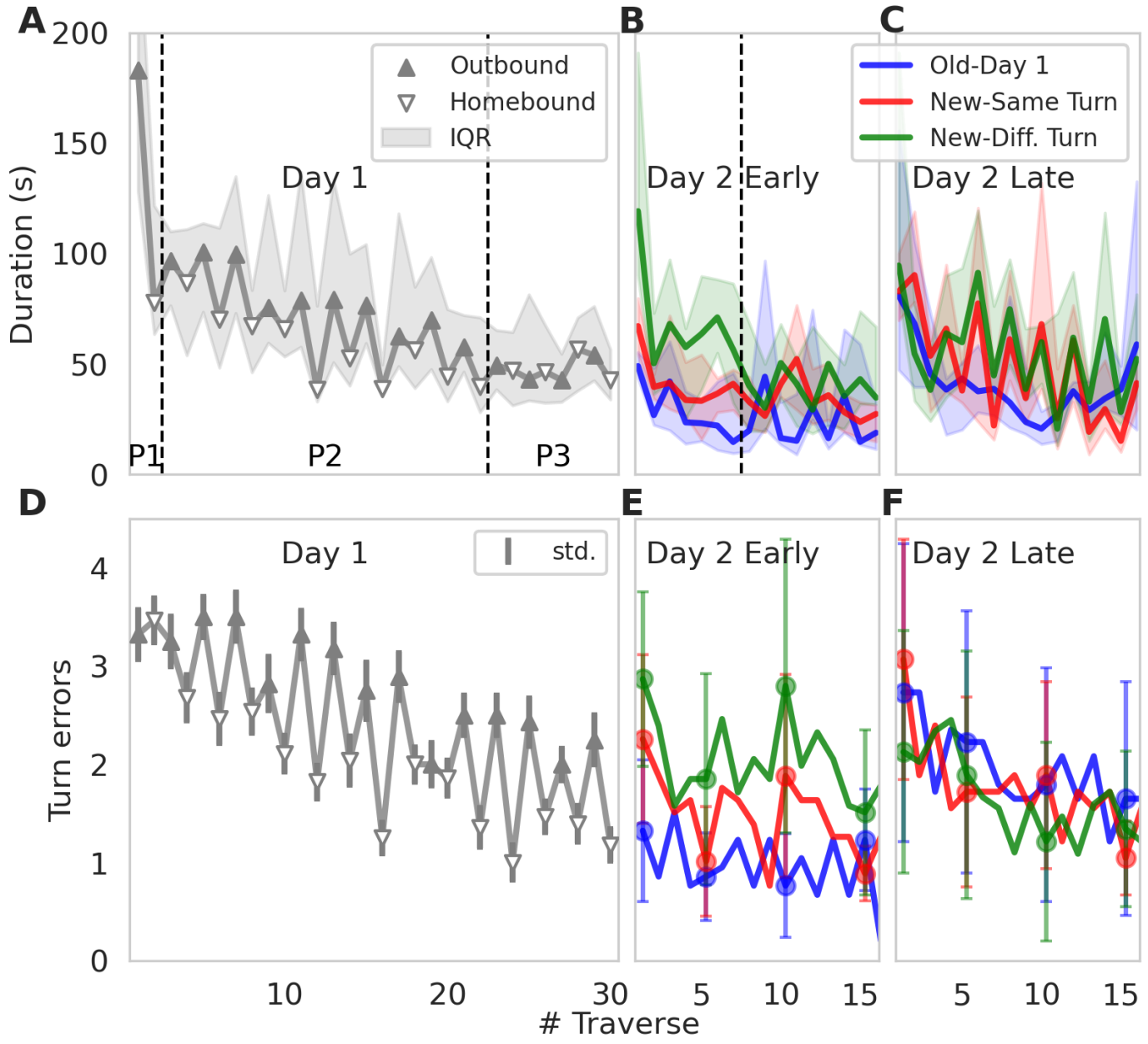
- Six groups of mask orders (XYXZ)
- Session 1, 2, 4:
  - Each column compares 3 maps
  - New maps (B and C) vs. old
- Session 3: repeat of Session 1
  - Mask A: overnight repeat
  - Mask B and C: same day repeat
- Mask B vs. Mask C: same turn sequence vs. Different turn sequence

Sequence learning

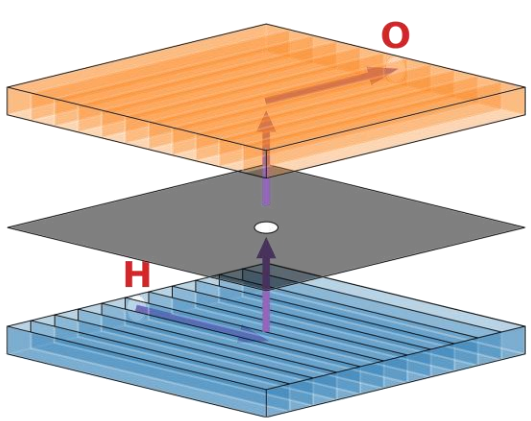
Role of olfaction

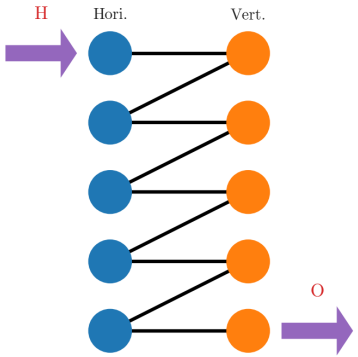
Day 2

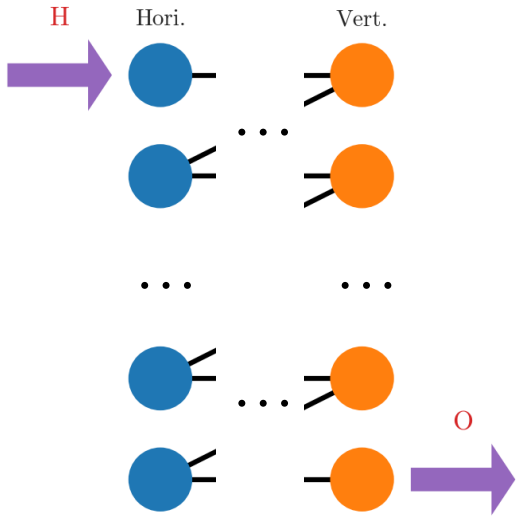
- Generalization and memory also reflected by turn errors (second row)

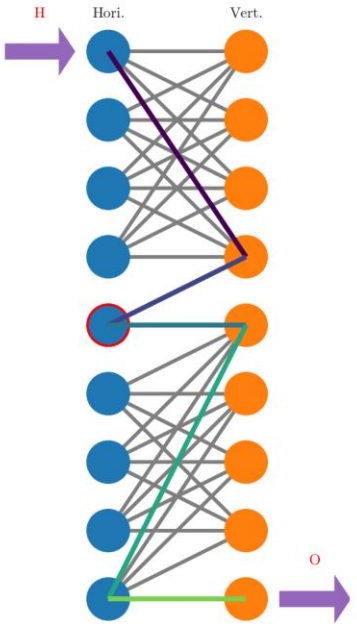


The Manhattan Maze: Insert video of mouse navigation









- Rapid learning in a few hours
- Long-term memory of multiple maps
- Generalization over different environments
- Neural substrate for complex cognition