Memory Acquisition and Retrieval in the Insect Brain

Exploring reinforcement learning algorithms by looking into the insects' head

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Motivation

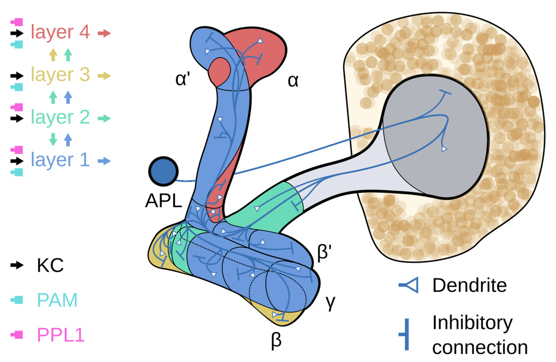


Figure 1: DAN-MBON network [1]

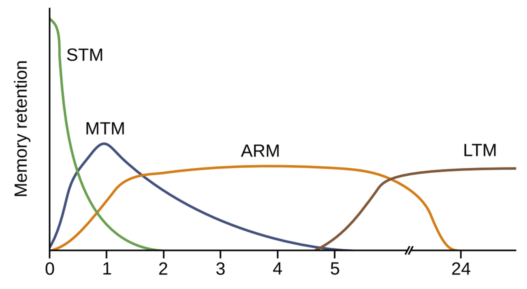


Figure 2: Memory types [2]

We use inspiration from the *insect brain* in order to discover novel *reinforcement learning* (RL) techniques.

Standard RL is difficult to use in online robot training due to its exploration phase. For safety, robots are usually trained in simulation, but this can limit their ability to adapt to real world dynamic environments.

RL models that can directly learn from their environment, as animals do, might provide a valid solution to the problem. Insect brains are small and easy to access, providing a good basis to study their learning mechanisms.

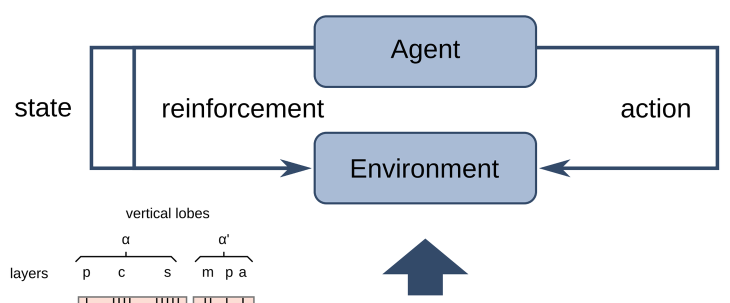
Goal: To build a detailed model of the insect learning circuit to capture its function.

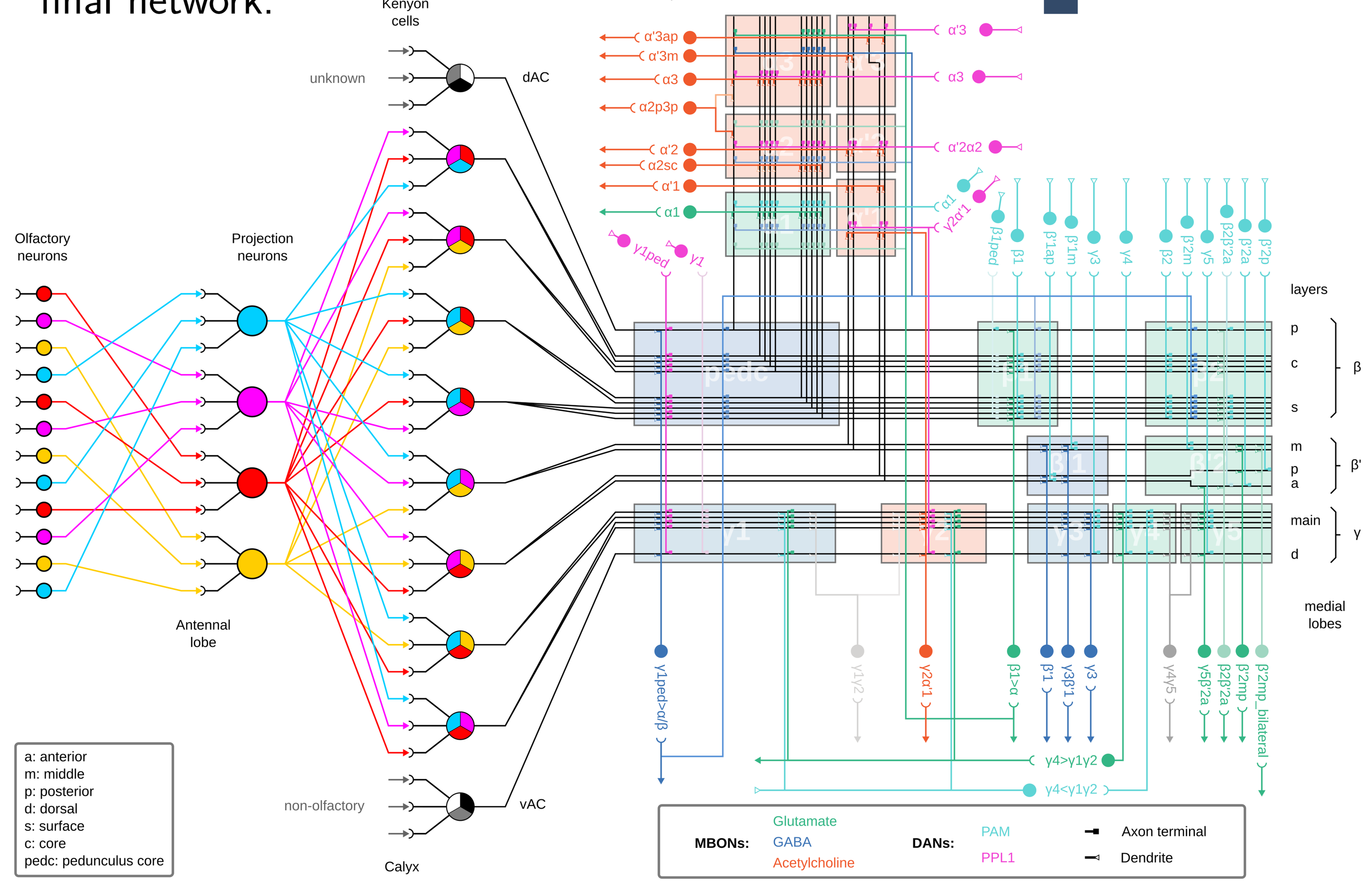
Modelling "bottom-up"

Detailed modelling of the MB **structure** (from published data [1]) – model each neuron separately.

Recurrently *build up* to larger networks of neurons.

Extract RL algorithm from the final network.

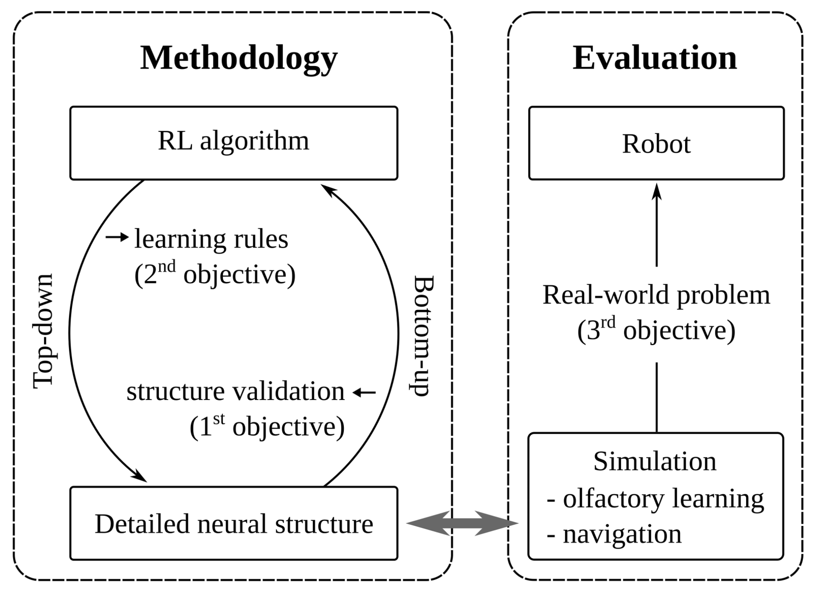




Function of the mushroom bodies (MBs)

MBs support learning in the insect mid-brain [2]. Sensory input is projected onto the **calyxes**, from where the numerous **Kenyon cells (KCs)** distribute it to the much fewer **output neurons (MBONs)**. **Dopaminergic neurons (DANs)** deliver *multi-dimensional* reinforcement signals and modulate the KC-to-MBON connections. MBON-to-DAN connections eventuate in multiple memory types.

Methodology

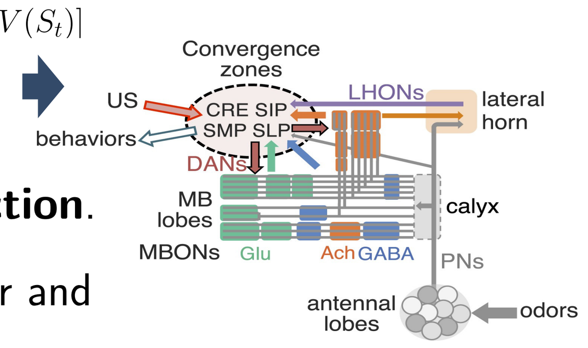


Modelling the MBs "top-down" and "bottom-up" simultaneously.
Bottom-up: extract models from the detailed MBs' *structure*.
Top-down: transform existing *RL rules* into MB machines.

Evaluate the models by their ability to enable a robot to *adapt online* in a dynamic environment.

Modelling "top-down"

TD learning: $V(S_t) \leftarrow V(S_t) + \alpha[R_{t+1} + \gamma V(S_{t+1}) - V(S_t)]$
Monte Carlo: $V(S_t) \leftarrow V(S_t) + \alpha[G_t - V(S_t)]$
DP: $V(s) \leftarrow \sum_{s',r} p(s', r|s, \pi(s))[r + \gamma V(s')]$

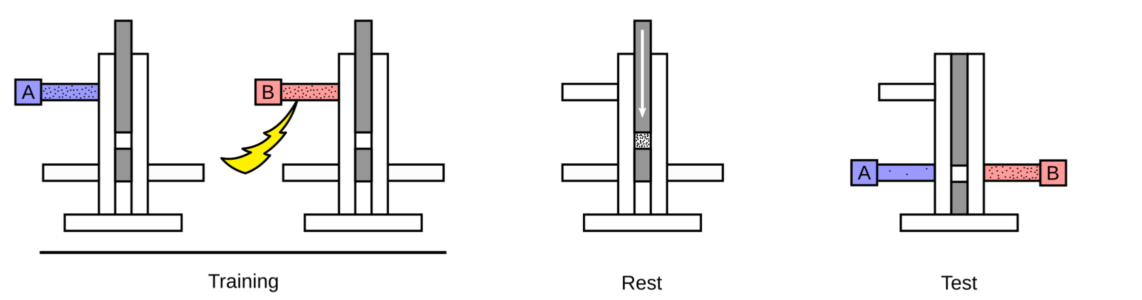


Context dependent modelling of the MB **function**.

Recurrently *break down* the model into smaller and independent components.

Stop when we have one model per neuron – the smallest possible component.

Evaluation – Olfactory learning



5 × A- B+ (training)

2 × A+ B- (reversal)

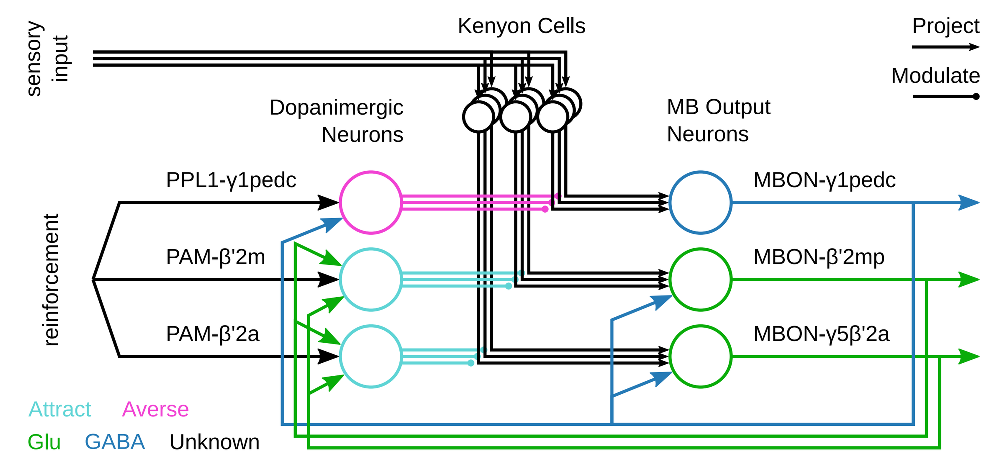
A, B: different odours used as conditional stimuli (CS).
+: shock reinforcement used as unconditional stimulus (US).

Initial 6-neuron model

Includes a representative set of neurons for learning associations between odours and electric shock.

Structure is extracted from the complete description of the MBs in the adult *Drosophila* [1].

We attempt to reconstruct the responses from individual neural recordings, in order to understand their function (bottom-up).

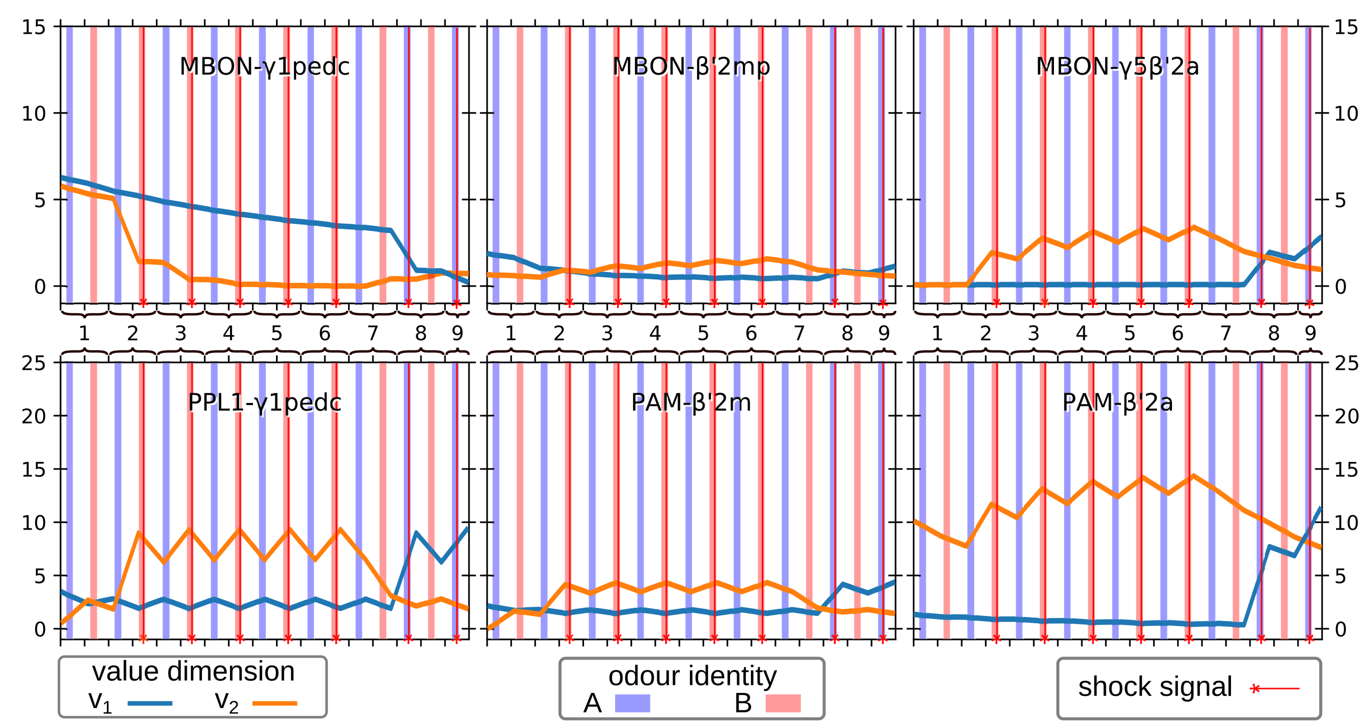


Reconstructed responses

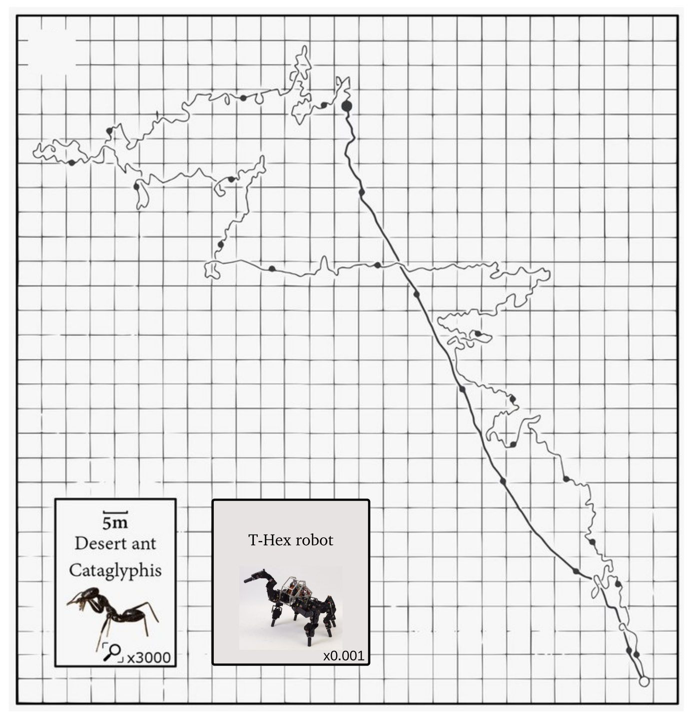
Modelling each neuron separately using the simple Rescorla-Wagner (R-W) model is sufficient to reconstruct the desired responses.

Progressively adding connections and simplifying the neurons' model in order to approach the desired structure of the network.

Analyse the model and understand its function before expanding into larger networks.



Future Work



Finalise the network and test its performance on an equivalent of the olfactory learning task on a robot.

Enable more complicated action selection mechanisms by expanding the network and adding neurons with known responses from the complete description.

Use the same model as a basis for a navigation mechanism (e.g as shown for ants) trying to replicate a more interesting and challenging behaviour.

Build a robot that navigates outdoors and use the model to adapt its behaviour in unknown environments.

References

[1] Y. Aso et al., "The neuronal architecture of the mushroom body provides a logic for associative learning," *eLife*, vol. 3, p. e04577, 2014.

[2] M. Heisenberg, "Mushroom body memoir: From maps to models," *Nature Reviews Neuroscience*, vol. 4, no. 4, pp. 266–275, 2003.

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