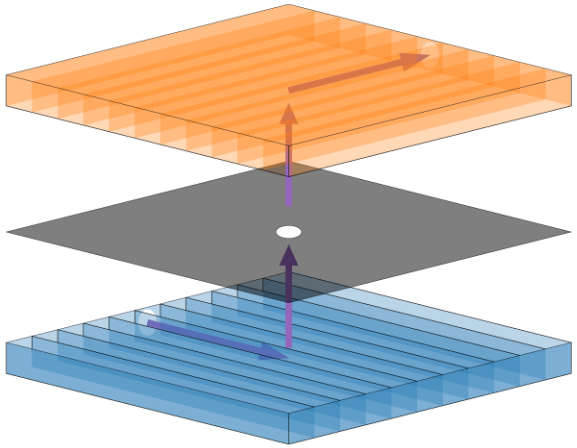
Mice in the Manhattan Maze:

Rapid learning, flexible routing and generalization,

with and without cortex

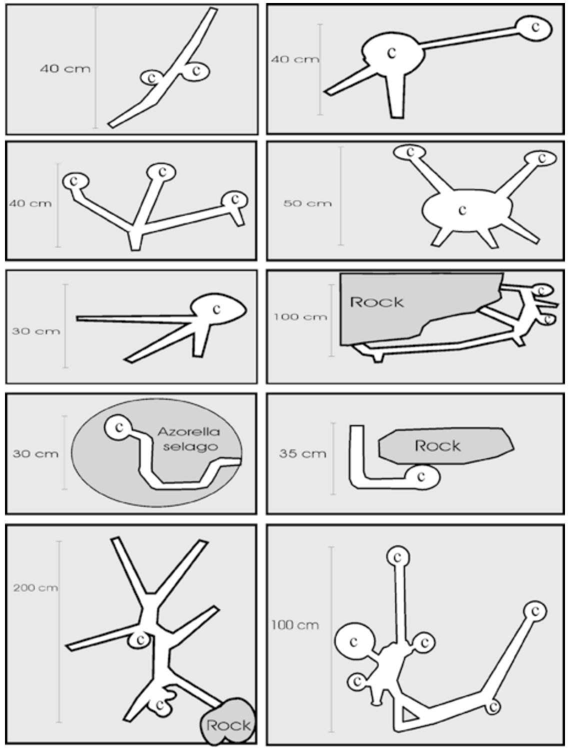


Aug. 9th CCN 2024

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

A Complex Navigation Task for Cognitive flexibility

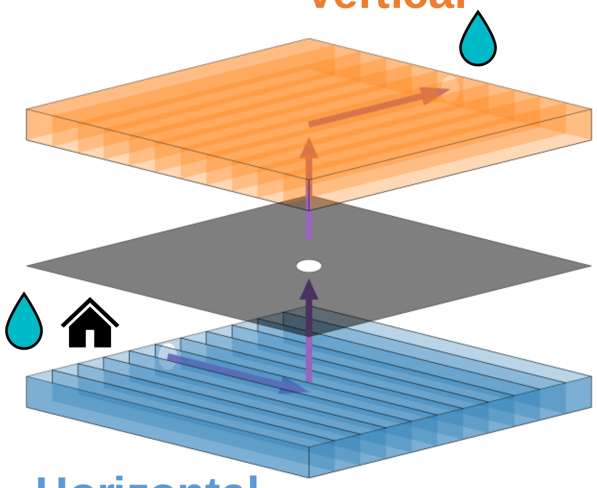
Vera Domingues/Hopi Hoekstra



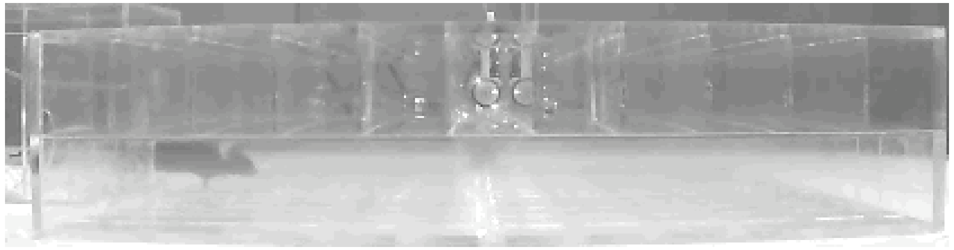
Avenant, 2002

David Rumsey

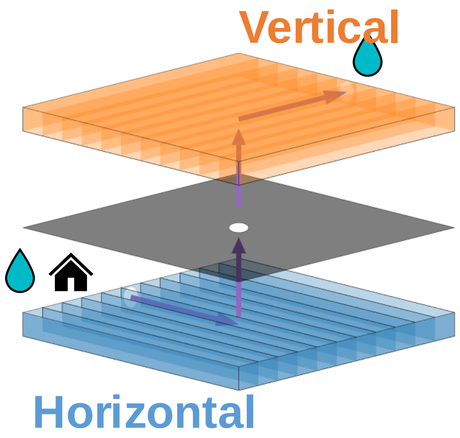
The Manhattan Maze

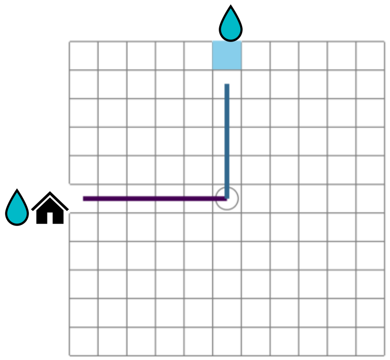


Side View (x2 speed)

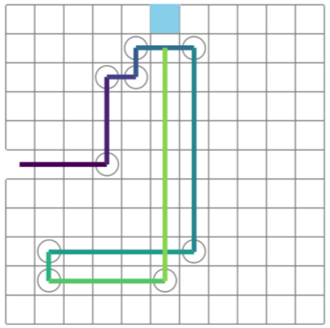


The Manhattan Maze design

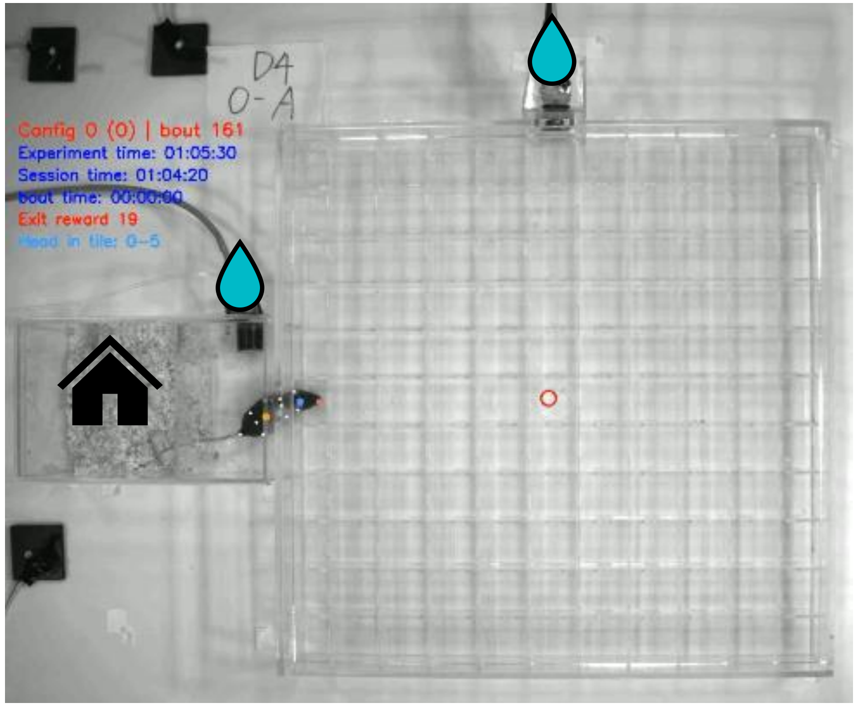


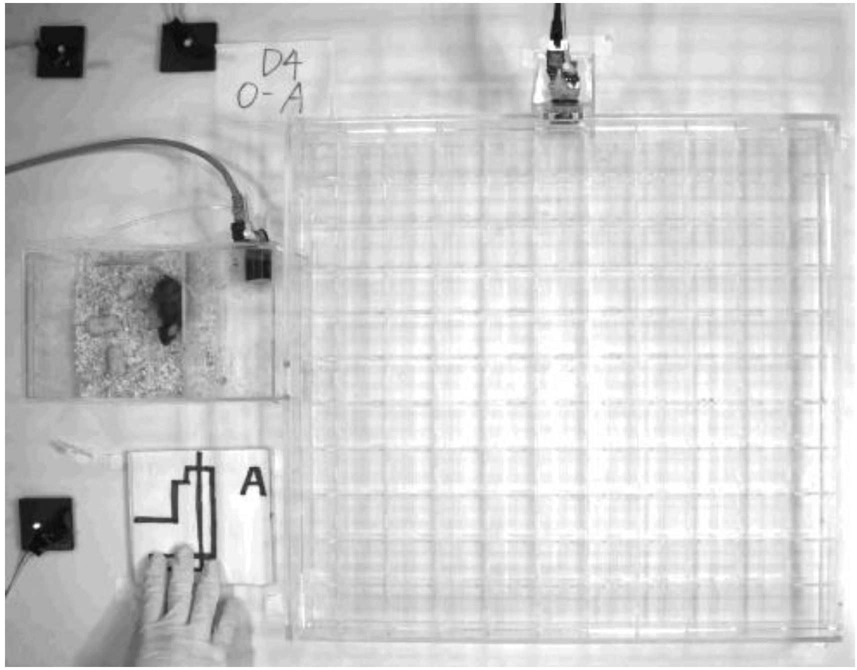


1-hole Mask O



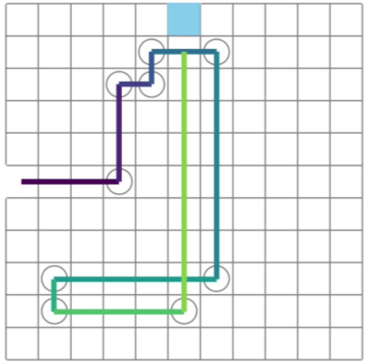
9-hole Mask A



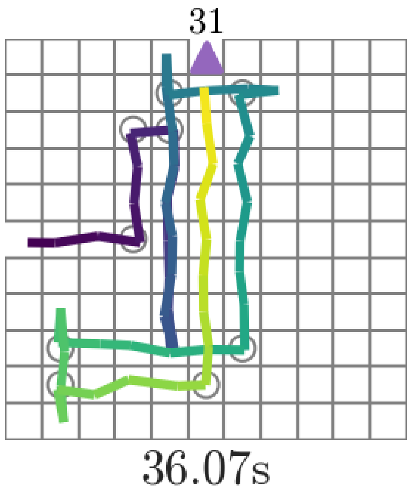


Easy Reconfiguration

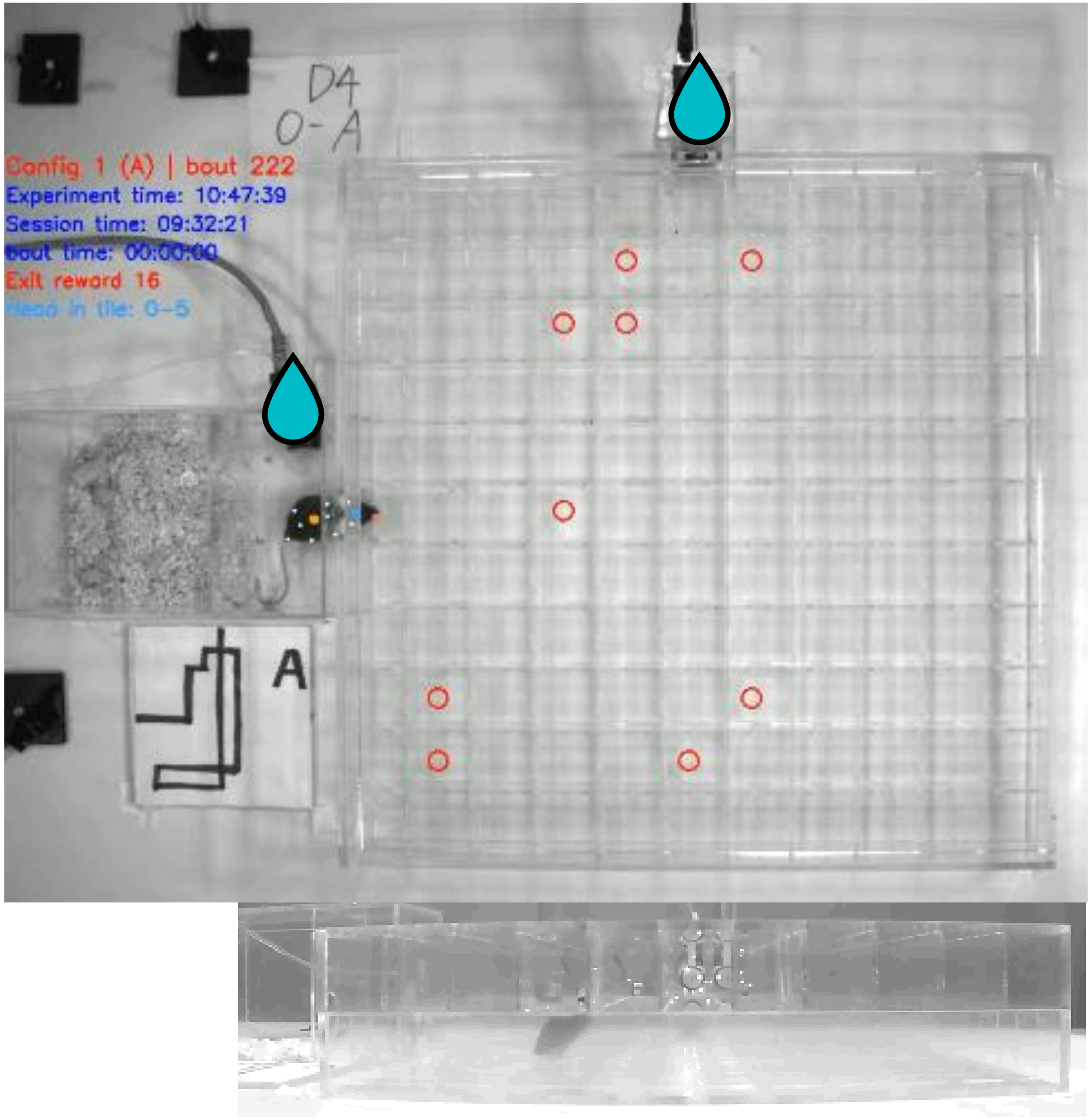
Learning a 9-hole mask



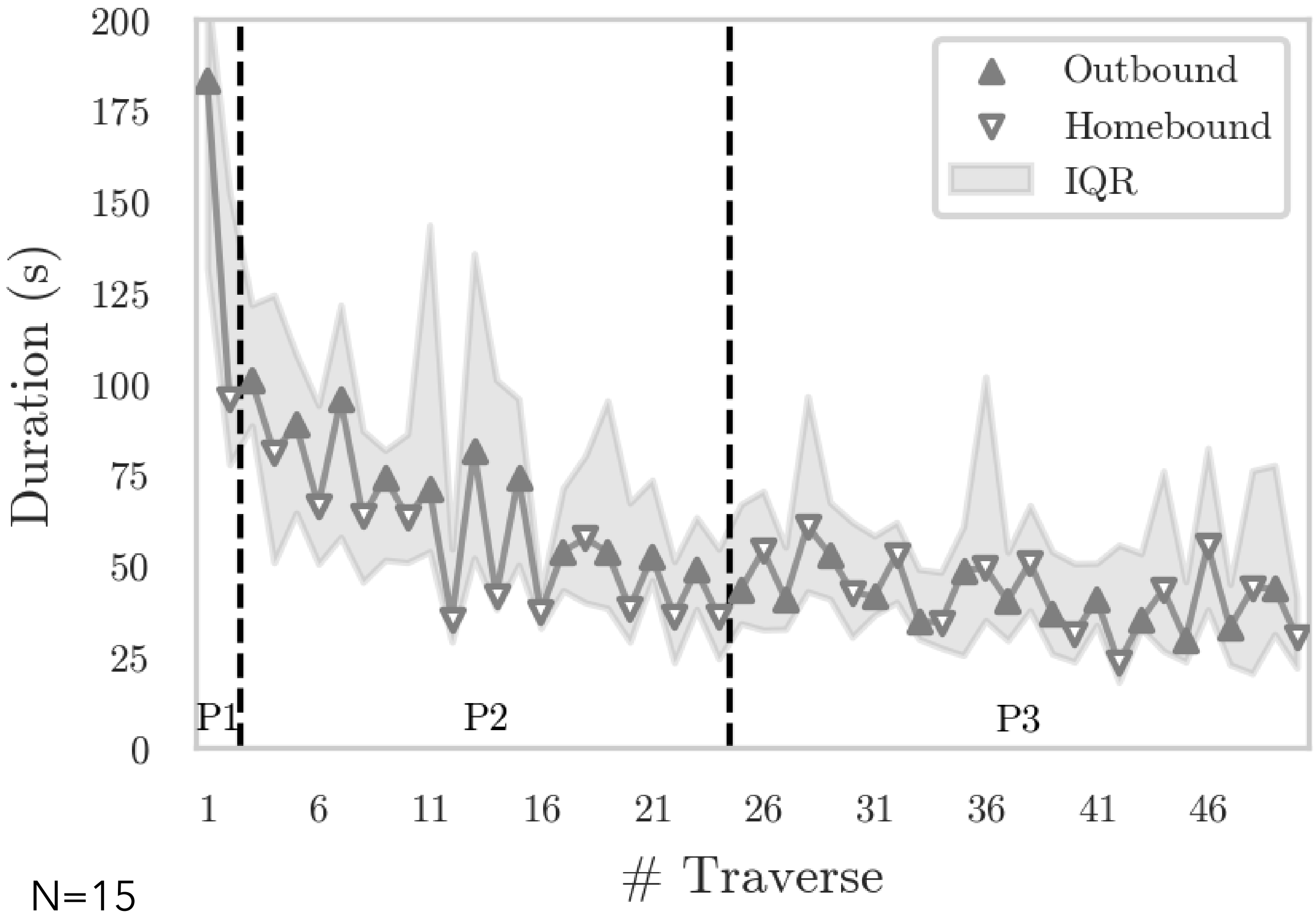
Optimal solution



Mouse Trajectory



Day 1: Rapid learning in Mask A

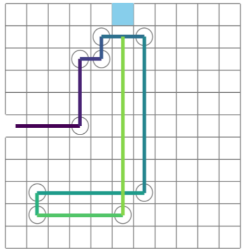


(A trip from one port to the other)

N=15

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

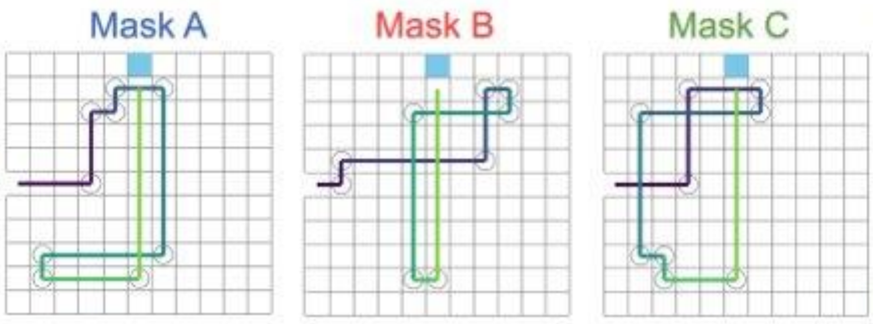
Day2 : Three masks introduced

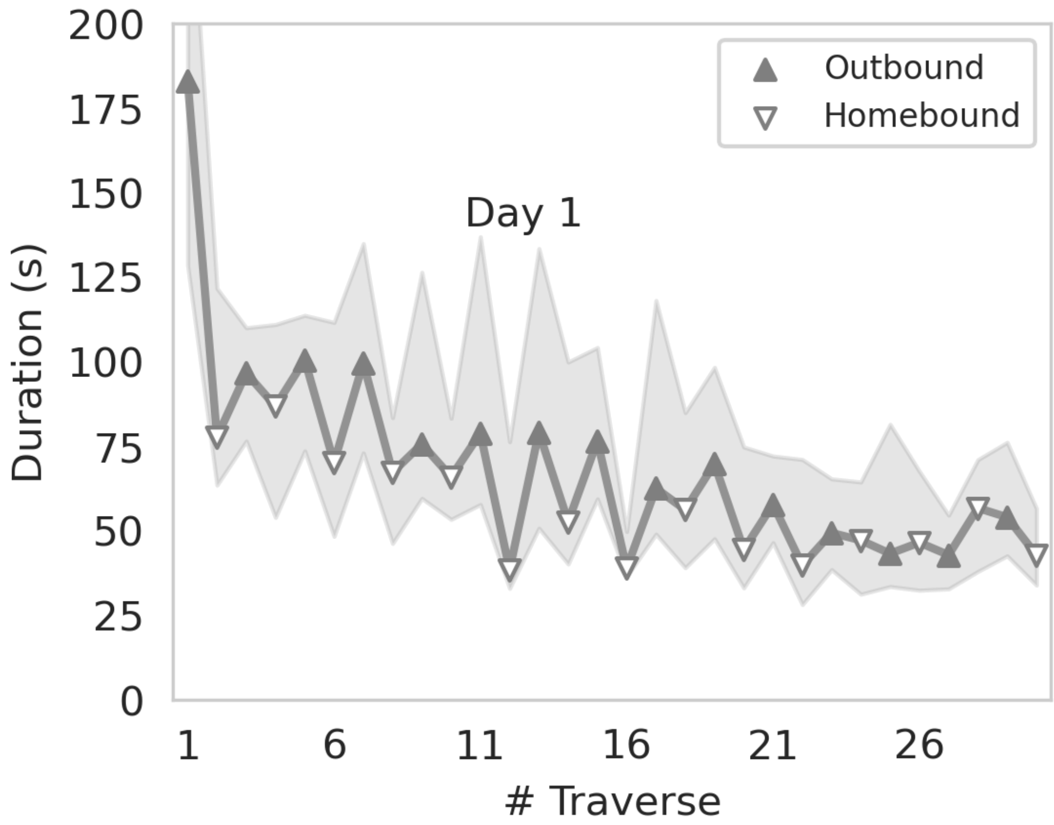


Day 1 Mask A

Day 2

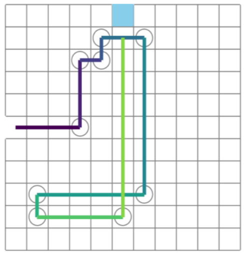
Old-Day1 New Mask 1 New Mask 2





Overnight memory

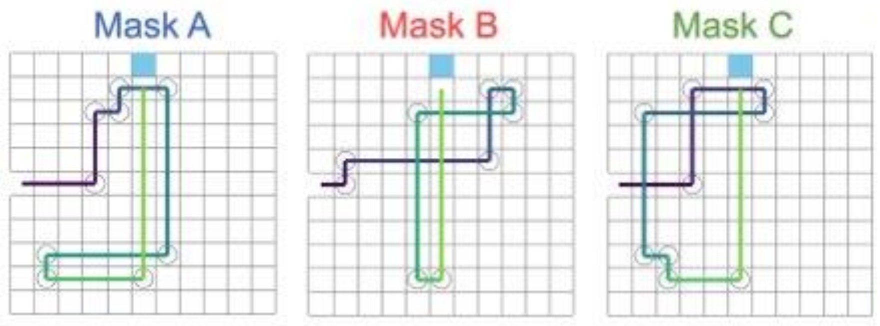
Day2 : Three masks introduced

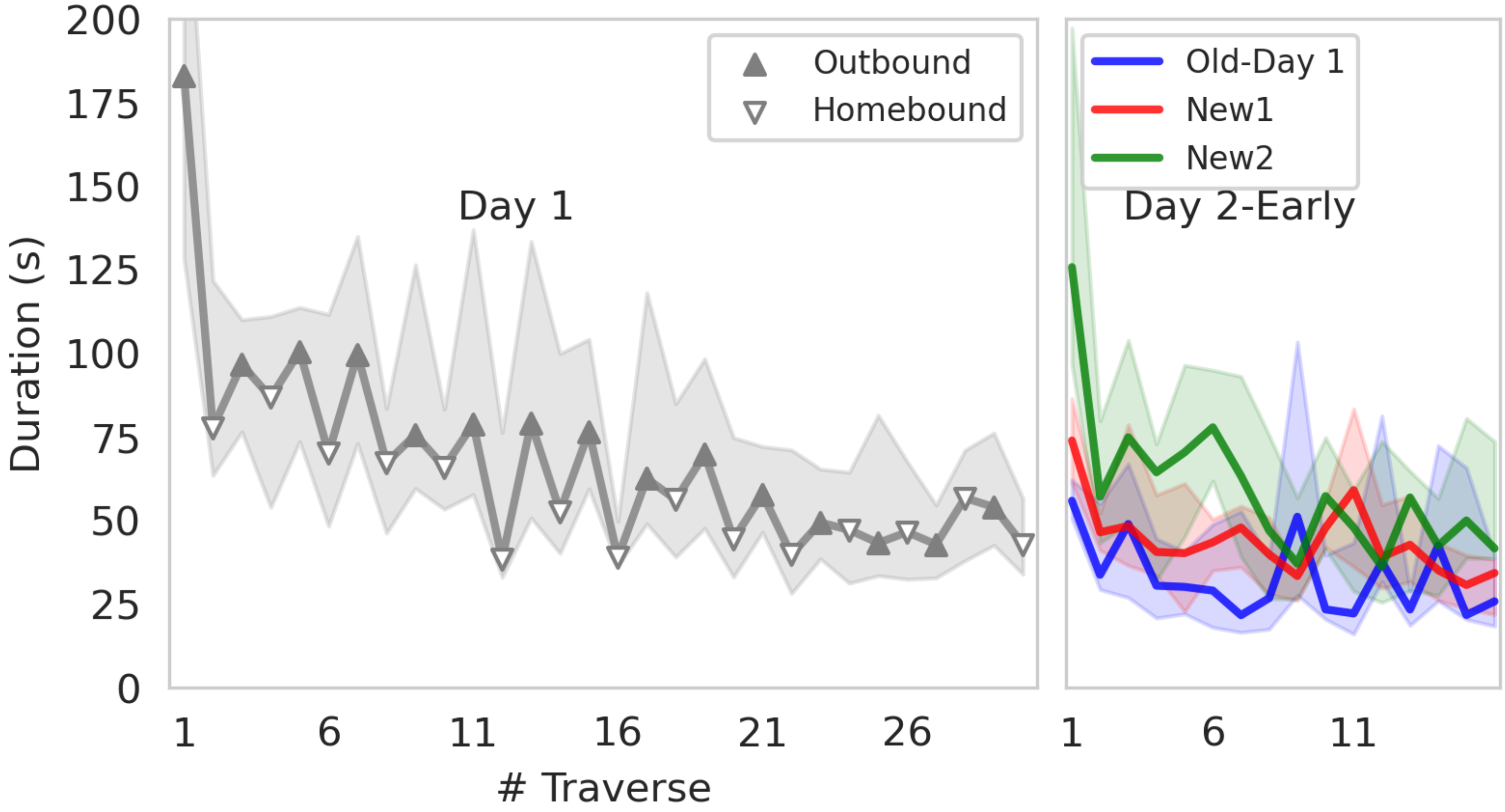


Day 1 Mask A

Day 2

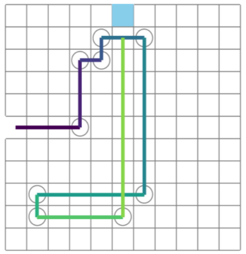
Old-Day1 New Mask 1 New Mask 2





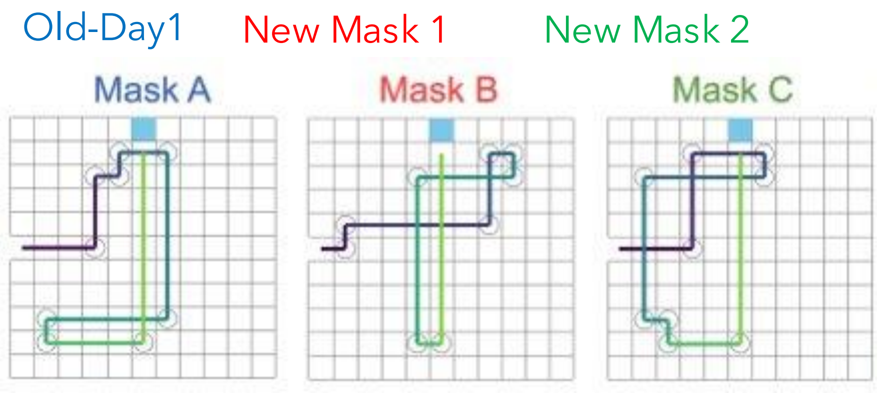
Meta-learning
/generalization

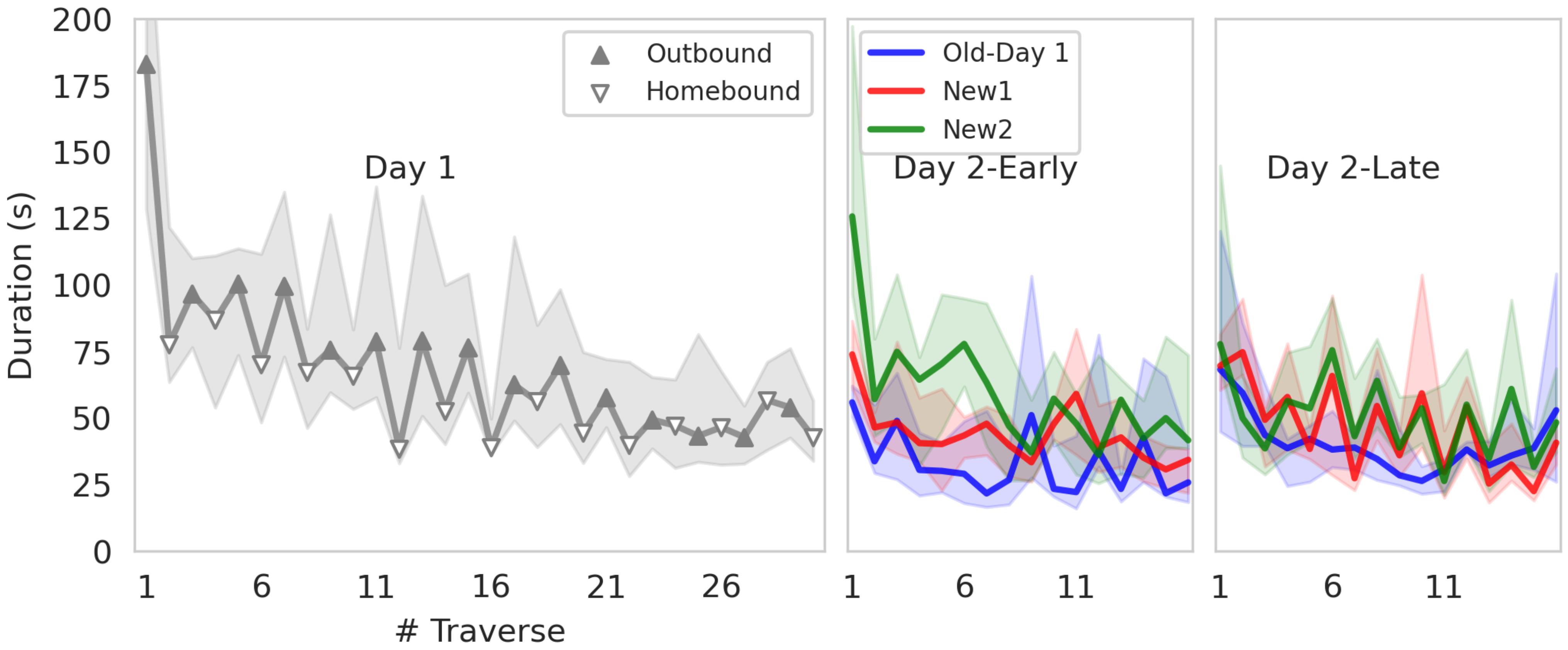
Day2 : Generalization and Memory



Day 1 Mask A

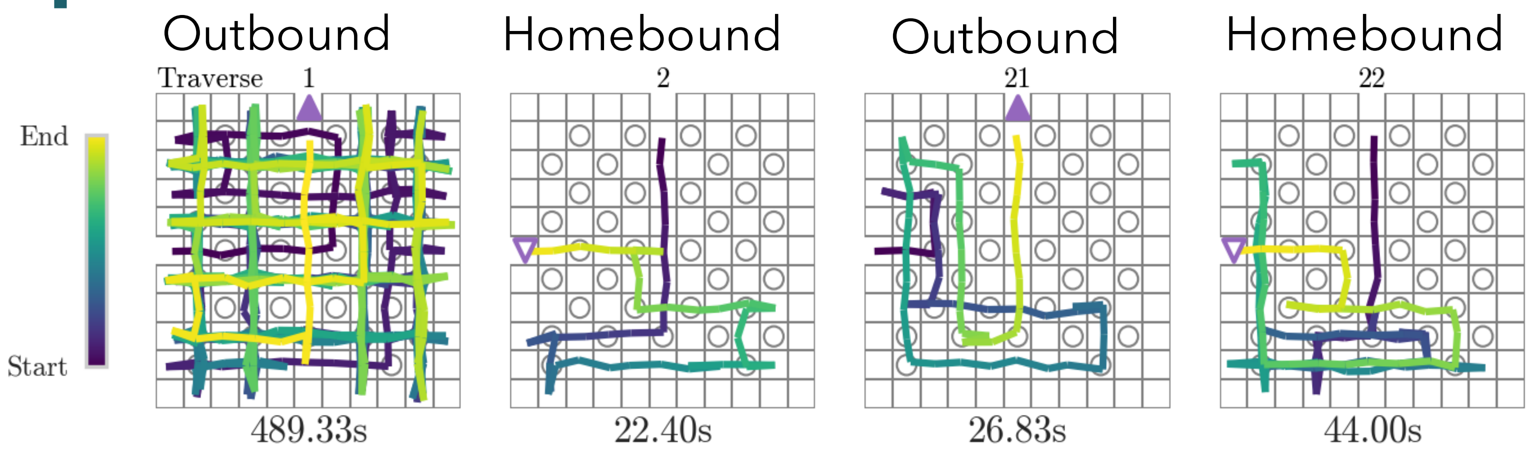
Day 2

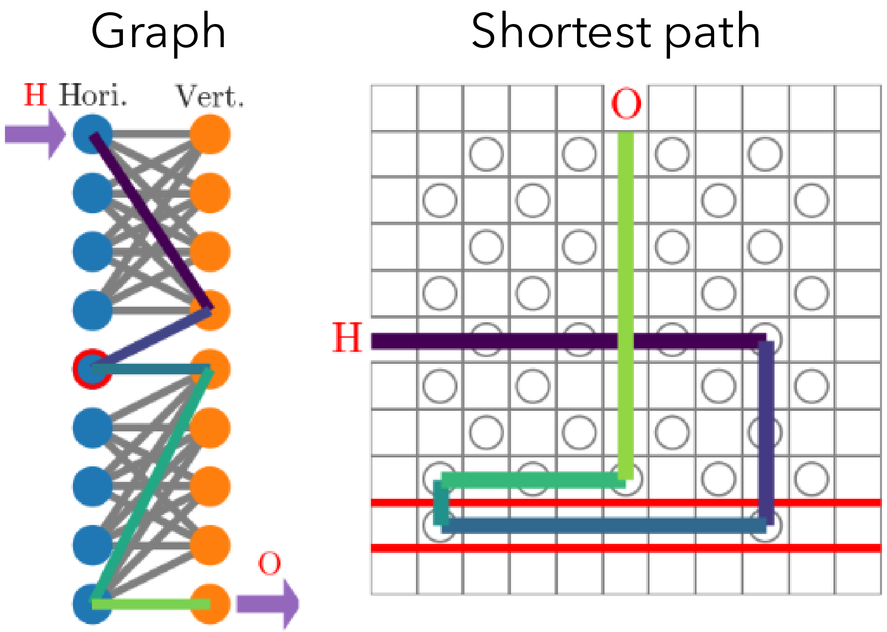


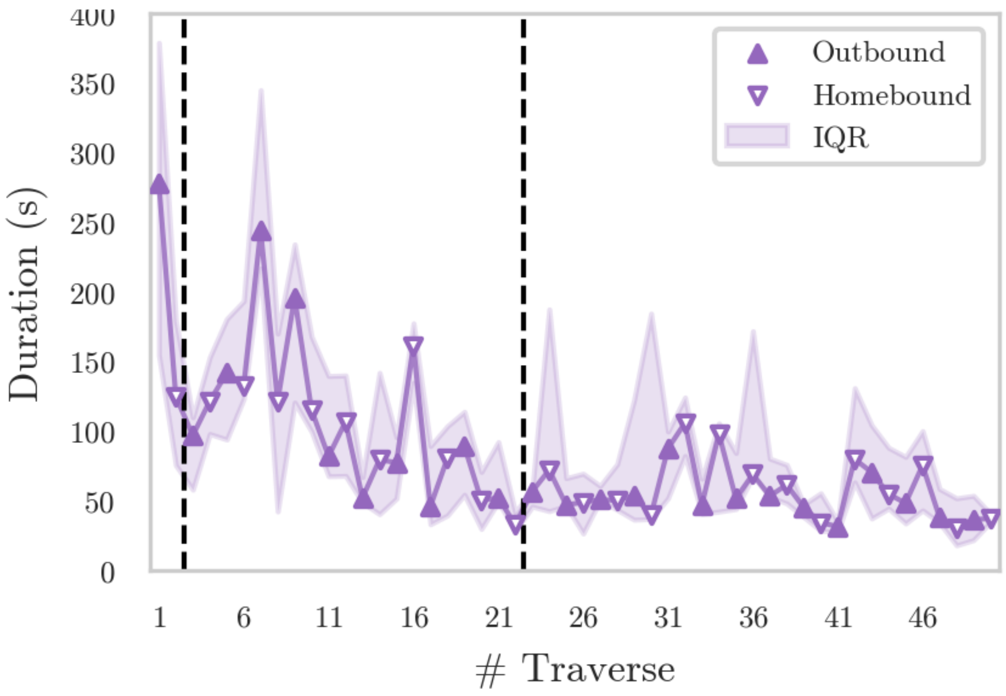


Flexible routing in a complex Mask

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





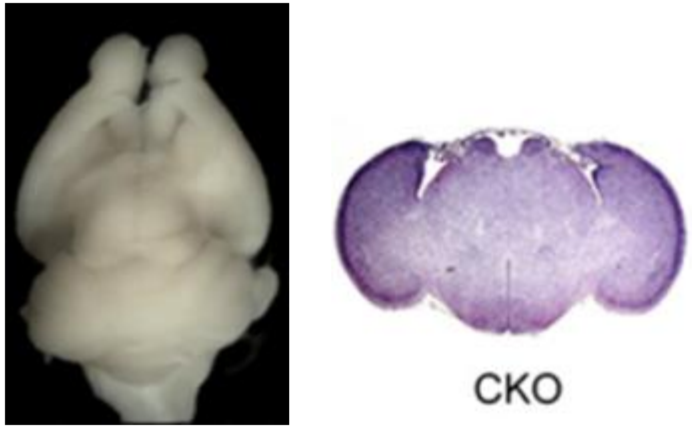


The role of cortex

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**

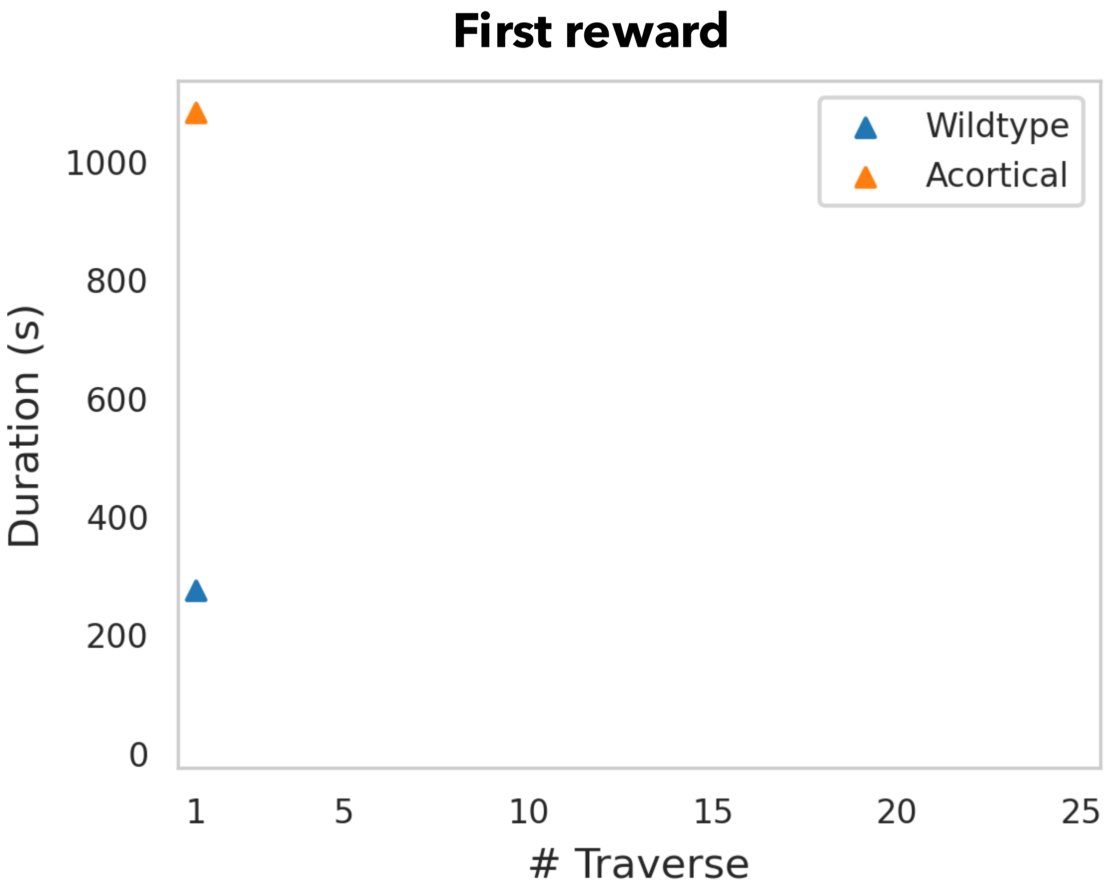
C57BL6/J Wildtype



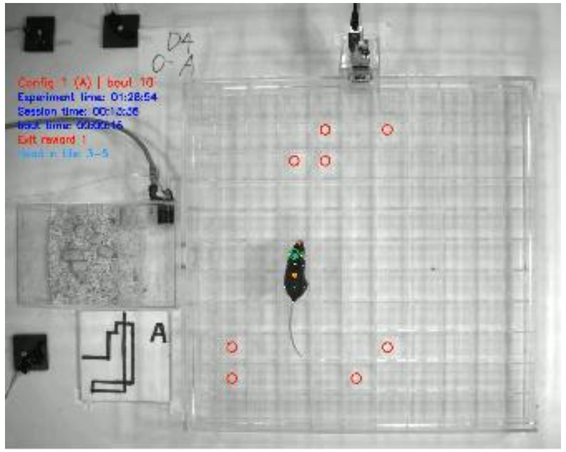
Emx1-Cre+ x Pals1 flox/flox

Kim et Walsh, 2010

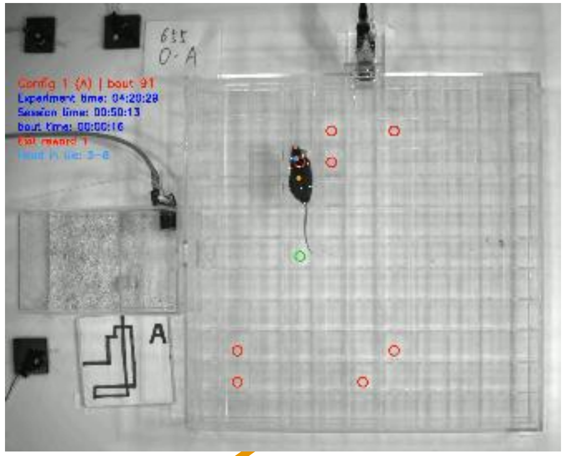
Acortical mouse took 3x time to solve the first mask

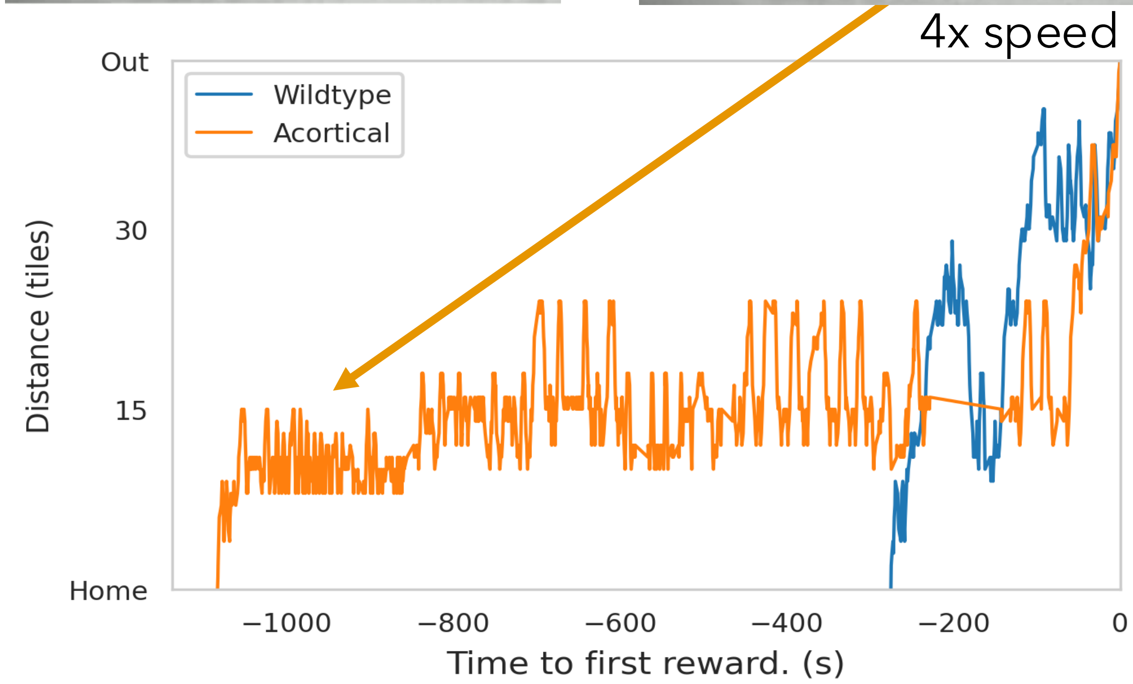


Wildtype

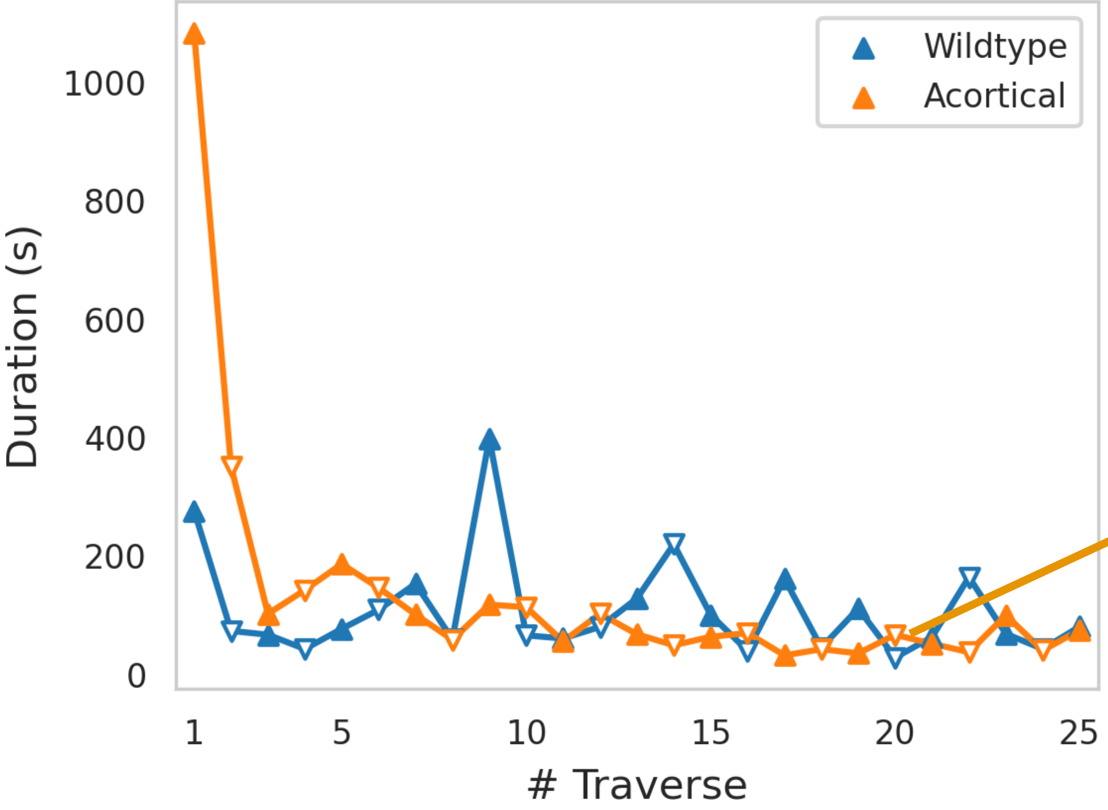


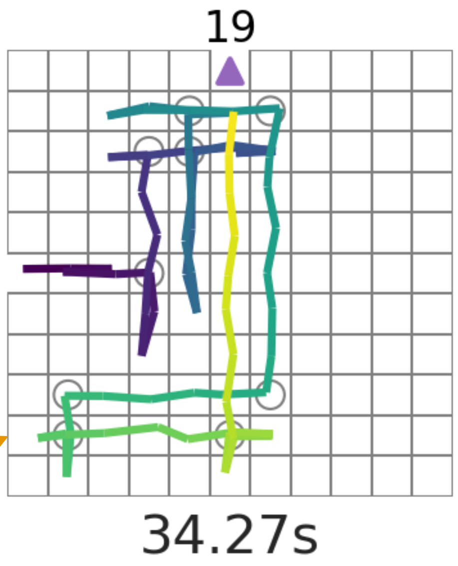
Acortical

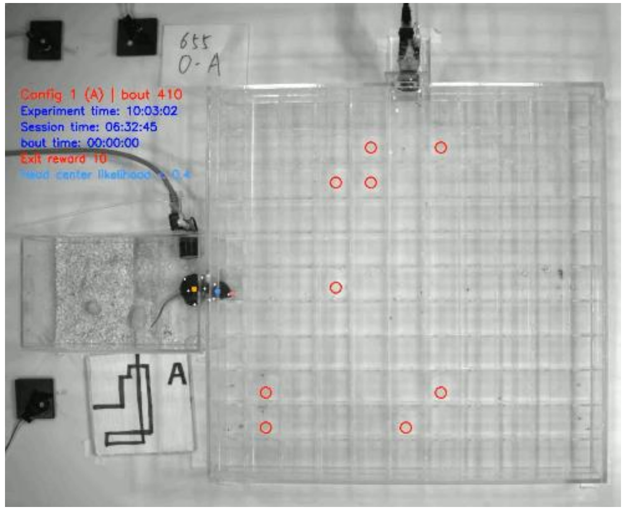




Acortical mouse learning the first mask

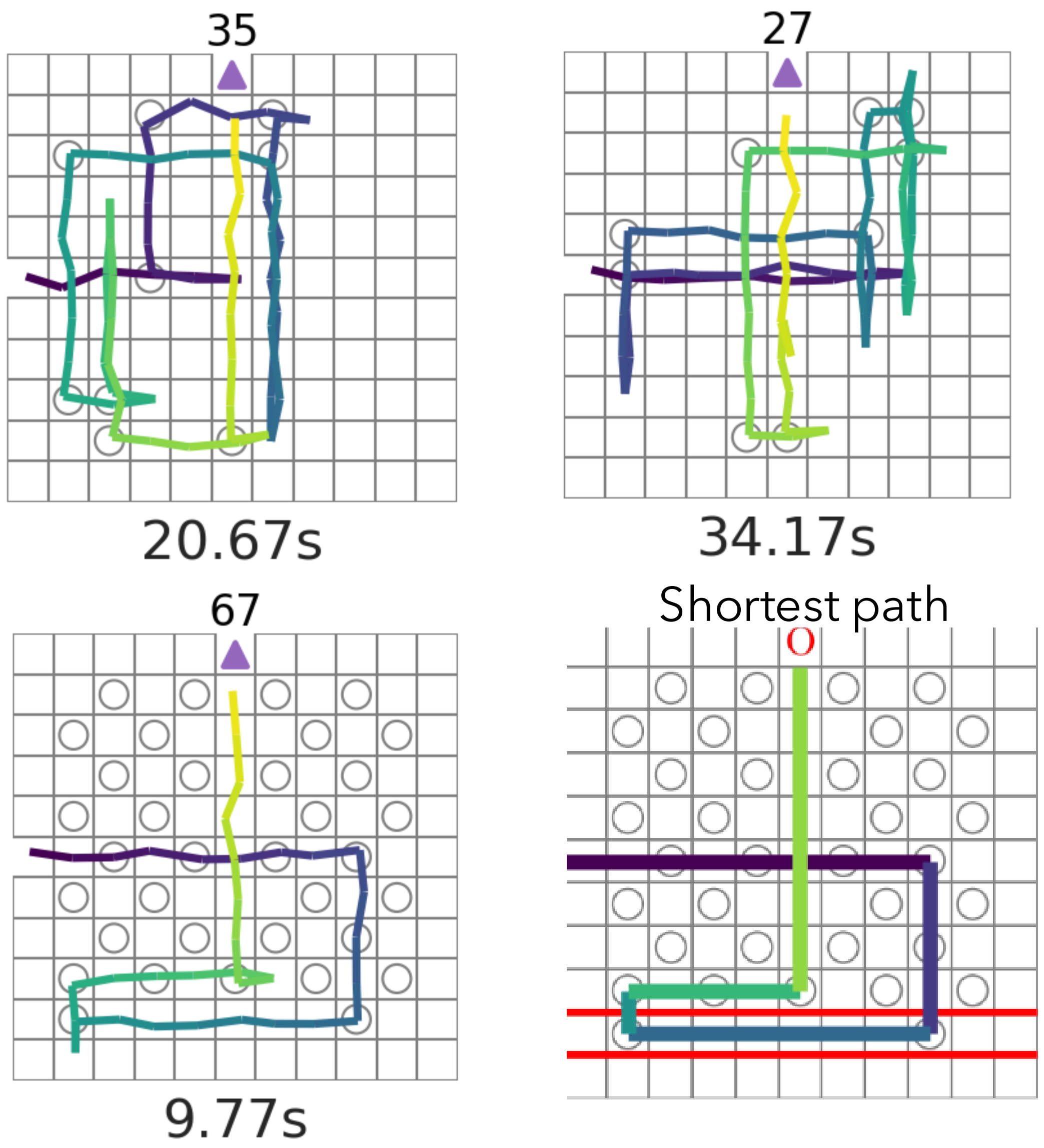


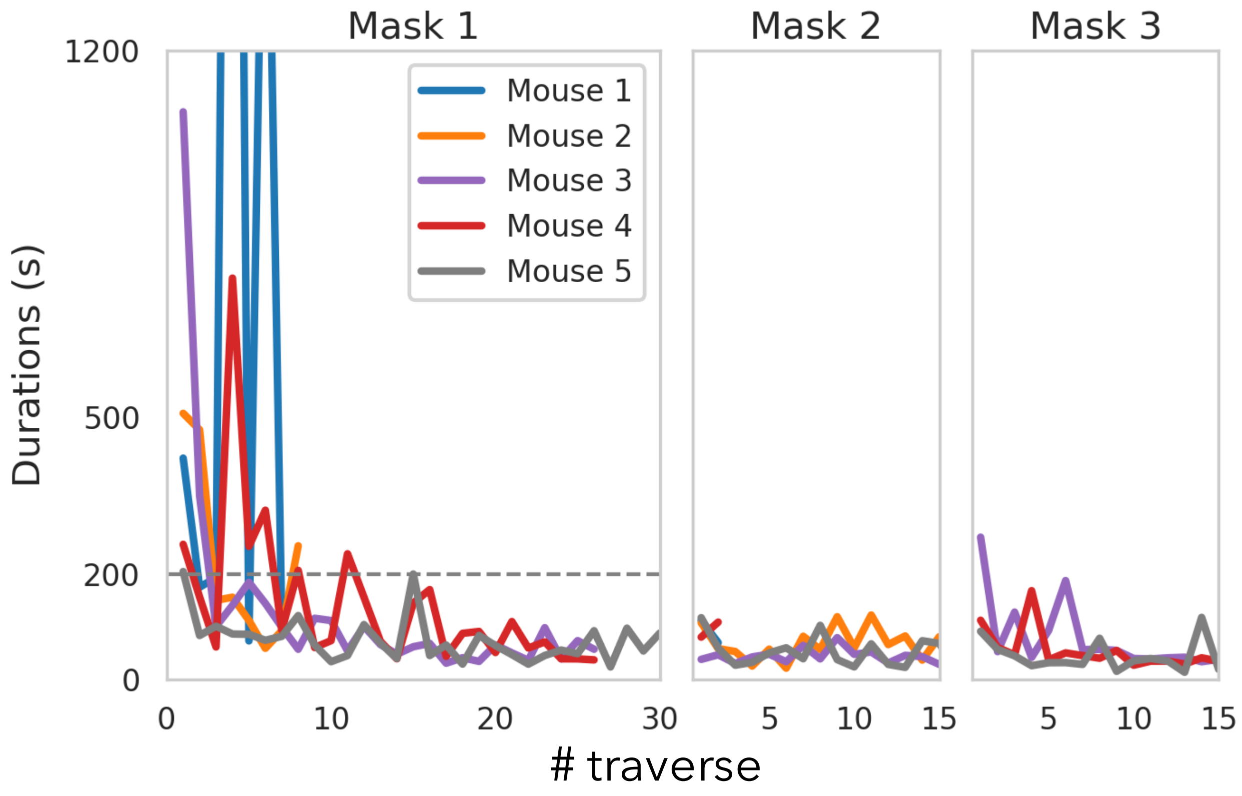




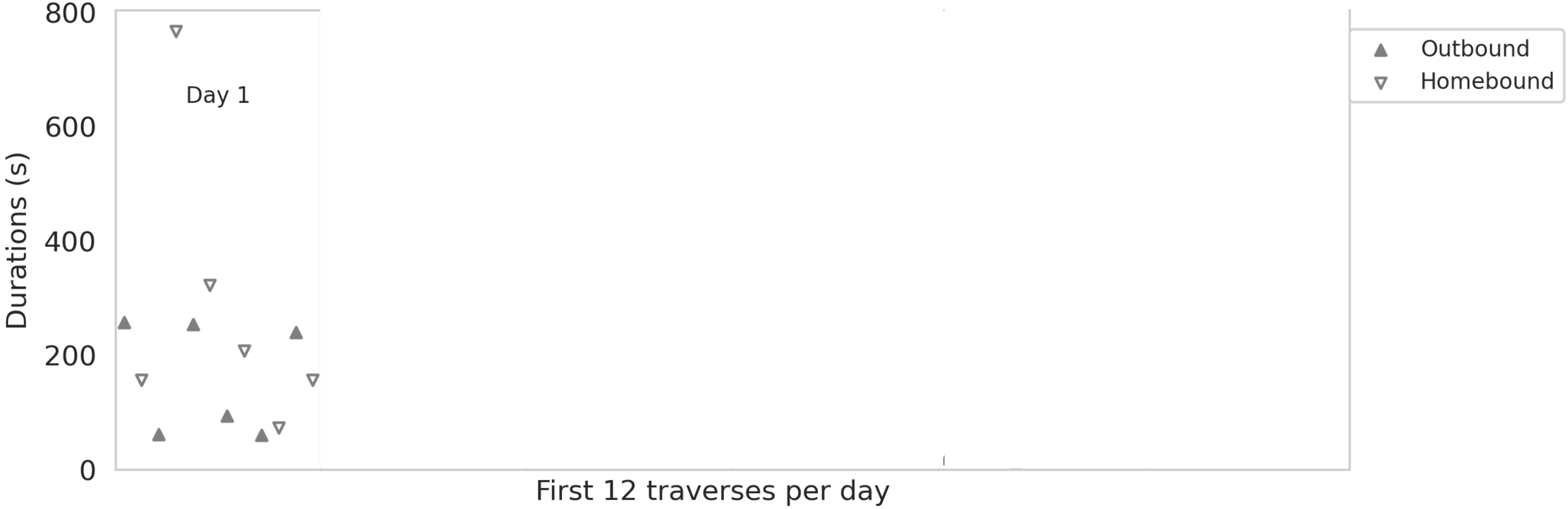
4x speed

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

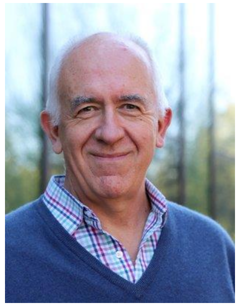
- Meta-learning over 2 days: **2 new maps**

- 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

Rogério Guimarães

Zeynep Turan

Scan for the slides and poster:

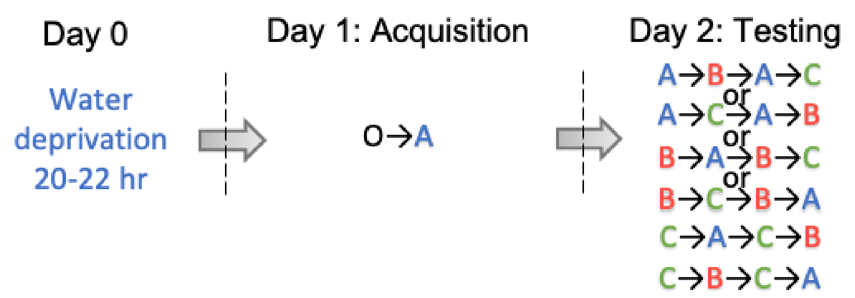
These projects were funded by Simons Collaboration on the Global Brain (SCGB 543015 and 543025).

Supplementary materials

Day 2 – experiment plan

Session

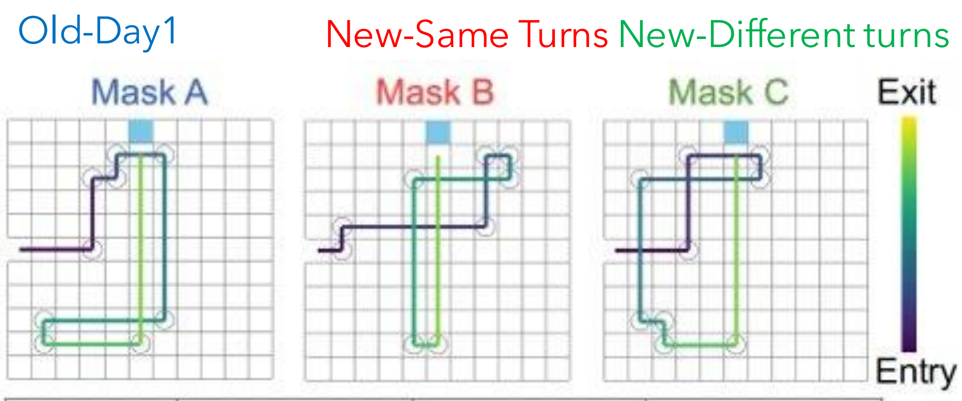
1	2	3	4
C	B	C	A
C	A	C	B
B	C	B	A
B	A	B	C
A	C	A	B
A	B	A	C



- 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

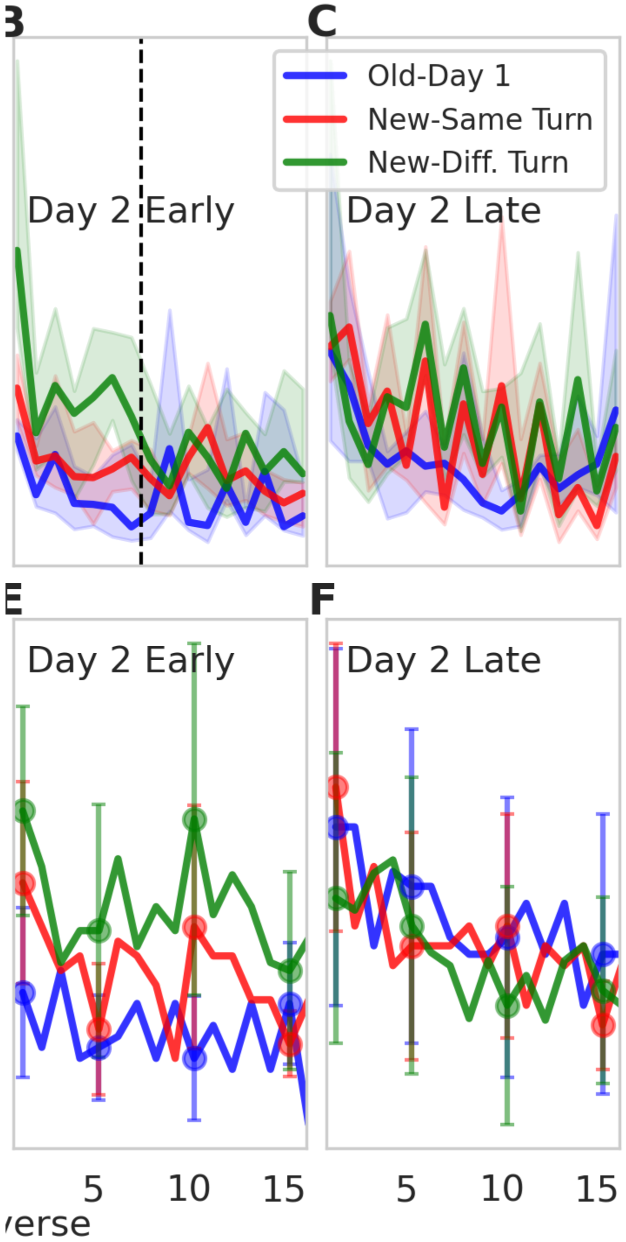
Day 2



	A	B	C
Turn seq.	LRLRRRLLL	Same as A	LRRRLLRLL

Duration:
Mask C >
Mask B

Turn errors:
Not
significant



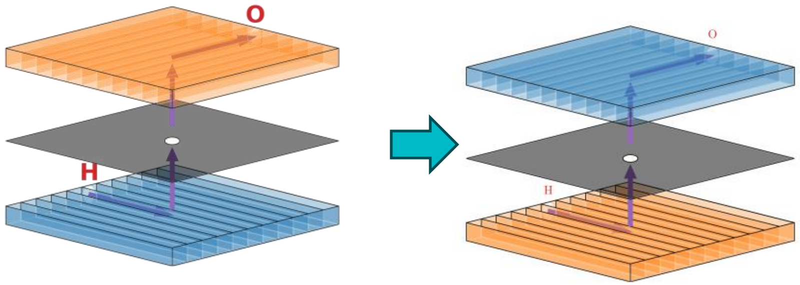
Mask Designs:

- The 9-hole mask features a sequence of 9 turns (from Home to Out)
- We did a numerical search of the space to select two different new masks

Learning was not facilitated by the same-turn sequence

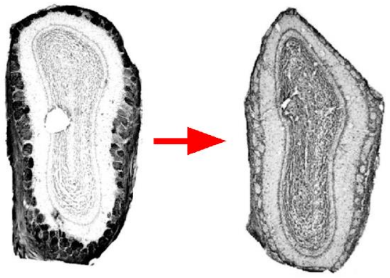
Role of olfaction in homing

Experiment 1: swap the trays
(disturb external cues)



Experiment 2: Olfactory ablation

Intranasal Zinc Sulfate administration



McBride 2003