# Mice in the Manhattan Maze:

# Rapid learning, flexible routing and generalization,

# with and without cortex

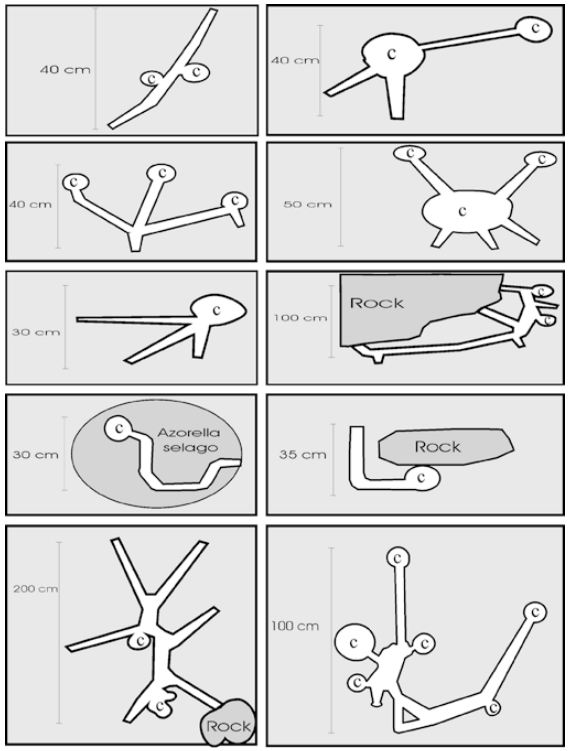

Disclaimer: Not the real Caltech Logo
Artist: Myself

Aug. 9th CCN 2024

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

# A Navigation Task for Mouse cognition

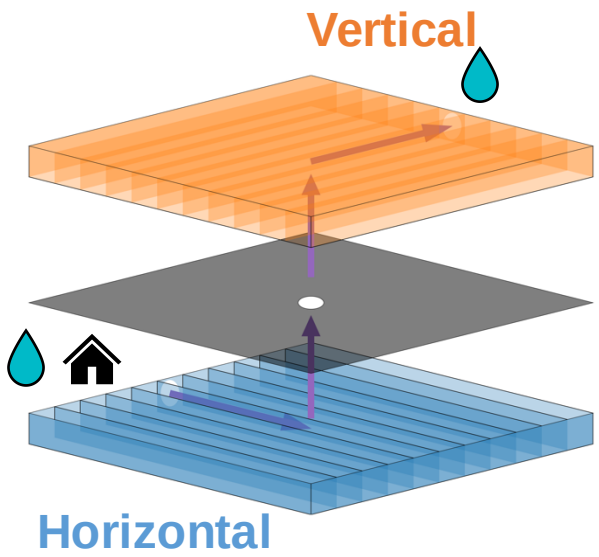
Vera Domingues/Hopi Hoekstra



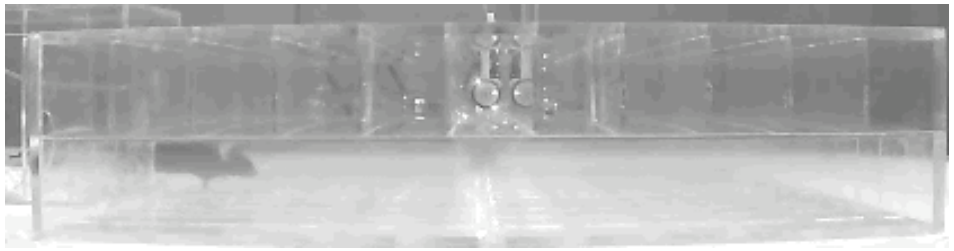

Avenant, 2002


David Rumsey

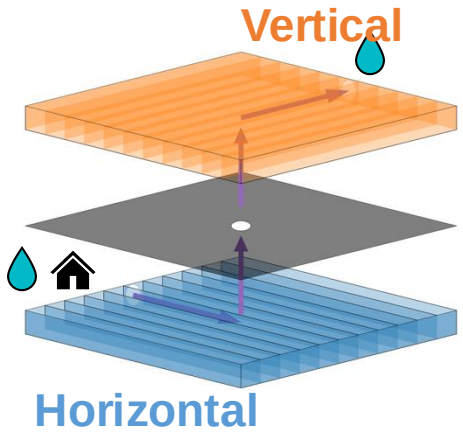
## The Manhattan Maze

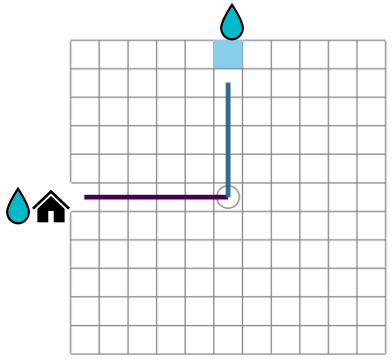



**Side View** (x2 speed)

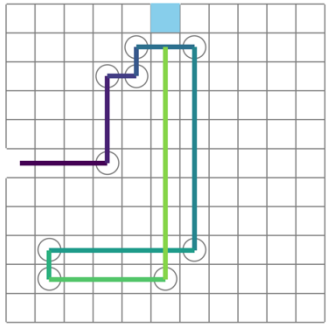


# The Manhattan Maze design

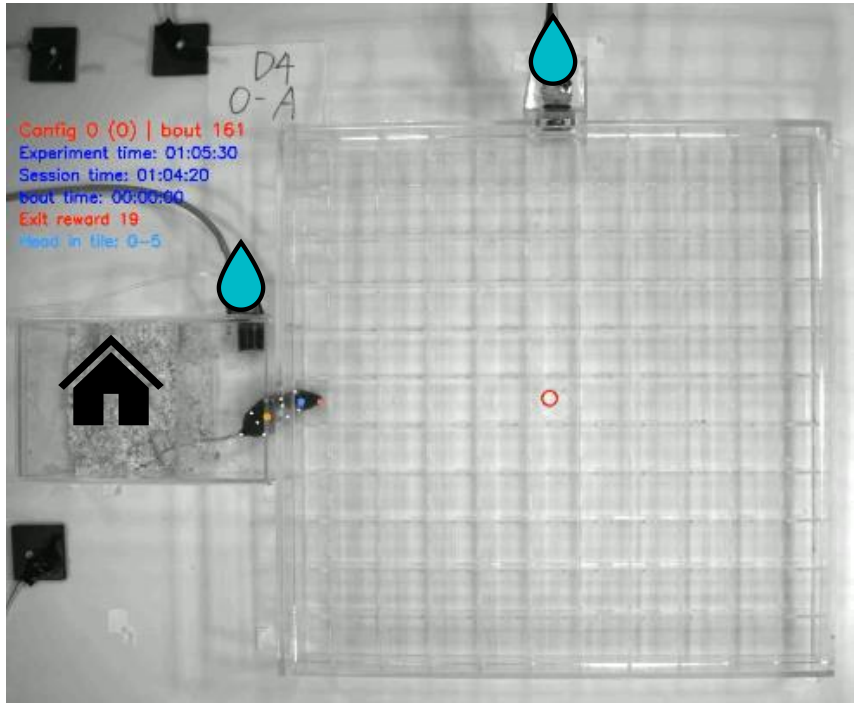


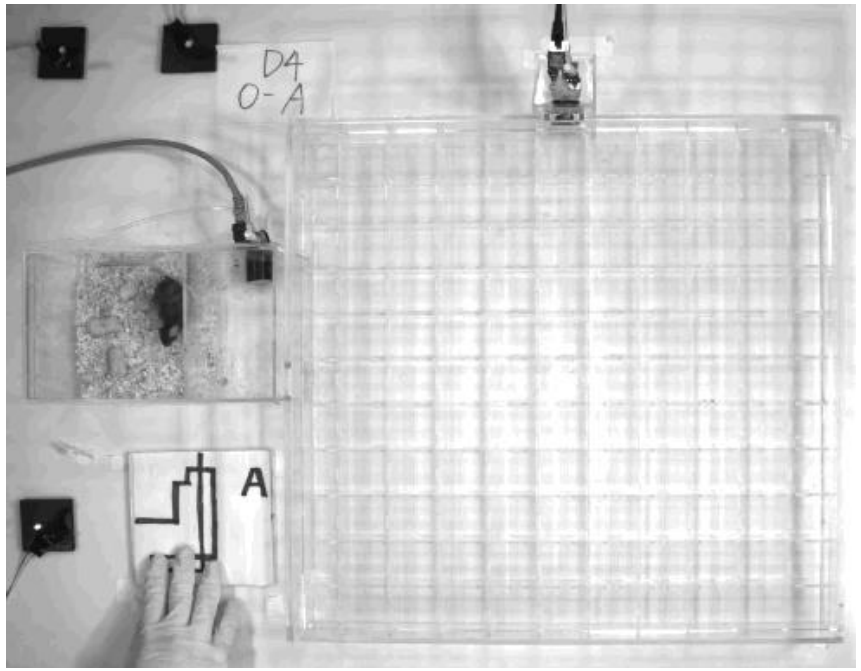



1-hole Mask O



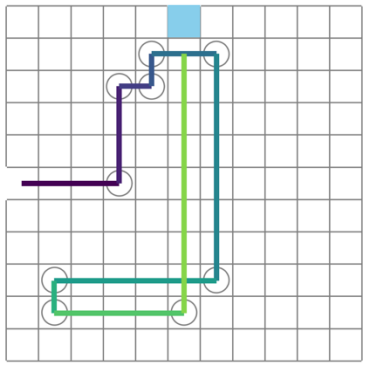
9-hole Mask A



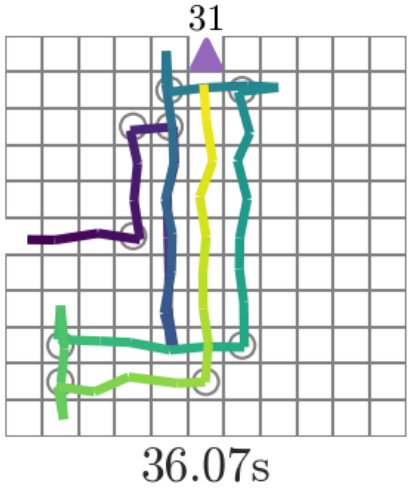




Easy Reconfiguration

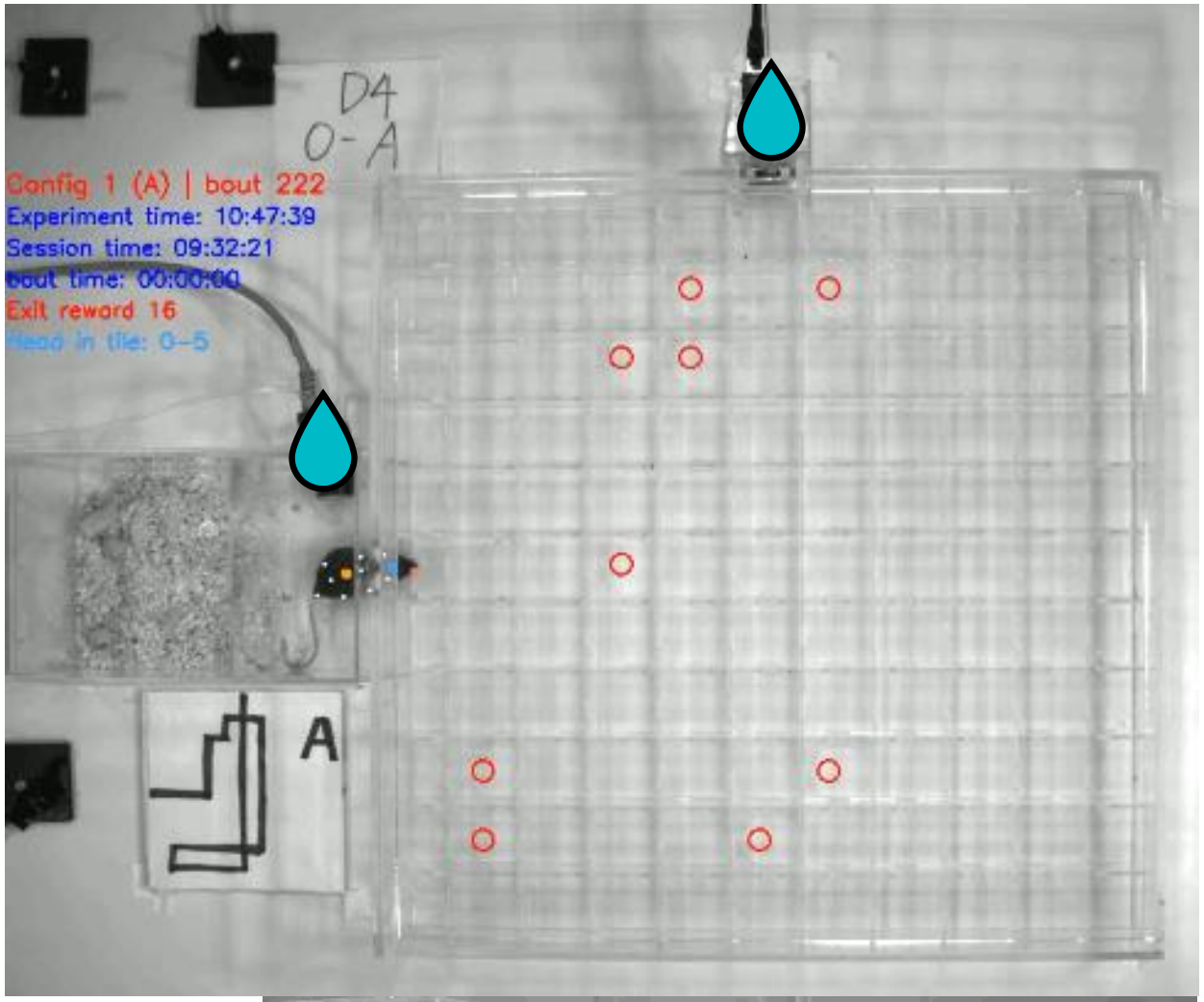
# Learning a 9-hole mask



**Optimal solution**

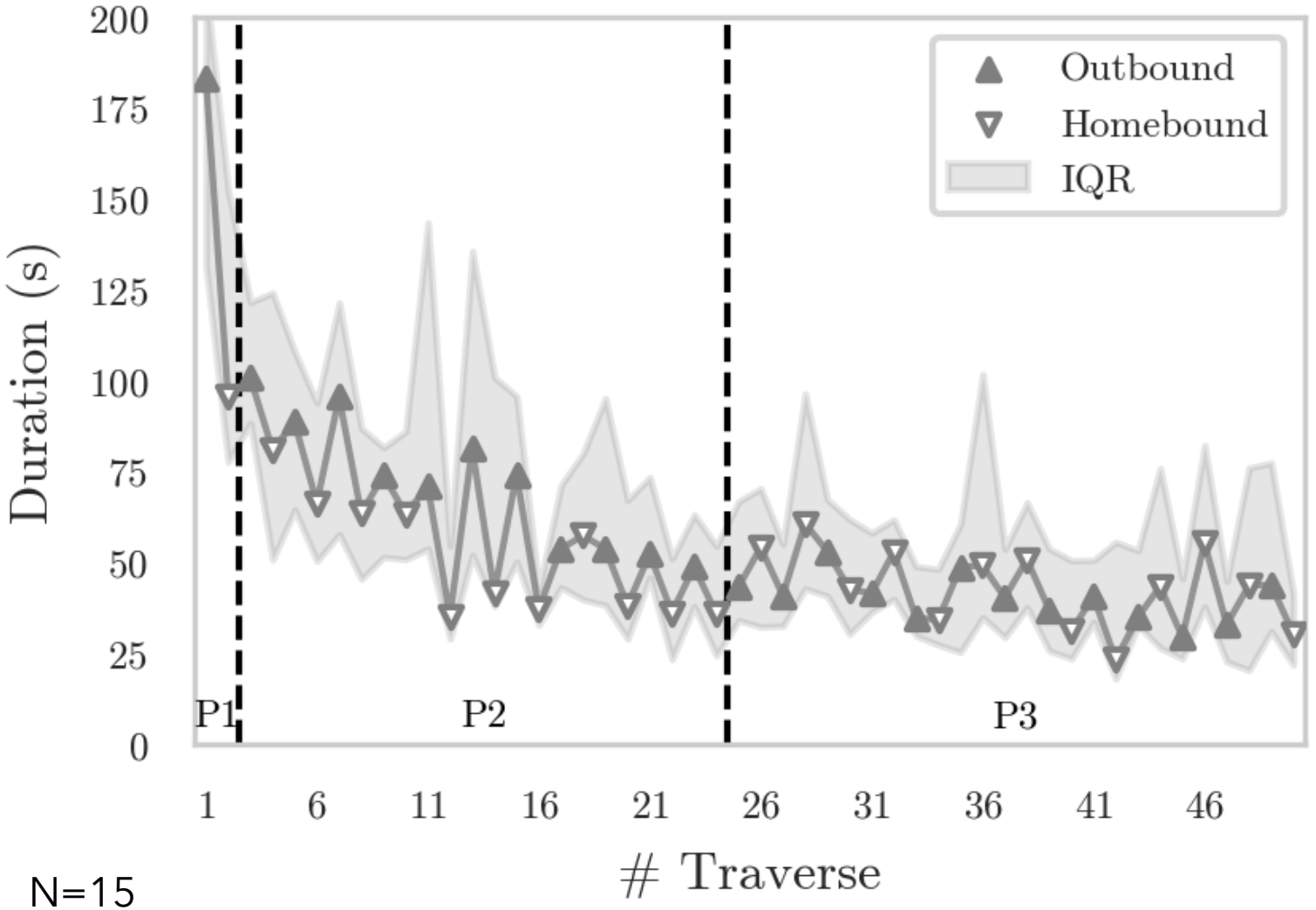



**Mouse Trajectory**




Side view

# Day 1: Rapid learning in Mask A

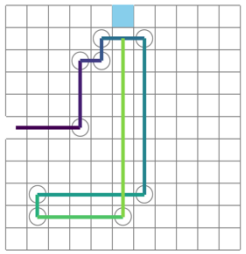



N=15

(A trip from one port to the other)

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

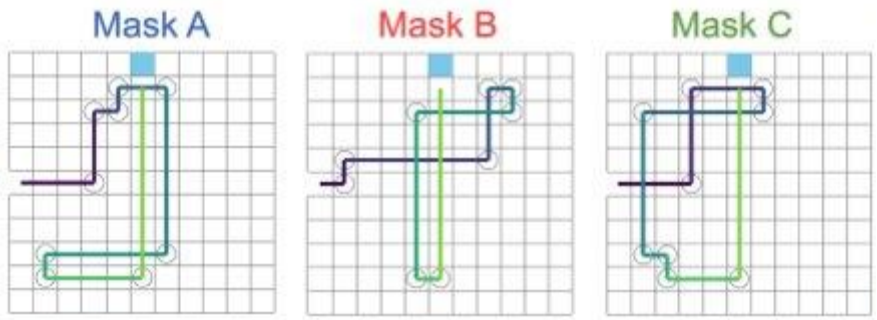
# Day2 : Three masks introduced

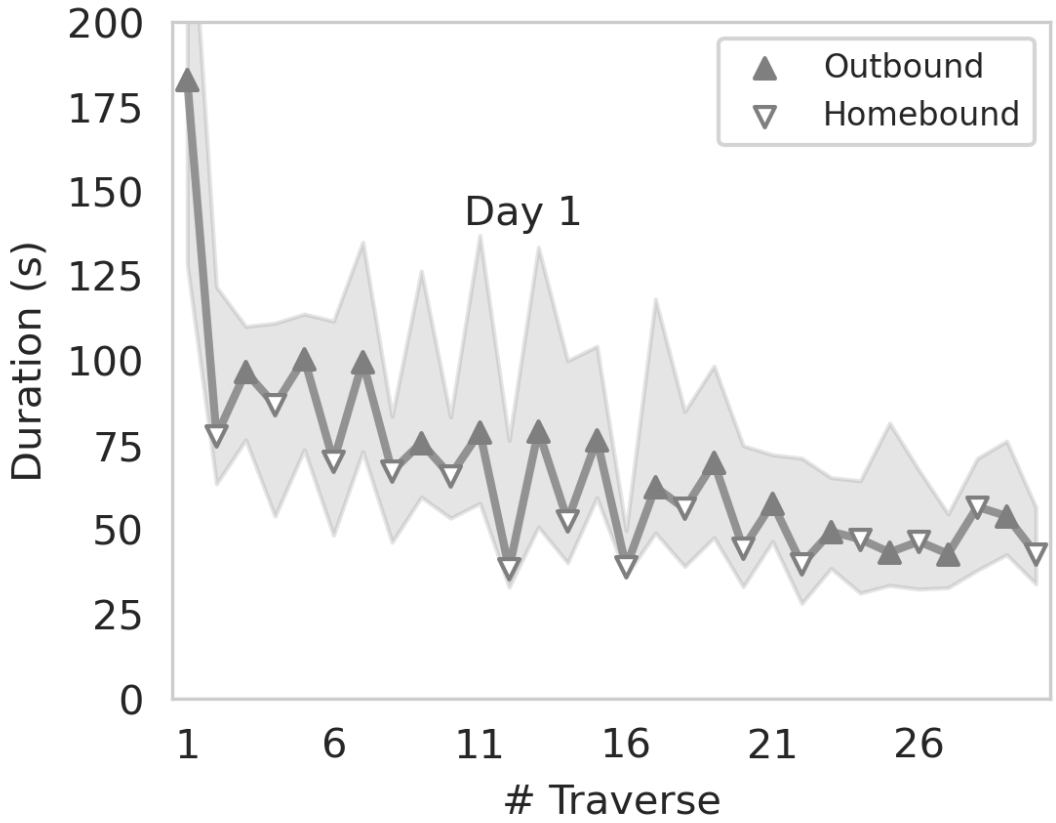


Day 1 Mask A

Day 2

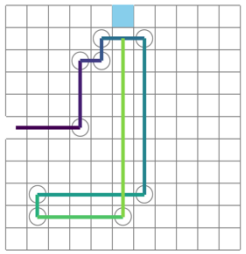
Old-Day1 New Mask 1 New Mask 2




**Overnight memory**

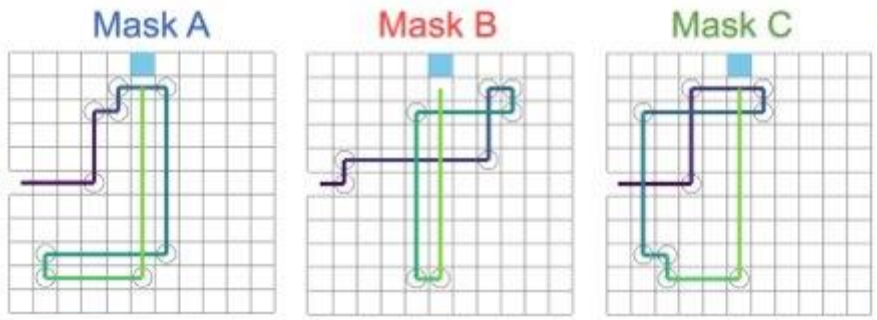
# Day2 : Three masks introduced

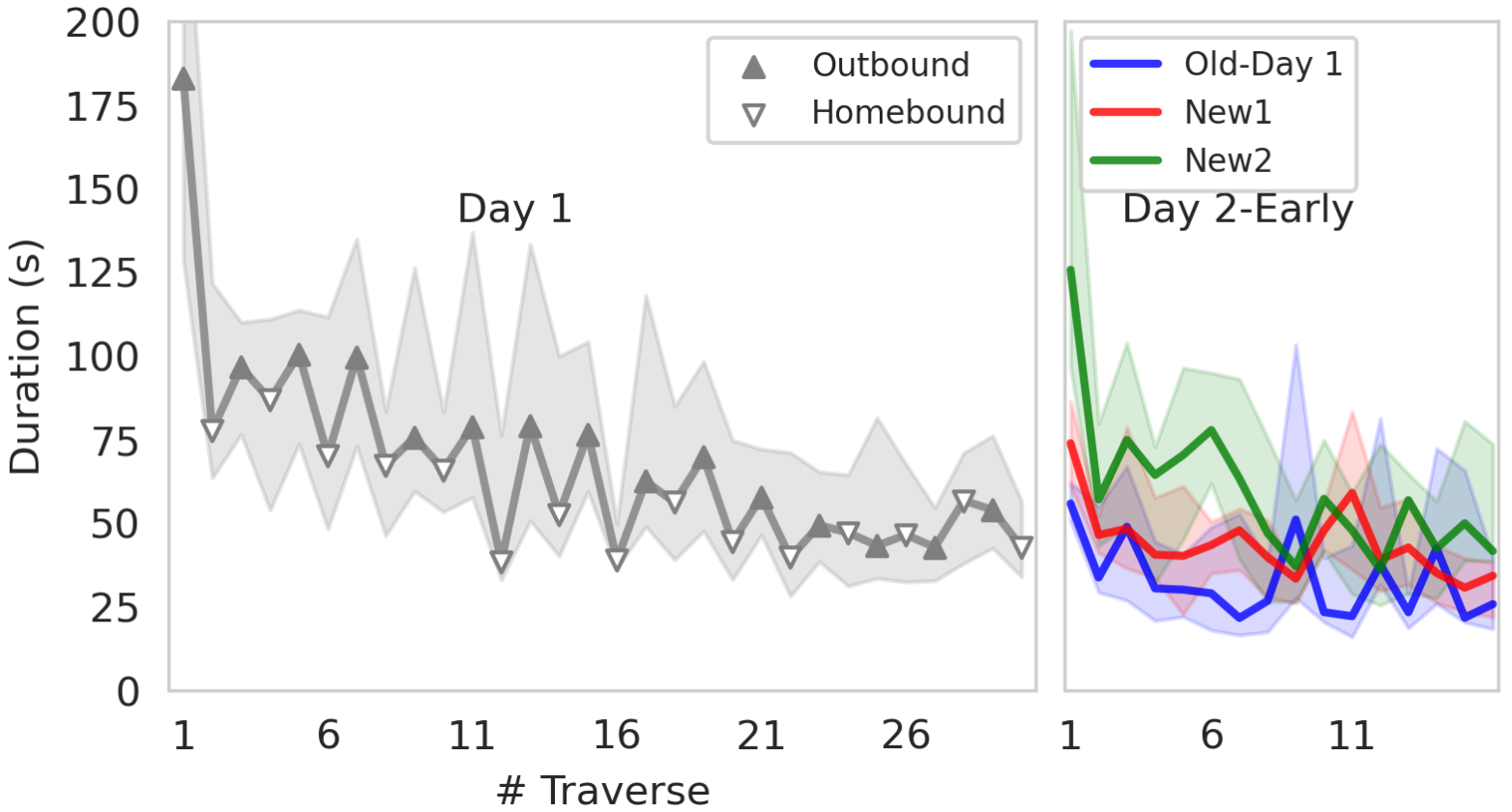


Day 1 Mask A

Day 2

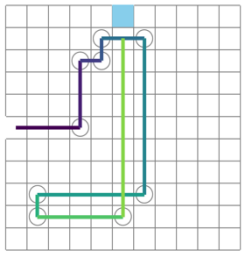
Old-Day1 New Mask 1 New Mask 2




**Generalization & Continual learning**

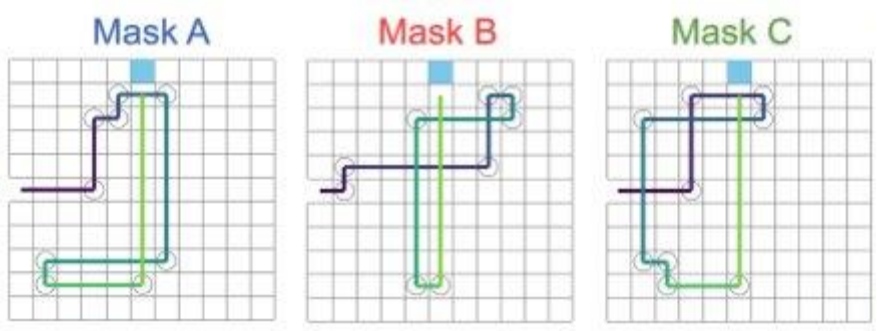
# Day2 Late: saturated performance

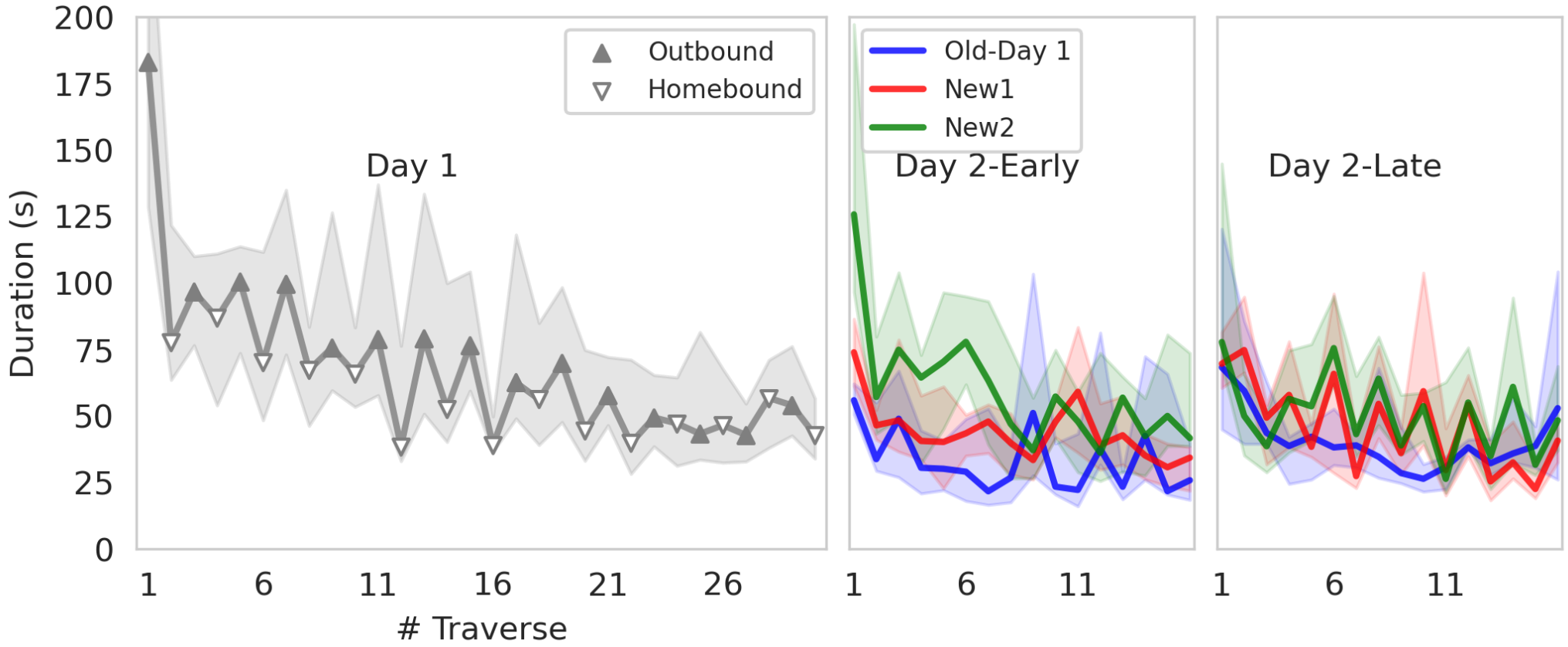


Day 1 Mask A

Day 2

Old-Day1 New Mask 1 New Mask 2

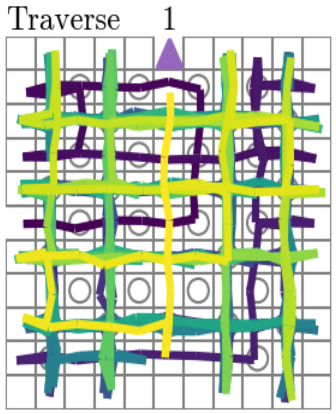


# Flexible routing in a complex Mask

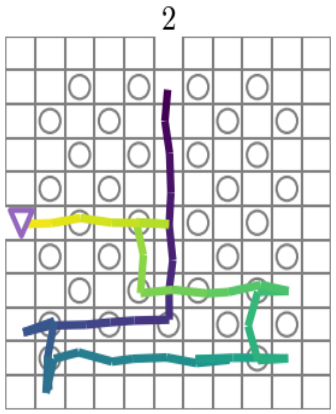
Two all-to-all connected areas with a bottleneck
- Many loops
- Redundant paths


Outbound



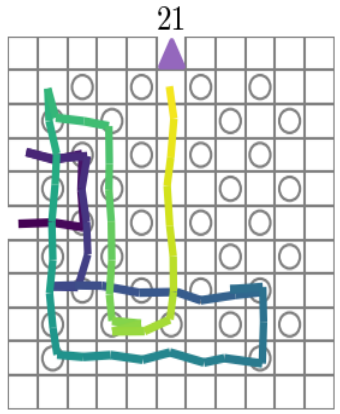

489.33s

Homebound



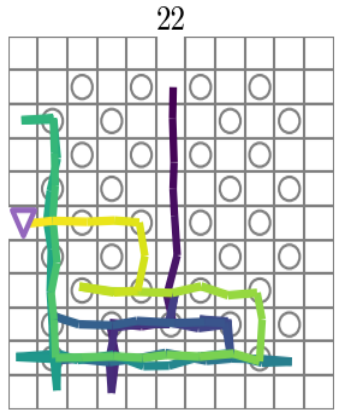

22.40s

Outbound




26.83s

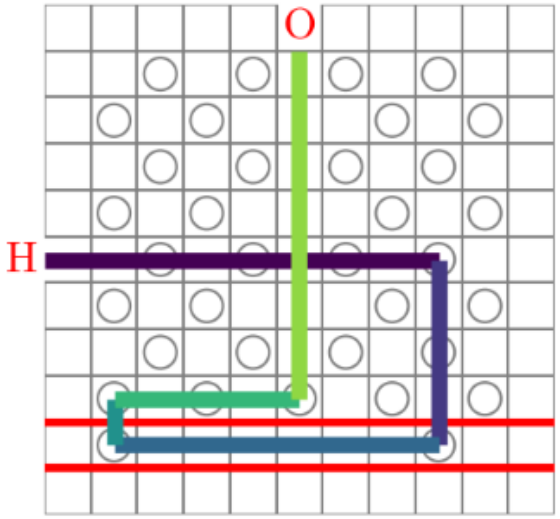
Homebound

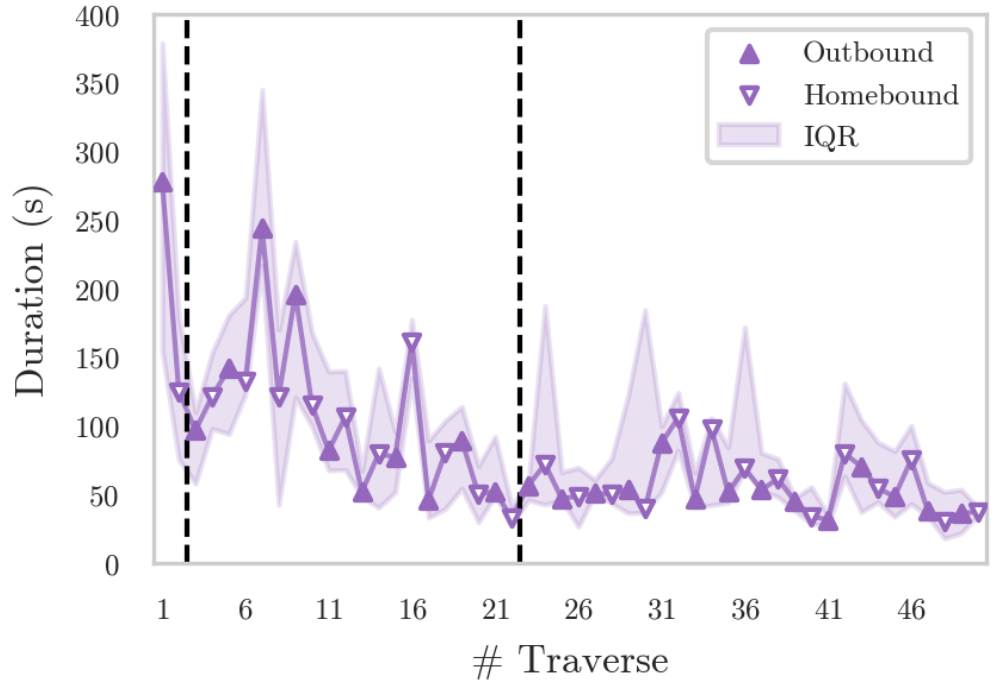



44.00s

Graph


Shortest path



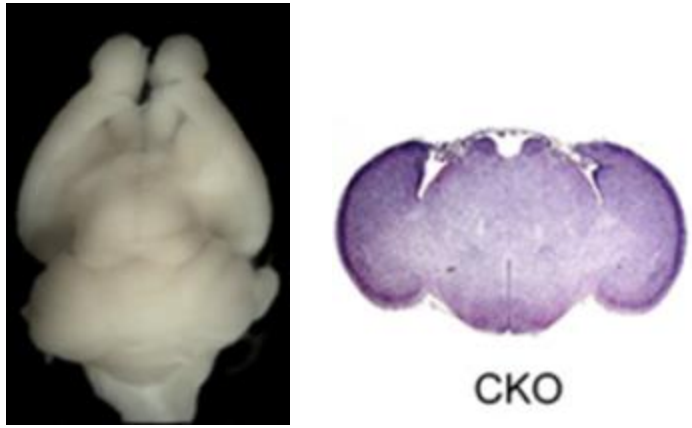



# The role of cortex

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**

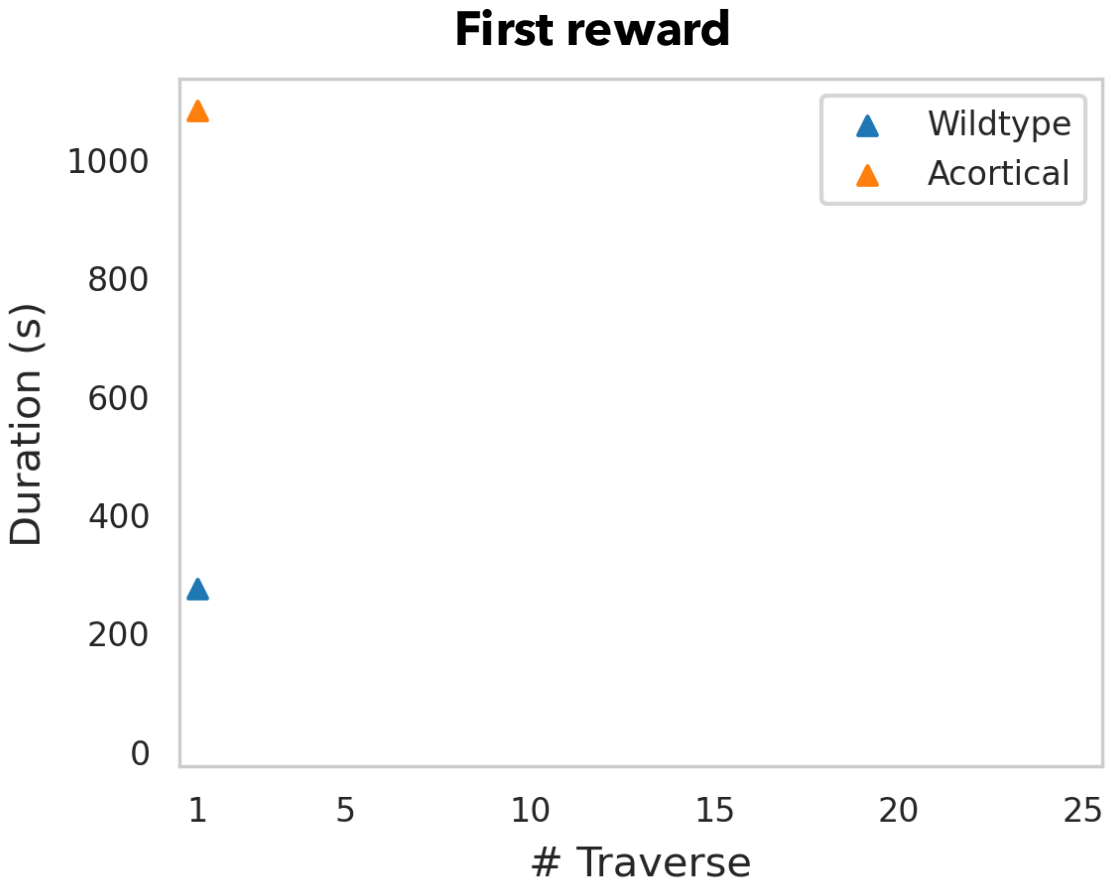

C57BL6/J Wildtype



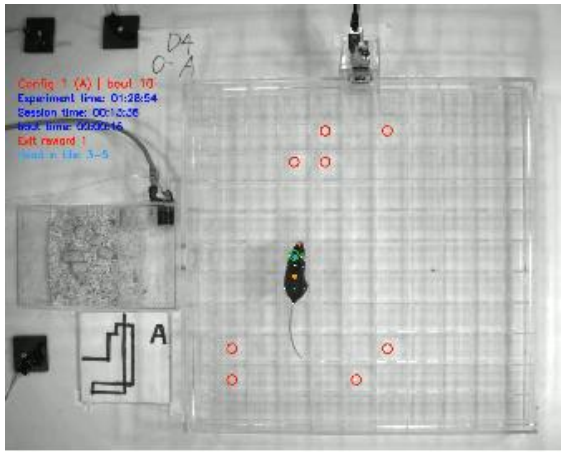

Emx1-Cre+ x Pals1 flox/flox

*Kim et Walsh, 2010*

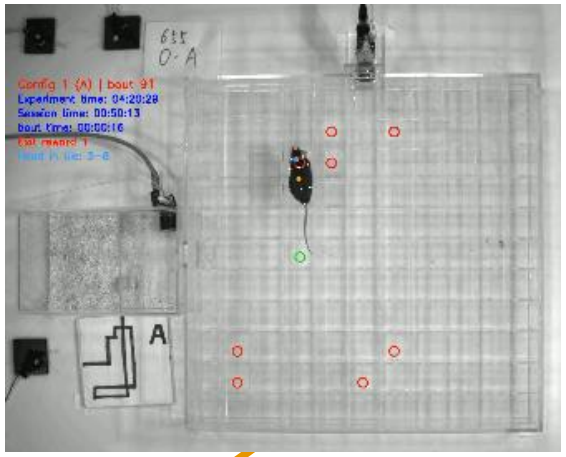
# Acortical mouse took 3x time to solve the first mask



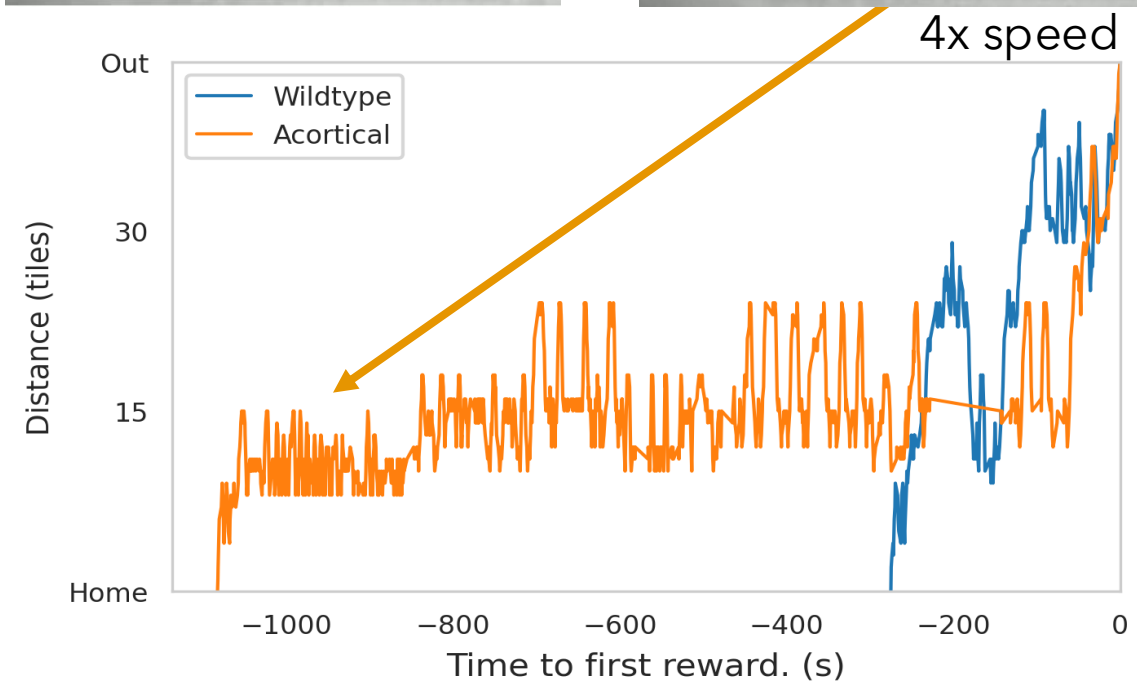

Wildtype



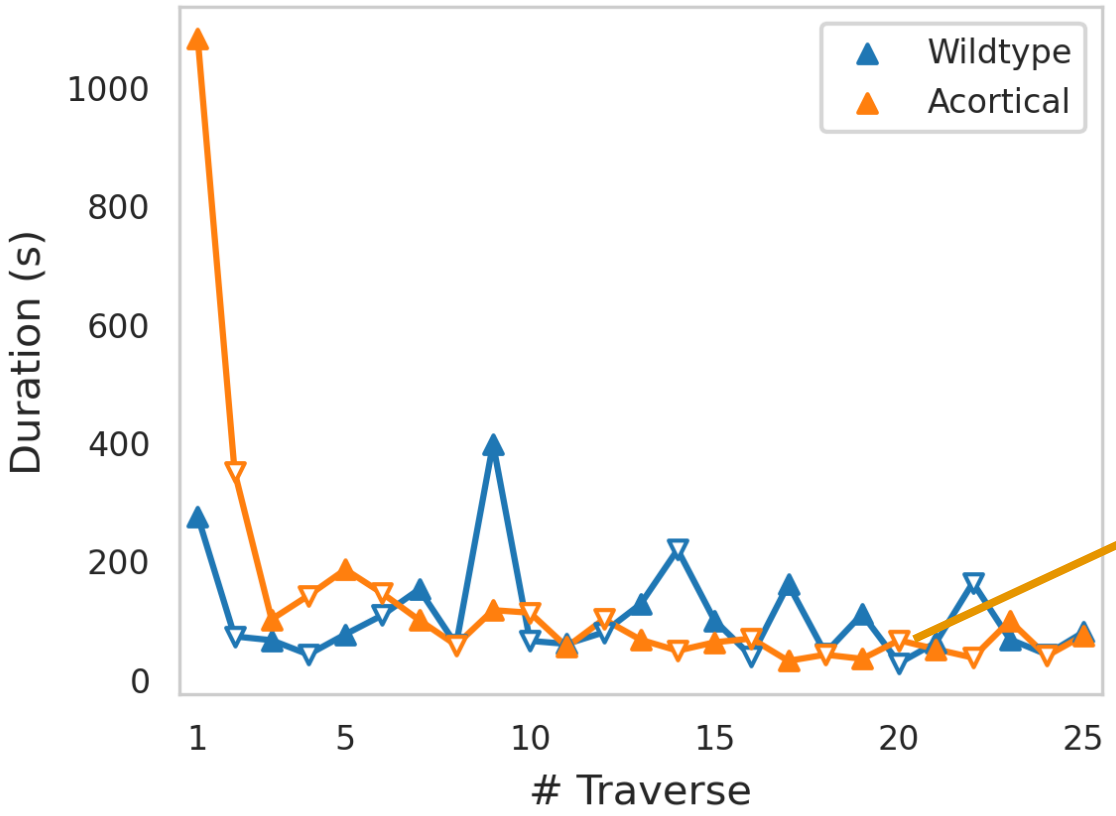
Acortical

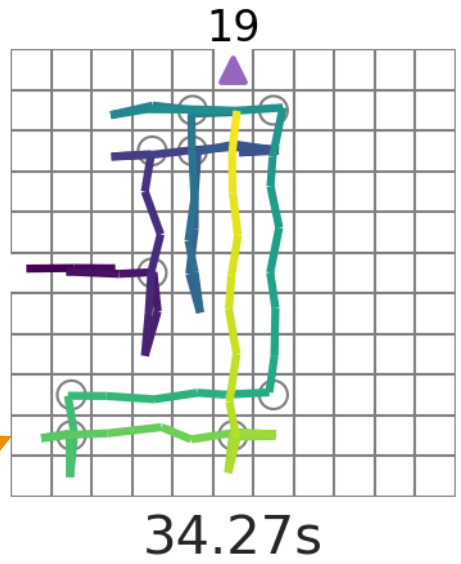


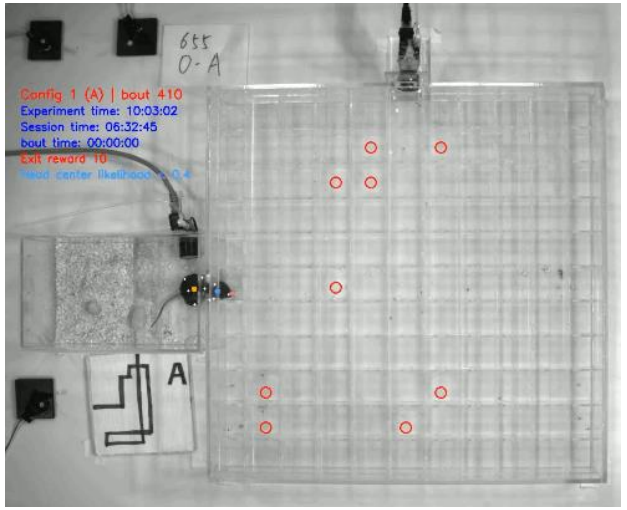
4x speed



# Acortical mouse learning the first mask



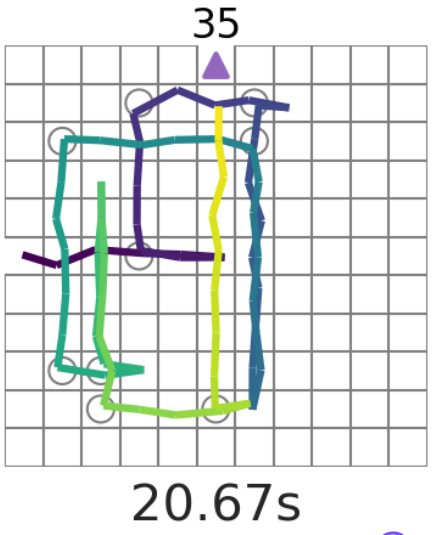



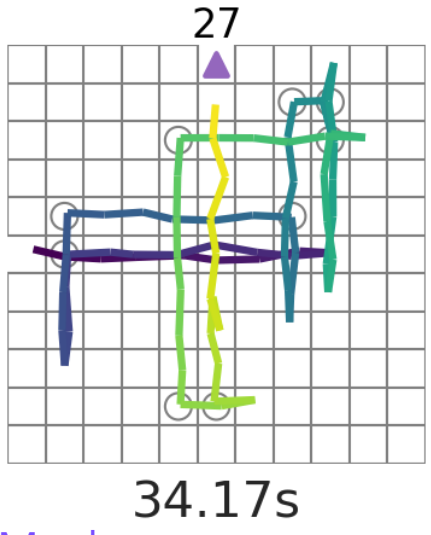

4x speed

# Learning multiple masks

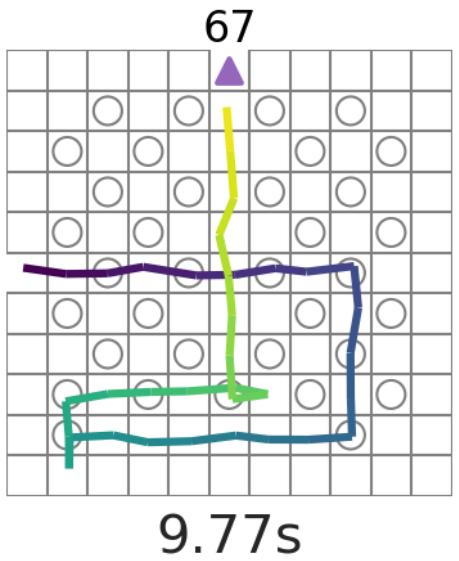
New Mask 1



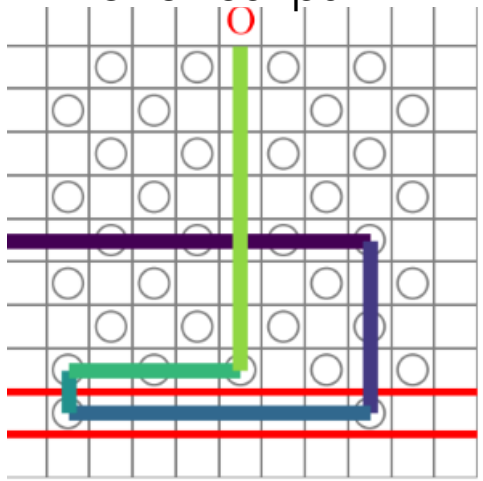

New Mask 2

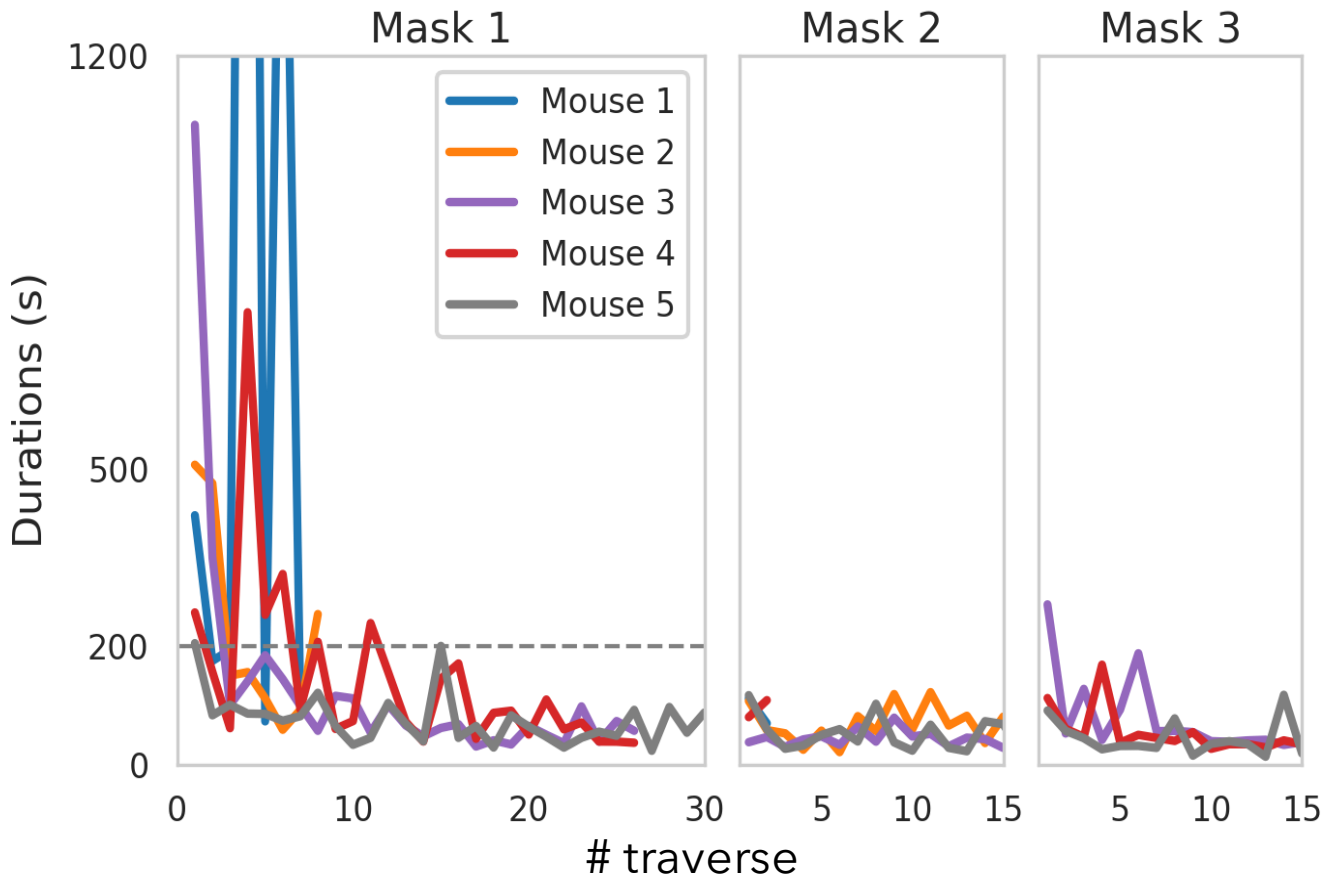



Complex Mask

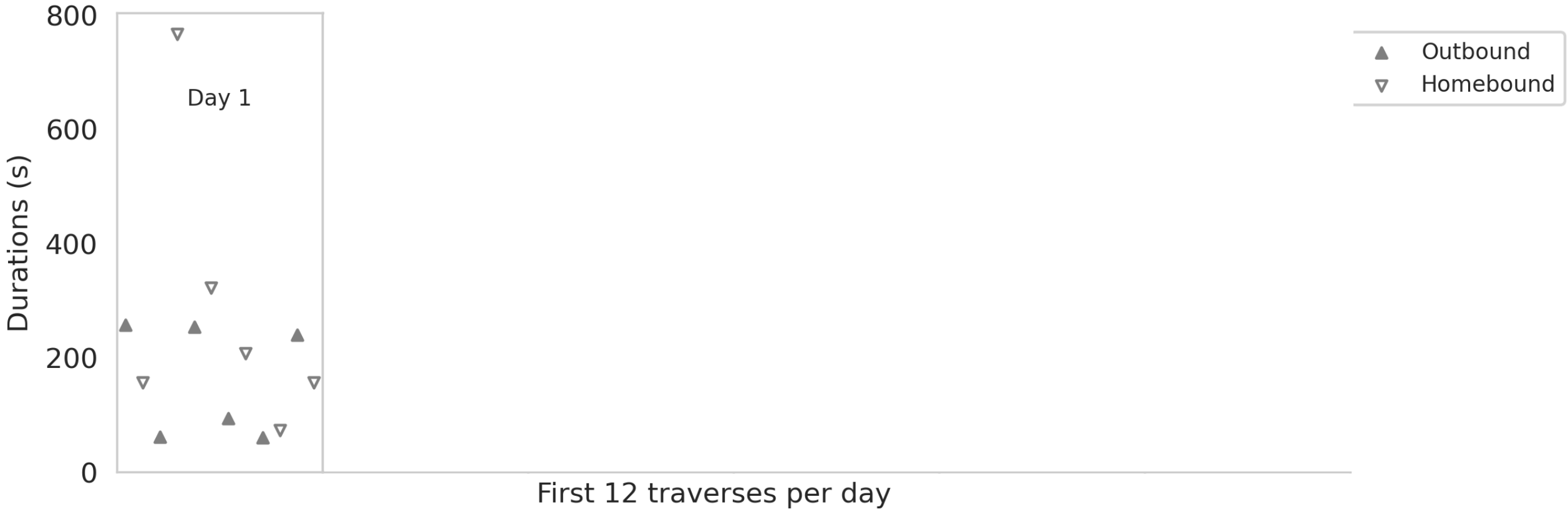



Shortest path





# 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

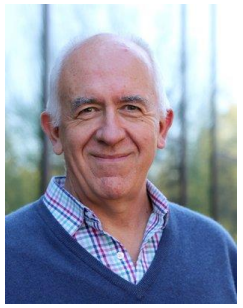
- Meta-learning over 2 days: **2 new maps**

- 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, poster and cute mouse videos

(Real Caltech Logo)

**More on my website**: jieyusz.github.io
**Twitter:** @Jieyuzheng3

# Supplementary materials

# Day 2 – experiment plan

Session

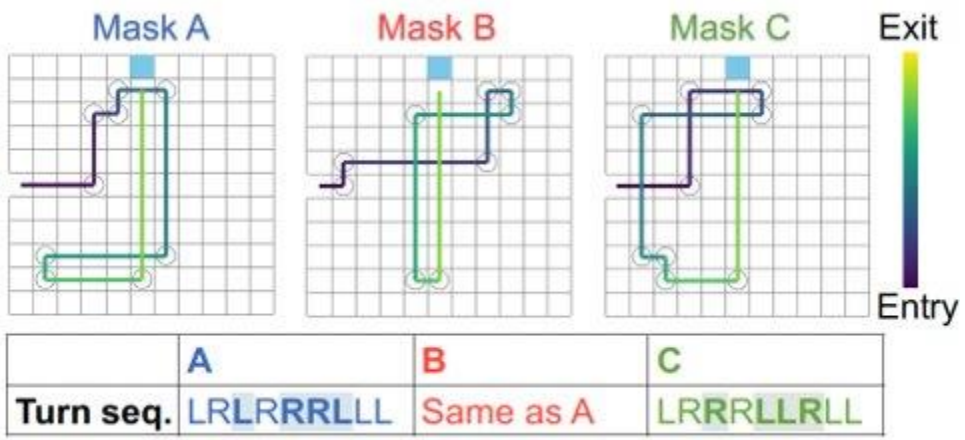
| 1 | 2 | 3 | 4 |
|---|---|---|---|
| C | B | C | A |
| C | A | C | B |
| B | C | B | A |
| B | A | B | C |
| A | C | A | B |
| A | B | A | C |


- 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

Old-Day1 New-Same Turns New-Different turns

Day 2



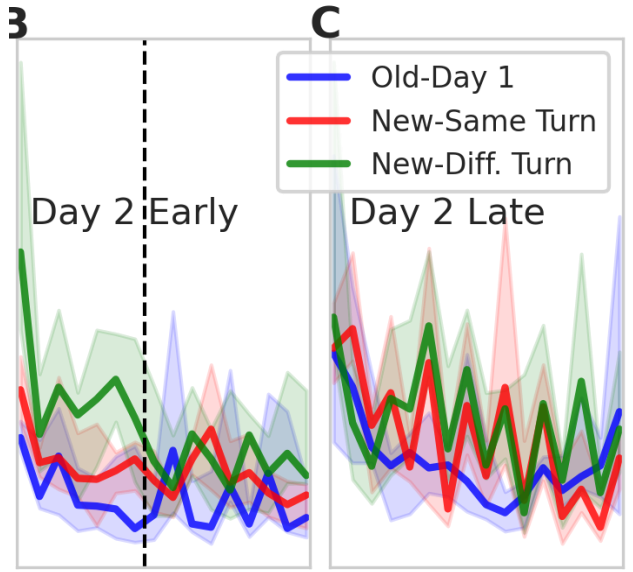

| | A | B | C |
|---|---|---|---|
| Turn seq. | LRLRRRLLL | Same as A | LRRRLLRLL |

Mask Designs:

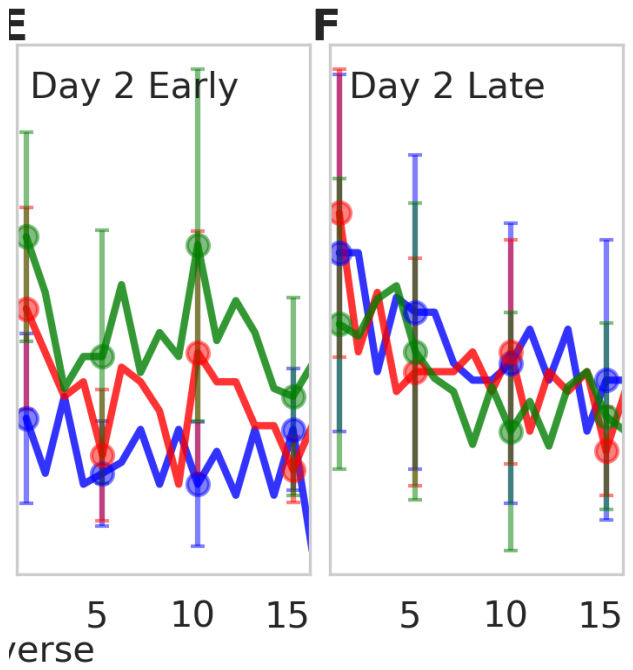
- The 9-hole mask features a sequence of 9 turns (from Home to Out)
- We did a numerical search of the space to select two different new masks

**Learning was not facilitated by the same-turn sequence**

Duration:
Mask C > Mask B for the first 6 traverses

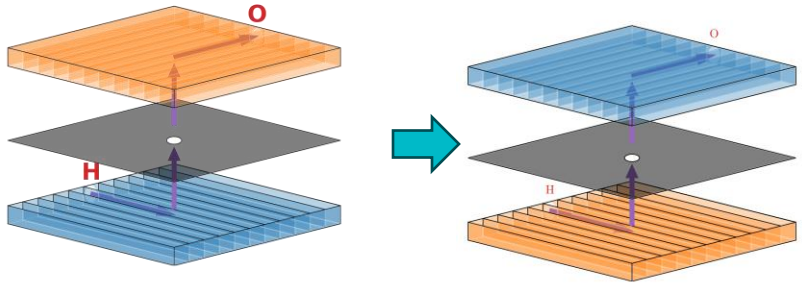



Turn errors:
Not significant for individual traverses

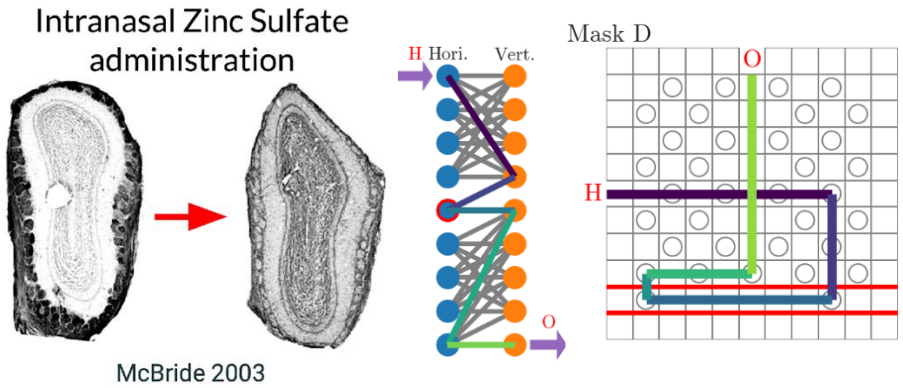


# Role of olfaction in homing

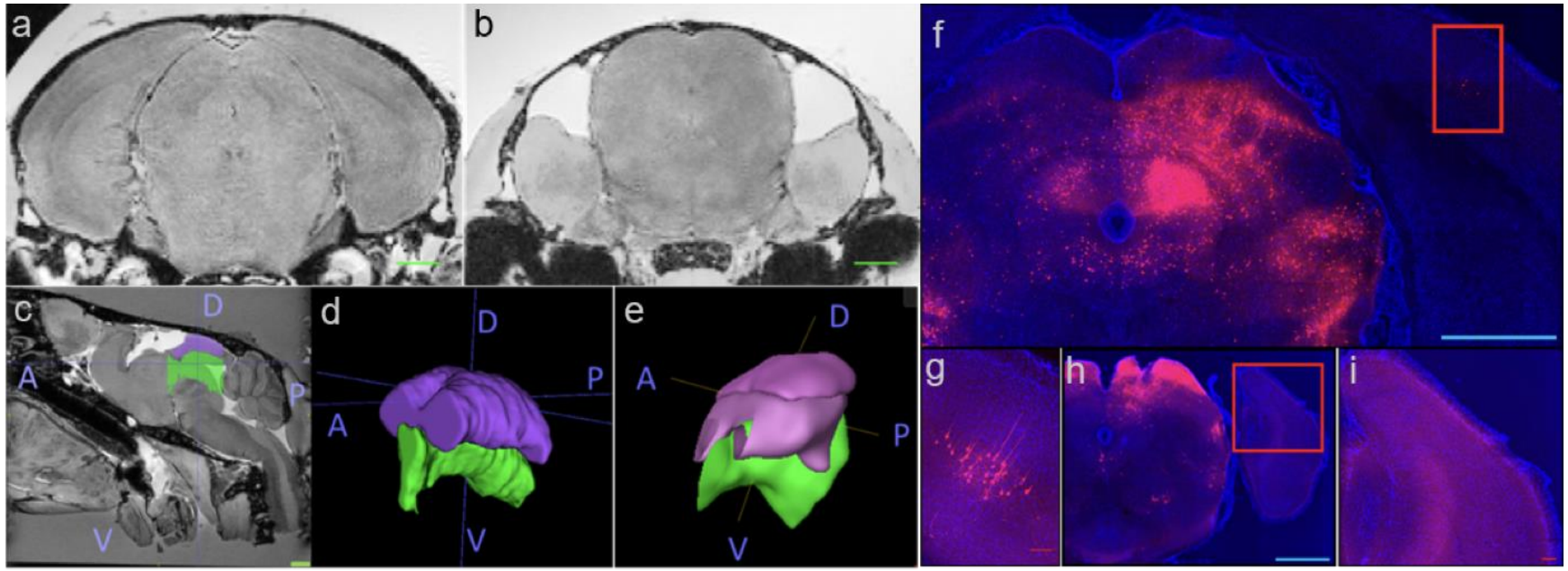
Experiment 1: swap the trays
(disturb external cues)




Experiment 2: Olfactory ablation



# The acortical brain




Turan 2021, MRI scan of the brains

- Dorsal cortex all gone: No neocortex or hippocampus, no primary visual cortex
- Has piriform cortex (“ancient”, two layers)
- Has vision through superior colliculus
- Projections from superior colliculus and periaqueductal grey to visual cortex were not found.

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## The Unbearable Slowness of Being

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California Institute of Technology
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@JieyuZheng3 @mameister4

## 1 Abstract

This article is about the neural conundrum behind the slowness of human behavior. The information throughput of a human being is about 10 bits/s. In comparison, our sensory systems gather data at an enormous rate, no less than 1 gigabits/s. The stark contrast between these numbers remains unexplained. Resolving this paradox should teach us something fundamental about brain function: What neural substrate sets this low speed limit on the pace of our existence? Why does the brain need billions of neurons to deal with 10 bits/s? Why can we only think about one thing at a time? We consider plausible explanations for the conundrum and propose new research directions to address the paradox between fast neurons and slow behavior.