Neurorobotics

Module 2: Neurorobot Design Principles

Lecture 3: Design Principle 2 – Adaptive Behaviour

Learning and Memory

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Prologue

Adaptation involves

- Learning
- Remembering what was learned so it can be applied in the future
- Motivation to drive the learning
    - Often referred to as value systems
- The ability to predict or anticipate future events
    - By generating a memory of expectations
- The ability to adjust when expectations do not match what actually happens

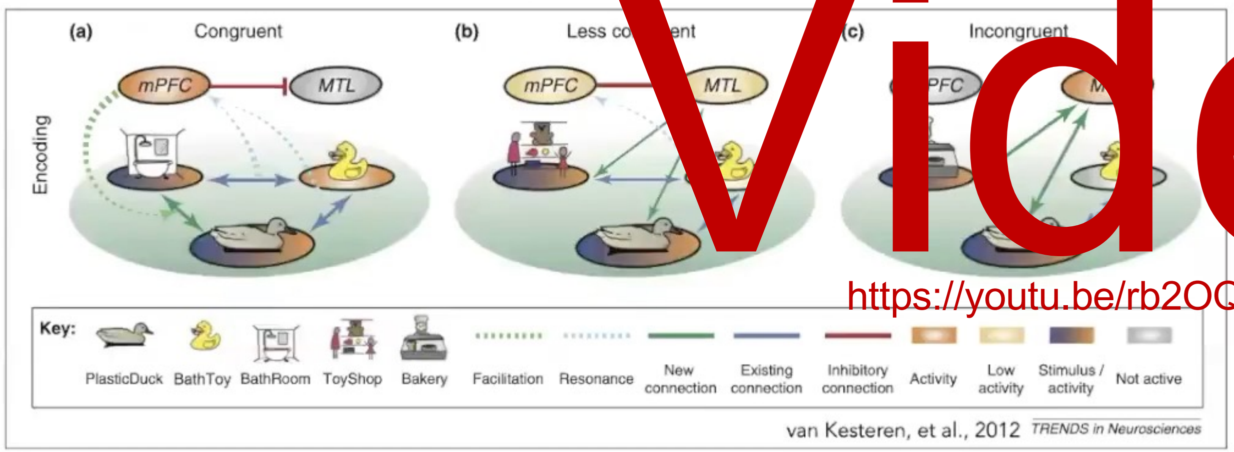
TransAIR Workshop on Cognitive Architectures for Robot Agents

https://transair-bridge.org/workshop-2021/

Neurorobotic Design Principles II
- Adaptive Behavior, a Change for the Better

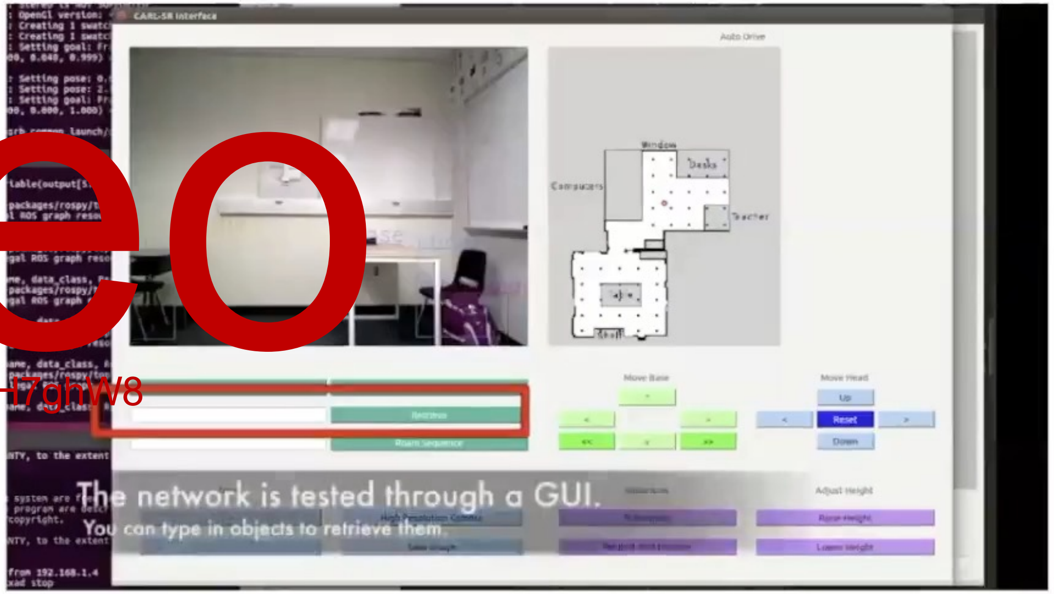
- Learning and Memory

SLIMM – Schema Linked Interactions between medial prefrontal and medial temporal regions



Video

https://youtu.be/rb2OQH7ghW8



- Hwu, T. and J. L. Krichmar (2020). "A neural model of schemas and memory encoding." Biological Cybernetics **114**(2): 169-186.
- Hwu, T., Kashyap, H.J. and Krichmar, J.L. (2020). A Neurobiological Schema Model for Contextual Awareness in Robotics. IJCNN).

Learning and Memory

Humans can learn quickly, incrementally, and continuously

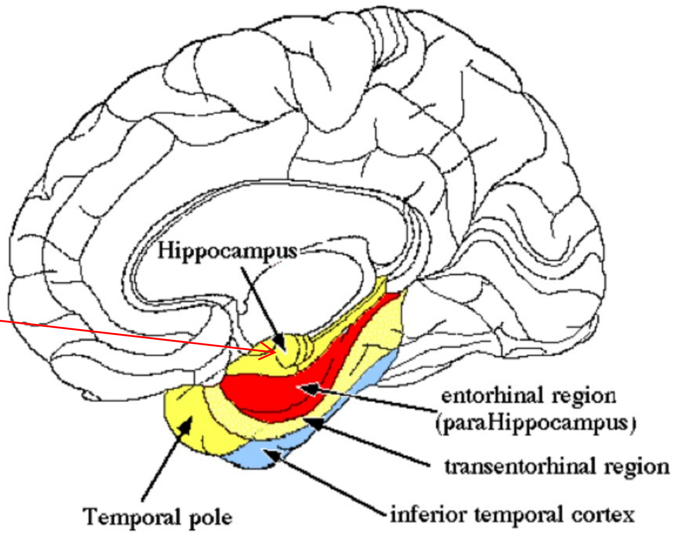
- Few-shot learning
- Without forgetting
- With the ability to redeploy what is learned in difference circumstances

Artificial systems

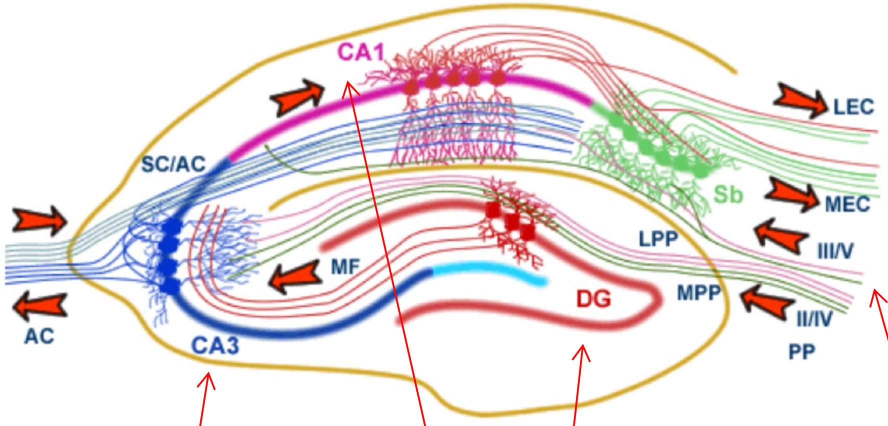
- Find this difficult
- Suffer from catastrophic forgetting
    - when something that is newly learned causes something previously learned to be forgotten
- Have difficulty generalizing from one task to another

Memory Consolidation and Spatial Memory

The hippocampus (aka the hippocampal formation) is important for learning



The hippocampus is important for episodic and semantic memory



Cortical information enters the hippocampus through the lateral and medial entorhinal cortex (LEC and MEC).
The LEC and MEC mainly project to the Dentate Gyrus (DG),
then projects to the CA3 subfield, then to the CA1 subfield, and back to the cortex via the entorhinal cortex

Memory Consolidation and Spatial Memory

- The hippocampus can rapidly learn episodic and semantic information

Autobiographical

  - One-shot learning

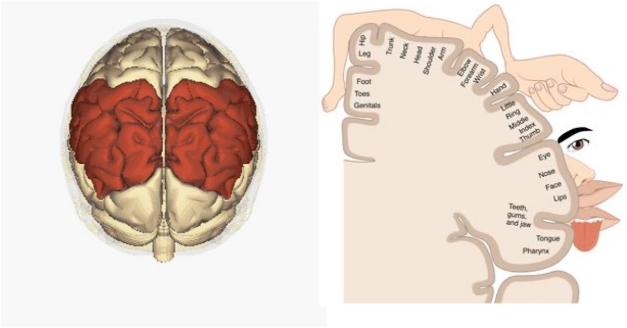
- This information is consolidated "in the rest of the brain" (i.e. the cortex)
  - Complementary learning systems (cf. McClelland)
  - Hippocampal indexing (cf. Teyler and Di Scenna)

Memory Consolidation and Spatial Memory

- The hippocampus has strong bi-directional connections with
  - The ventral stream
  - The dorsal stream
  - The inferotemporal cortex (IT)
  - The parietal cortex (Pr)
  - The vestibular system via the Anterior Thalamic Nucleus (ANT)
- Builds a memory of places and goals

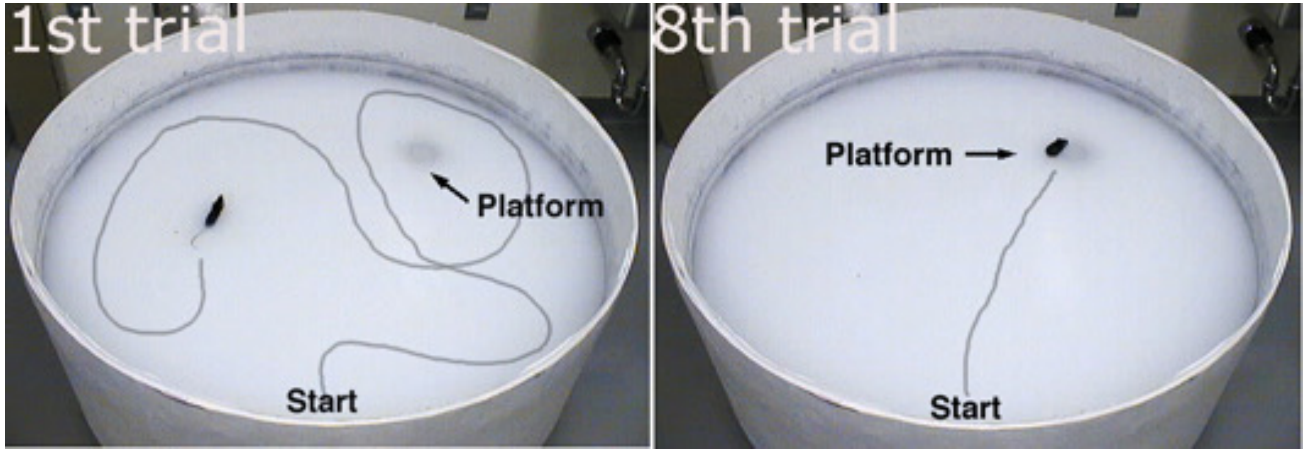
The parietal lobes integrate somatosensory information

Produces information about self-motion and, hence, heading or head direction



https://www.physio-pedia.com/Parietal_Lobe

Recall NR02-01: Sensory-Motor Integration



(https://brainstuff.org/blog/morris-water-maze-learning-memory)

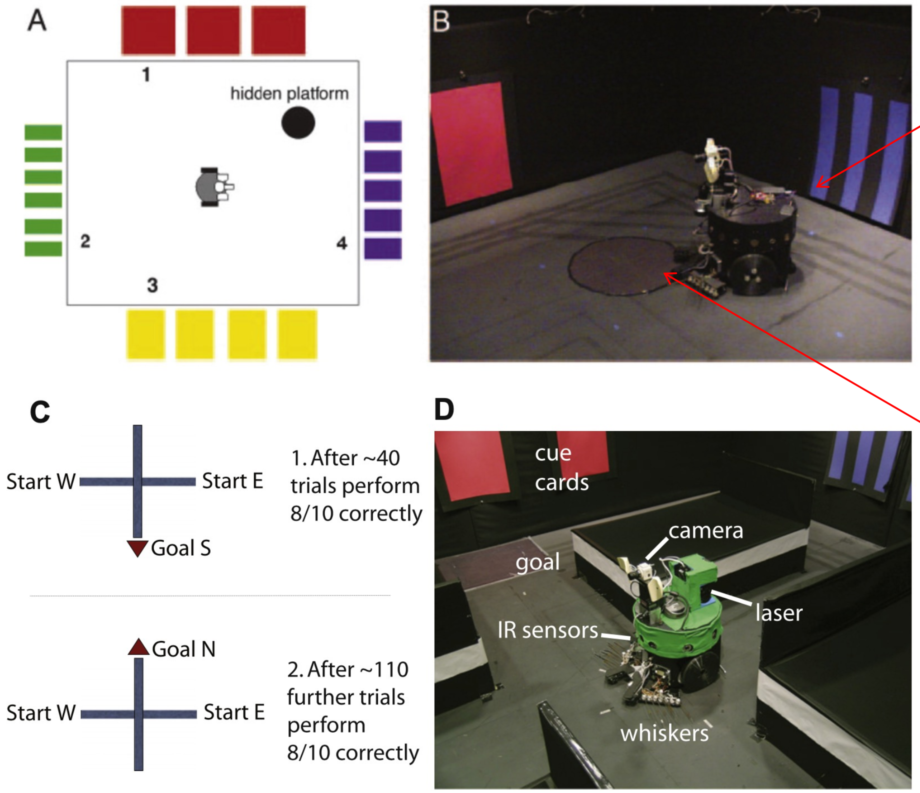
The rat creates a map of the water maze in its hippocampus

See https://www.nobelprize.org/prizes/medicine/2014/advanced-information/ for the scientific background to the award of the Nobel Prize in Physiology or Medicine to J. O'Keefe and M-.B. Moser, and E. Moser for their work on the brain's navigational place and grid cell systems in the hippocampus and entorhinal cortex

Recall NR02-01: Sensory-Motor Integration

- Darwin X has a model of the
  hippocampus
  and surrounding cortical areas

- As Darwin X explores the maze, hippocampal place cells emerge
  - A place cell is active in a specific location

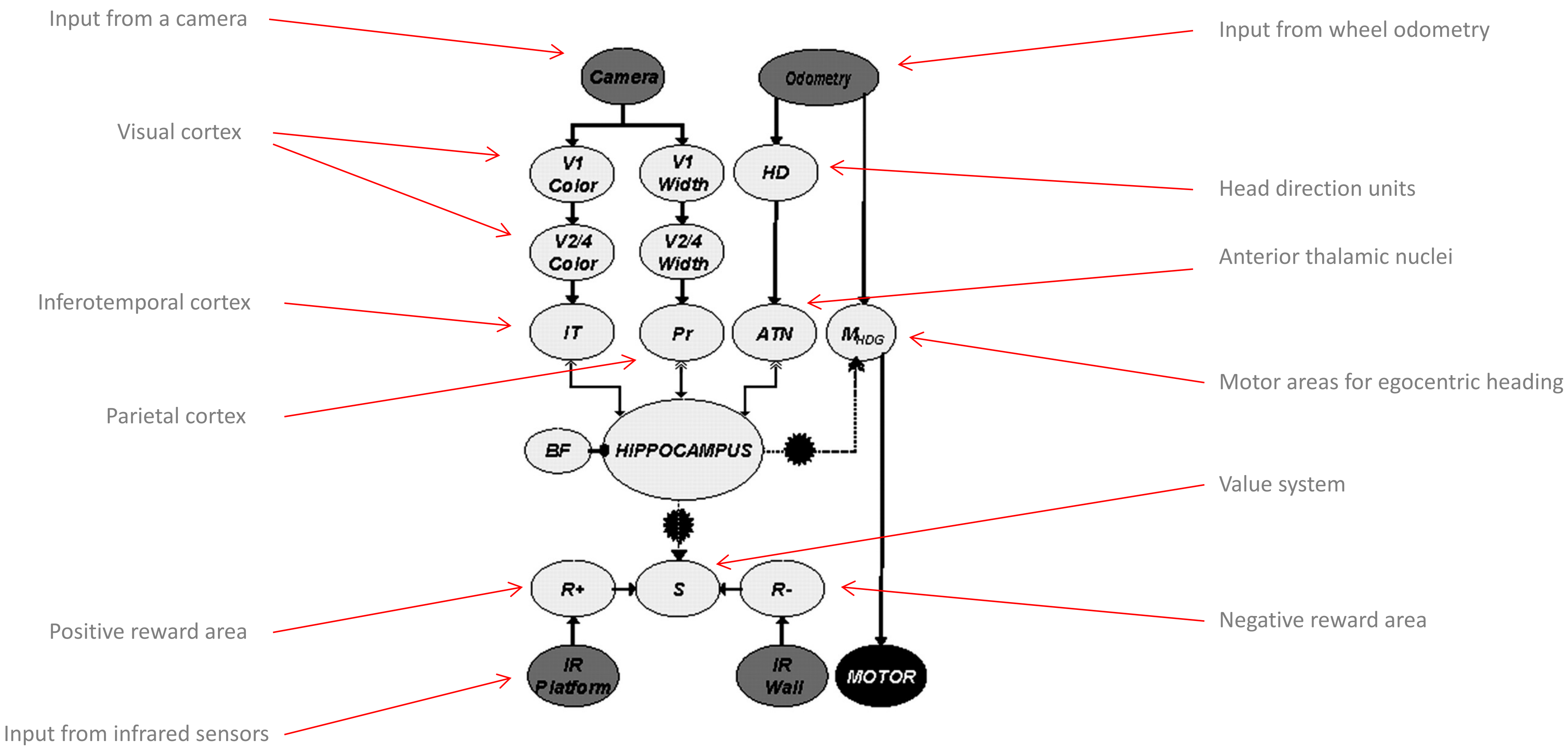


Darwin X in a dry version of the Morris water maze

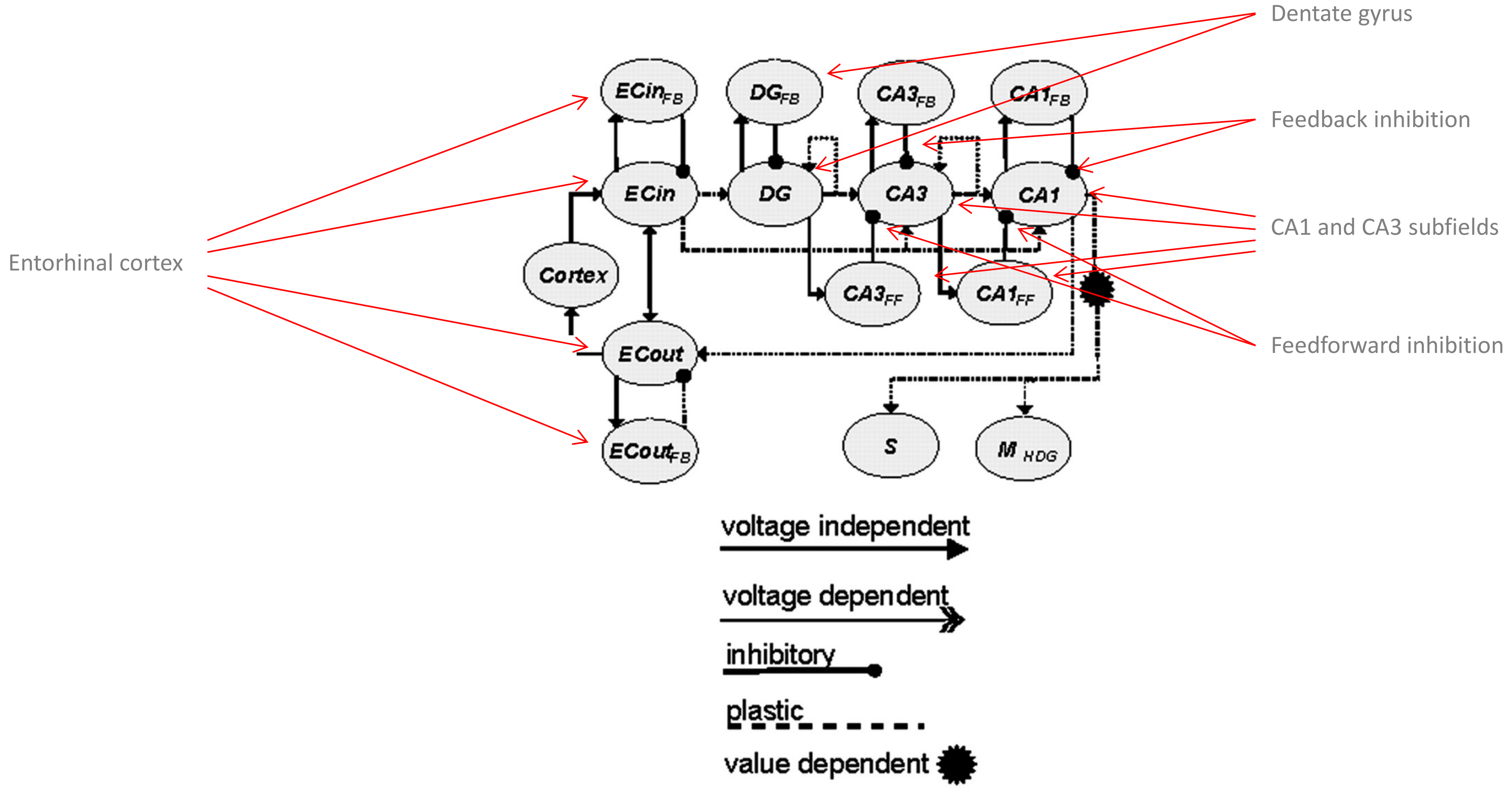
Reflective paper is a proxy for the platform:

invisible to the camera but is detected by light sensor when Darwin is on the platform

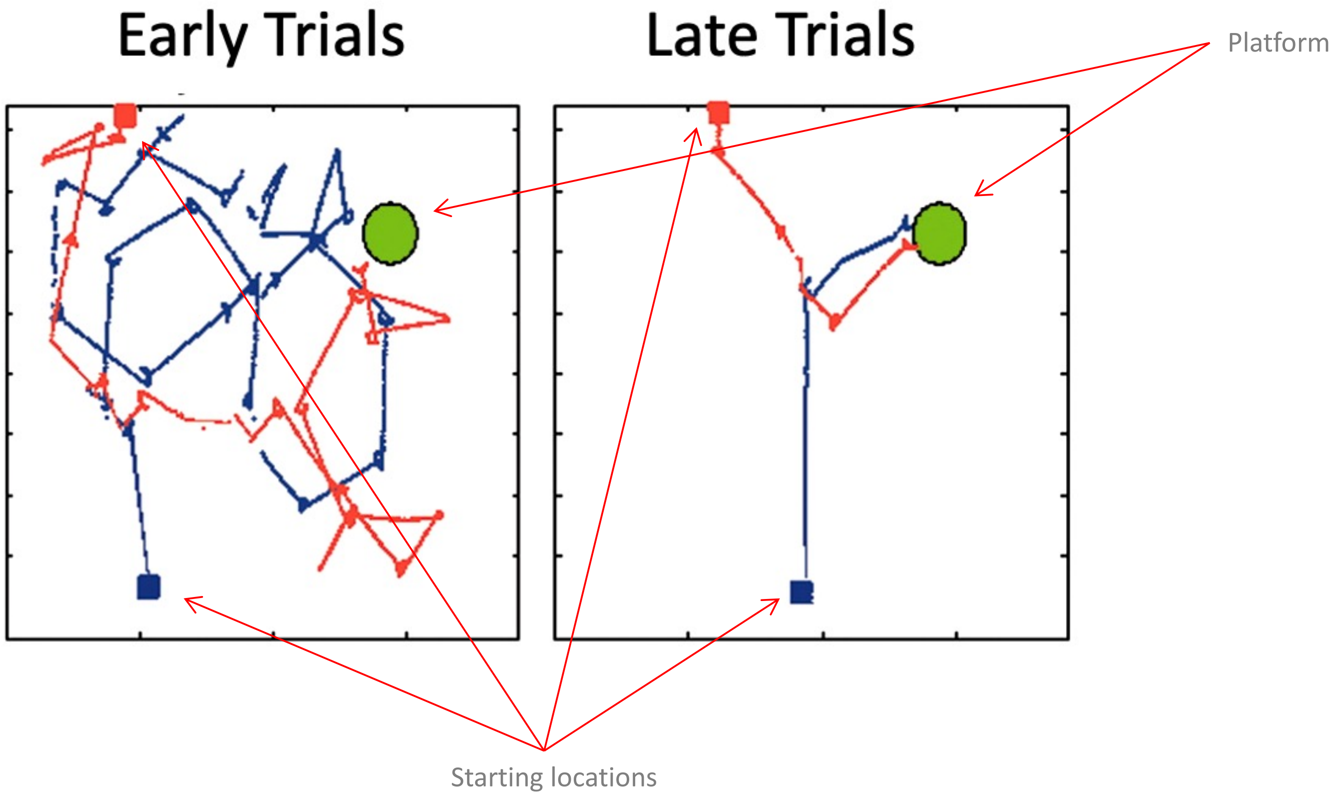
Darwin X: Cortical-Hippocampal Connectivity



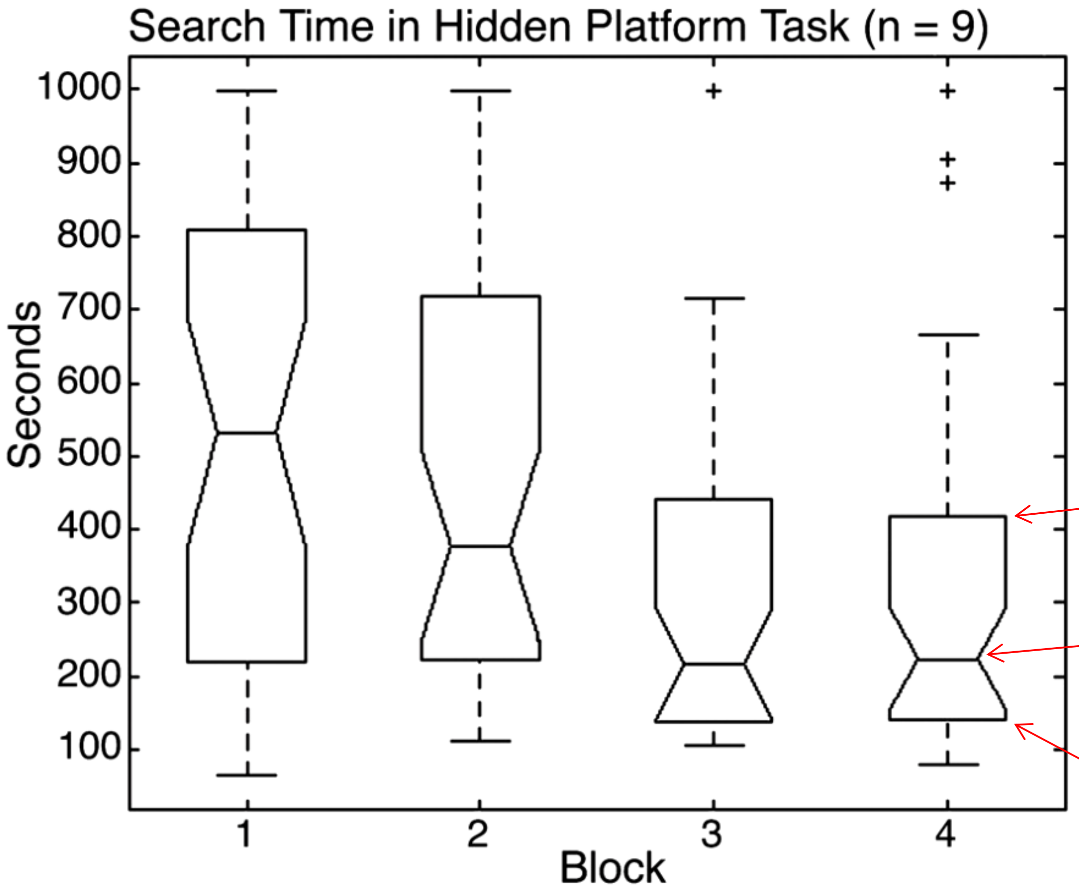
Darwin X: Connectivity withing the Hippocampal Region



Darwin X: Trajectories



Darwin X: Search Times



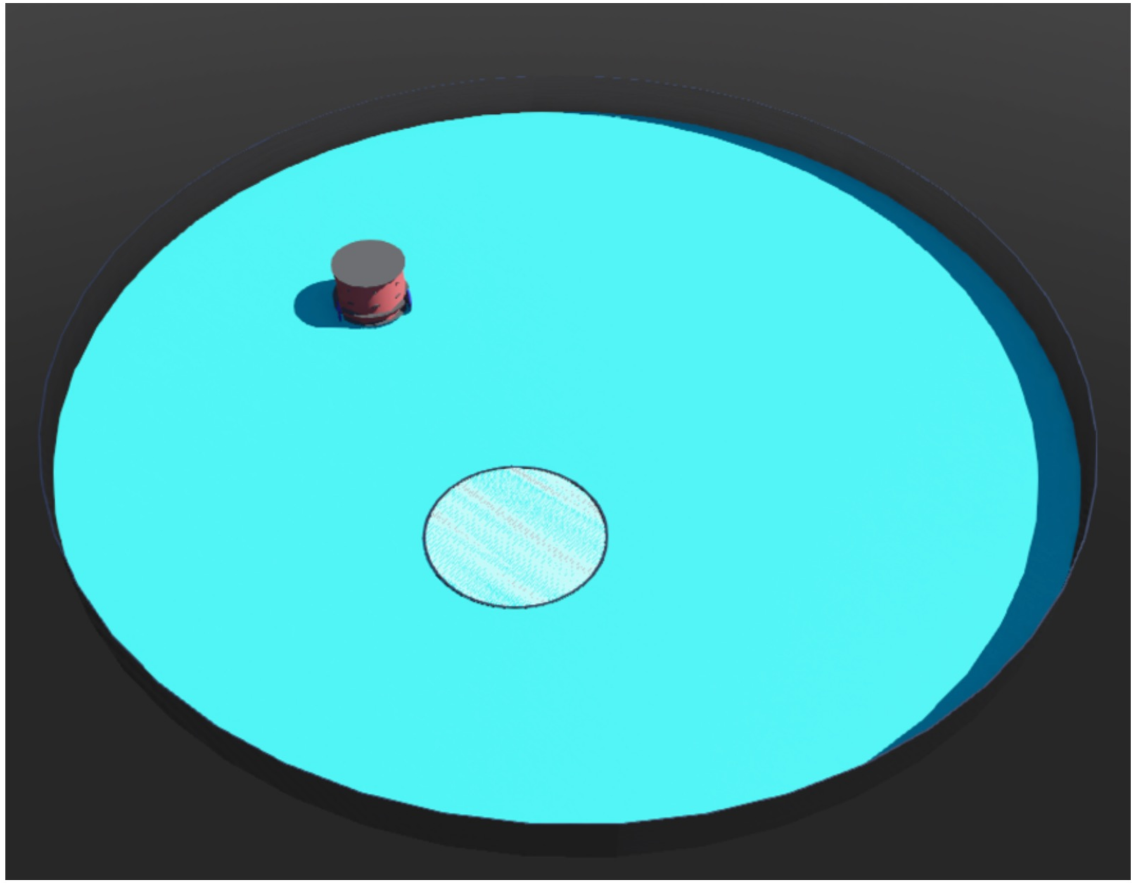
Each Darwin X robot ran 16 trials in blocks of 4 trials, each with a different starting location

75th percentile

Median search time

25th percentile

Webots Simulation of the Morris Water Maze



Model-free reinforcement learning:

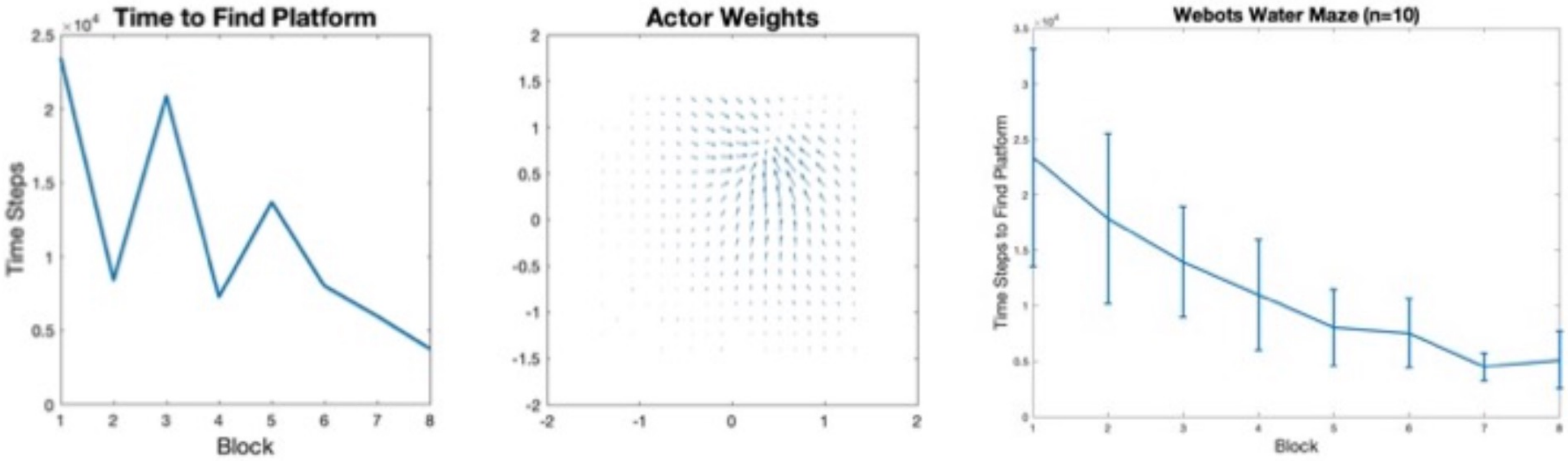
Actor-critic model using temporal difference learning

The states are a population of place cells

The actions are movements in one of eight compass headings

Details in (Foster et al., 2000)

Learning and Memory



Context and Schemas

Schema

- Memory of a set of items or actions bound together by a common context
- Helpful when generalizing: redeployment in novel (but similar) circumstances
- Requires representations that are
  - Flexible enough to learn task in new contexts
  - Stable enough to retrieve and maintain tasks in the old context
  - This is the stability-plasticity dilemma

Addressed by Adaptive Resonance Theory (ART) developed over many years by Steven Grossberg

Context and Schemas

Schema

- Rapid consolidation of information occurs when it fits with a schema

- The hippocampus is necessary
  - For learning schemas
  - For learning new information matching a schema

- Studies show increased plasticity in the medial prefrontal cortex (mPFC) when information is consistent with a familiar schema
  - However, the hippocampus was not necessary to recall these memories
  - This challenges the complementary learning systems hypothesis

Context and Schemas

Schema

For examples of related examples, see

- (Sigalas et al., 2017): Robot arm learning how to serve breakfast in a manner that suits a user's needs
- (Zender et al., 2008): A robot that learns an internal representation of a indoor environment
- (Kostavelis and Gasteratos, 2017): Simultaneous Localization and Mapping (SLAM) with additional semantic information while navigating an office space.

Reading

Hwu, T. and Krichmar, J. (2022). Neurorobotics: Connecting the Brain, Body and Environment, MIT Press.

Chapter 6, Sections 6.1 - 6.2, pp. 105 - 111

More Reading

Hwu, T. and Krichmar, J. (2022). Neurorobotics: Connecting the Brain, Body and Environment, MIT Press.

Chapter 6, Sections 6.1 - 6.2, pp. 105 - 111

ll System

John O'Keefe

May-Britt Moser and
Edvard I. Moser