Imitating Drosophila Larval Learning Behaviour on a Robot

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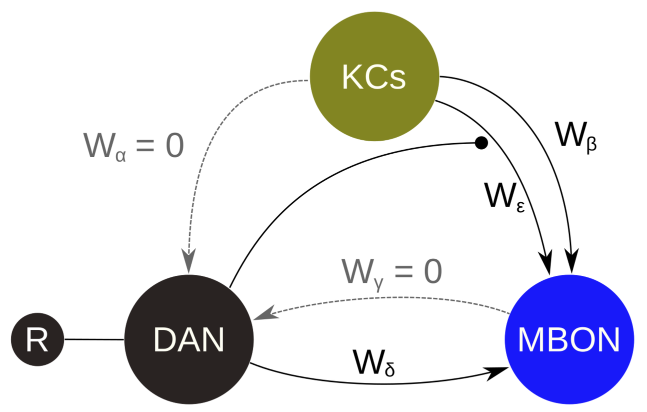
Olfactory Learning

Drosophila larva can learn to associate an odour with a reward which is perceived through their gustatory sensors. The animal follows the odour gradient to move towards or away from the source; in the absence of reward this depends on how the reward was paired to odour.

The Mushroom Body Model

We take the MB circuit motif from [1] as the basis of our computational model. Using behavioural data [2] we can define the desired output (M) for a given odour (KC) and reward (R) modulation. Solving the equations based on the network topology in turn determines the required change in connection weights.



$$D^{(t)} = R^{(t)} + \cancelto{0}{KC^{(t)} w_\alpha} + \cancelto{0}{M^{(t-1)} w_\gamma}$$

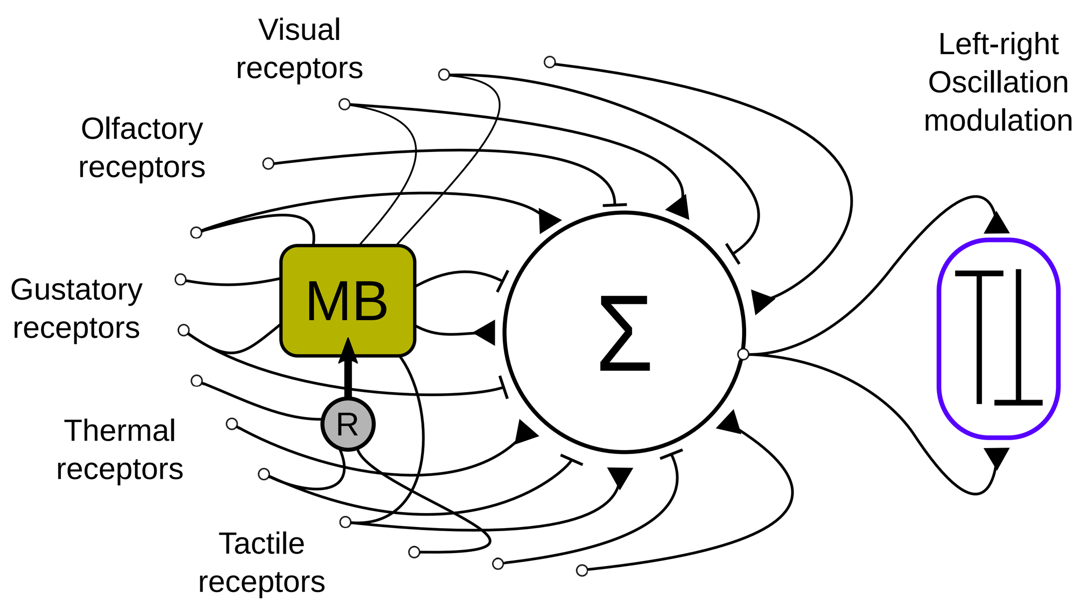
$$M^{(t)} = KC^{(t)}(w_\beta + D^{(t)} w_\epsilon) + D^{(t)} w_\delta$$

Naive (N)			Paired (P)			Unpaired (U)		
R	KC	M	R	KC	M	R	KC	M
1	1	1	1	1	1	1	1	1
0	1	1	0	1	0	0	1	2
1	0	0	1	0	0	1	0	0
0	0	0	0	0	0	0	0	0

Connection Weights			
	W_β	W_δ	W_ϵ
N	1	-1	1
P	0	-1	2
U	2	-1	0

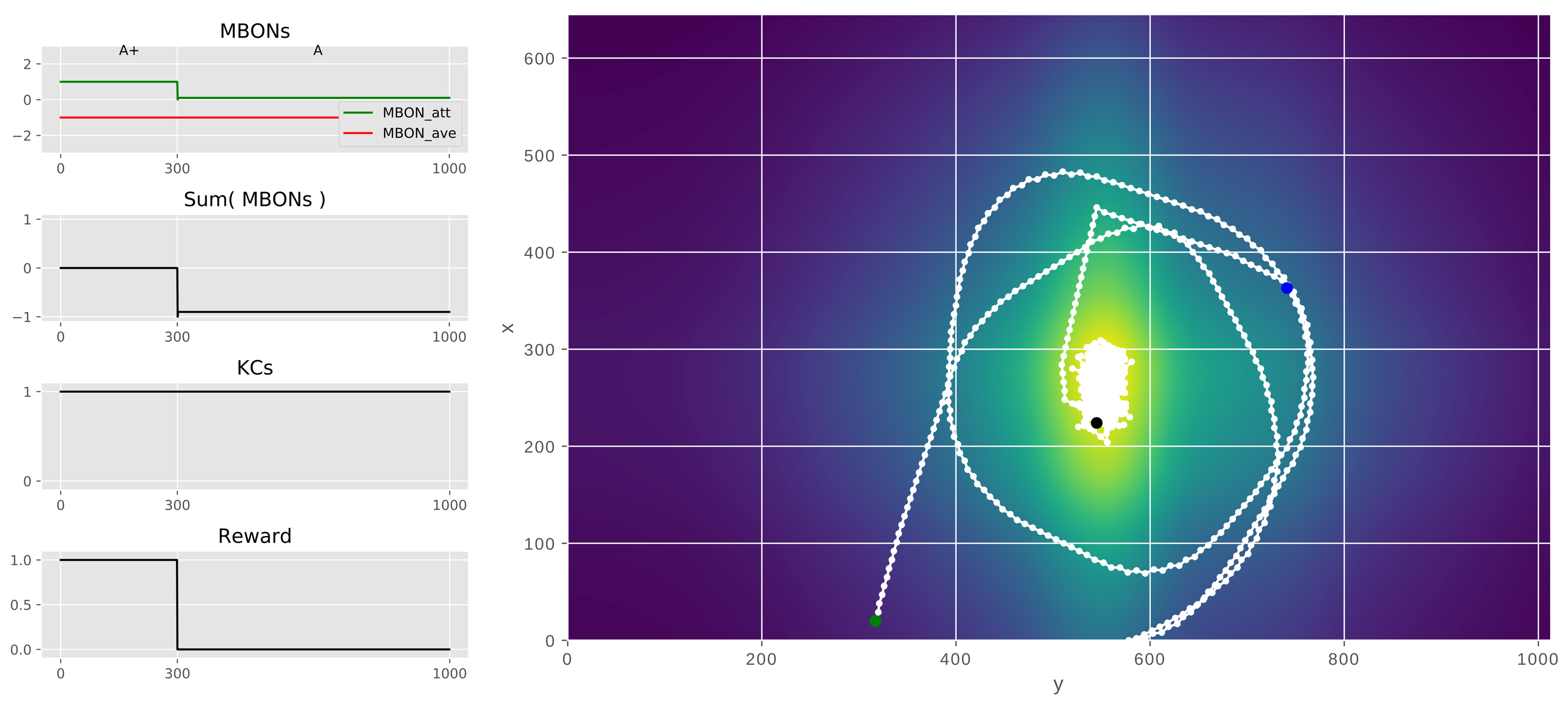
The output (M) modulates the movement model below when $M \neq 1$. For $M < 1$ ($M > 1$) there is increased attraction (aversion).

The Oscillation Model



We model larval gradient following as a continuous left-right oscillation with an amplitude modulated by changes in sensory input [3]. The mushroom body output contributes additively to this modulation.

Attractive Odour – Pairing



Initially, the odour has never been experienced before.

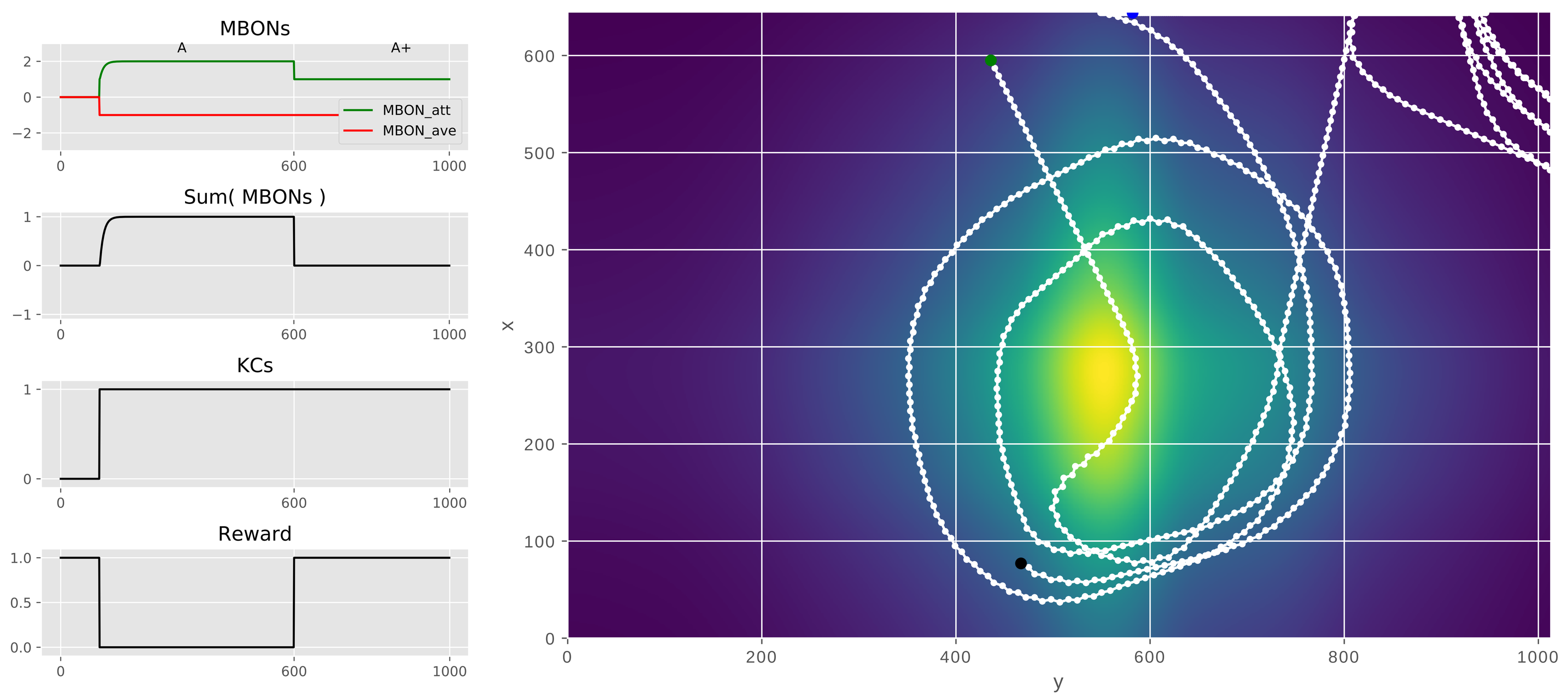
The odour is presented with a reward in the first 300 time-steps.

– The agent learns to associate the odour exposed with the reward. Its behaviour does not change.

The reward is removed in step 301.

– The agent now follows the odour gradient in order to find the reward.

Attractive Odour – Unpairing



Initially, the reward is presented with the absence of any odour.

– The agent performs a random walk on the arena.

An odour is presented without a reward for the first 600 time-steps

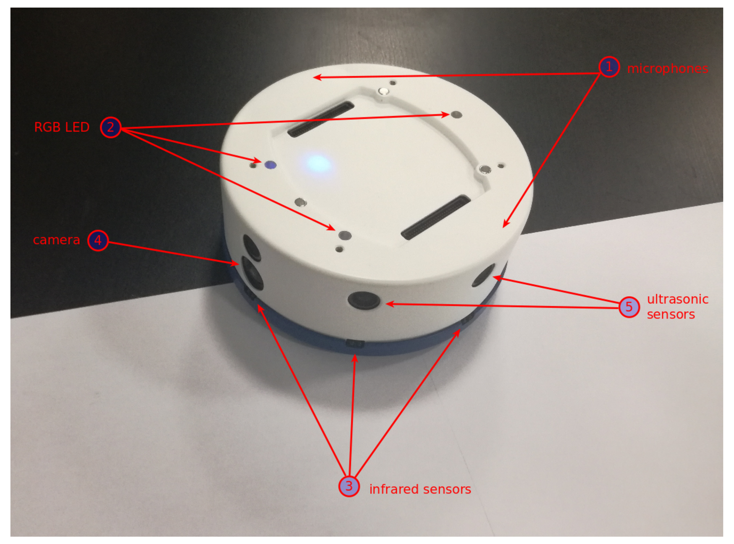
– The agent now learns that the odour does not give a reward. It turns away to explore other areas.

A reward added in step 601.

– The agent performs the innate behaviour.

Robot platform

We set up a robot platform, able to test alternative models using real sensors and actuators. Qualitatively, the results obtained were similar to the ones using the simulation.



A range of sensors can be used to represent the conditioned and unconditioned stimulus inputs

Camera: analogue of the olfactory sensing of the larva; e.g. colour can represent odour identity, and light level the odour intensity

Ground infrared sensors: analogue of the gustatory sensing of the larva; e.g. bright floor can represent sugar, and a dark floor, quinine

Conclusions

A similar approach was used for aversive odours, but we could not find a set of weights that works for the unpaired case.

Alternative solutions for the attractive case are possible, but require more connections.

Future work: discriminating between odours; incorporating a feedback to KCs neuron

Acknowledgements

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[2] M. Schleyer, T. Saumweber, W. Nahrendorf, B. Fischer, D. von Alpen, D. Pauls, A. Thum, and B. Gerber, "A behavior-based circuit model of how outcome expectations organize learned behavior in larval drosophila," *Learning & Memory*, vol. 18, no. 10, pp. 639–653, 2011.

[3] A. Wystrach, K. Lagogiannis, and B. Webb, "Continuous lateral oscillations as a core mechanism for taxis in drosophila larvae," *Elife*, vol. 5, p. e15504, 2016.