EU HORIZON 2020 PROJECT STEP2DYNA SEMINAR
Bio-inspired Neural System and Models

A Ring Attractor Model for Cues Integration

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Monday, 21 May 2018
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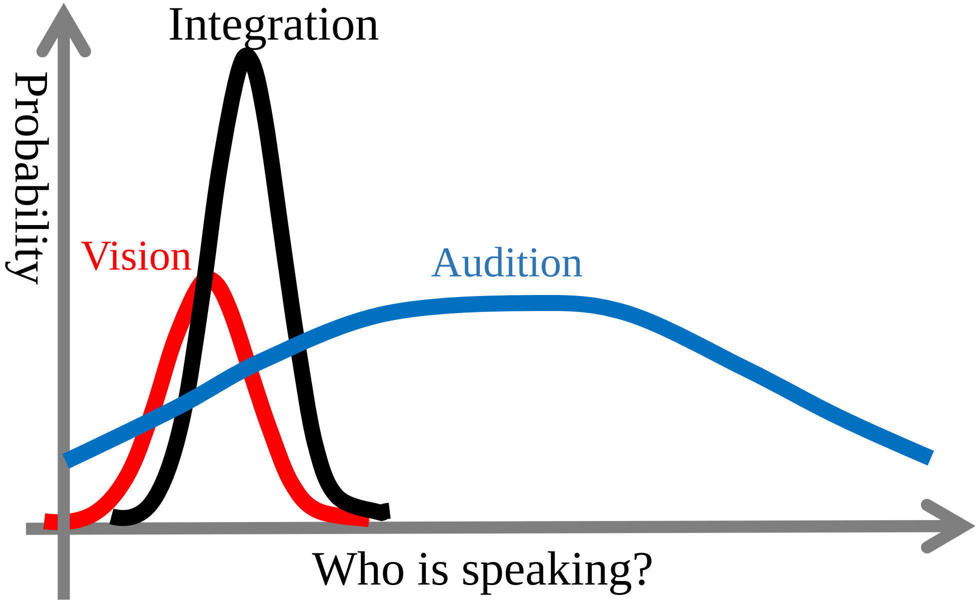
Background & Motivations

A fundamental principle underlying animal intelligence is the capacity to appropriately combine redundant sensory (e.g. **vision, olfactory and haptic**) of the same percept to achieve a **more accurate and robust estimate.**

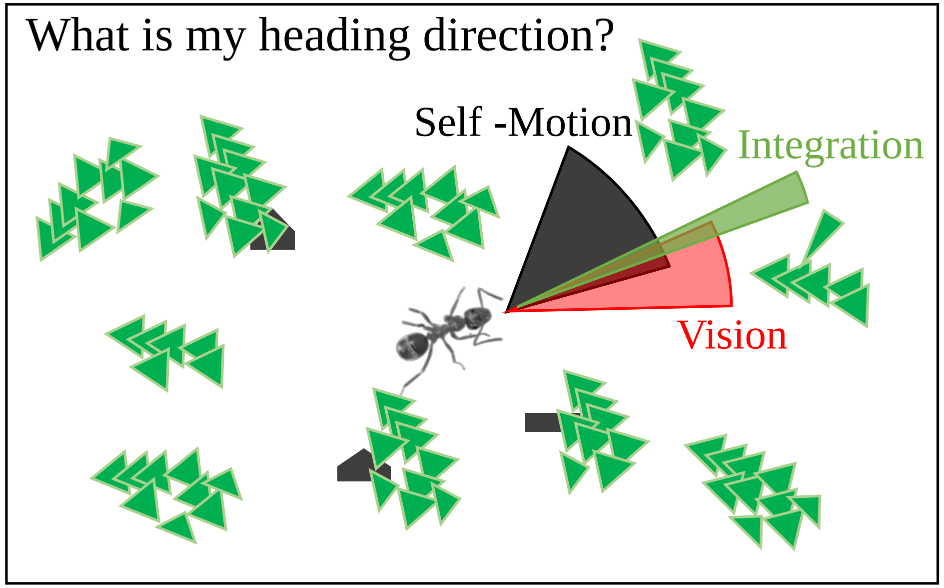
Example 1:

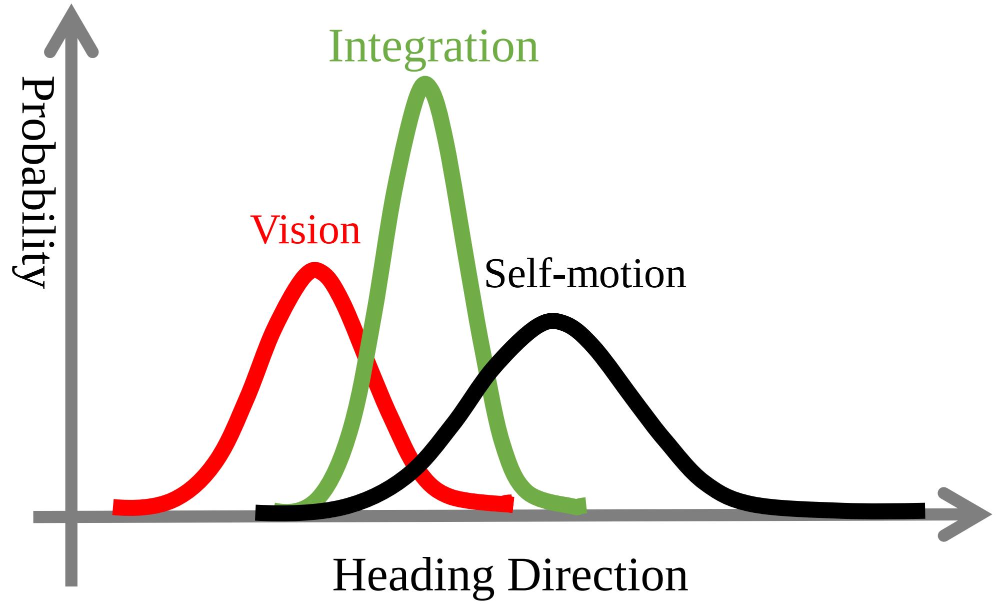
Who is speaking?



Shettleworth, S. J. (2010). Cognition, evolution, and behavior. Oxford University Press.

Example 2:





Bayesian Method: $P(x_{true} \mid x_{cue}) = P(x_{cue} \mid x_{true})\, P(x_{true}) / P(x_{cue})$

Optimal integration!

Maximum Likelihood Estimation: $\hat{X} = \sum_{i}^{n} W_i X_i, W_i = 1/\sigma_i^2 / (\sum_{j}^{n} 1/\sigma_j^2)$

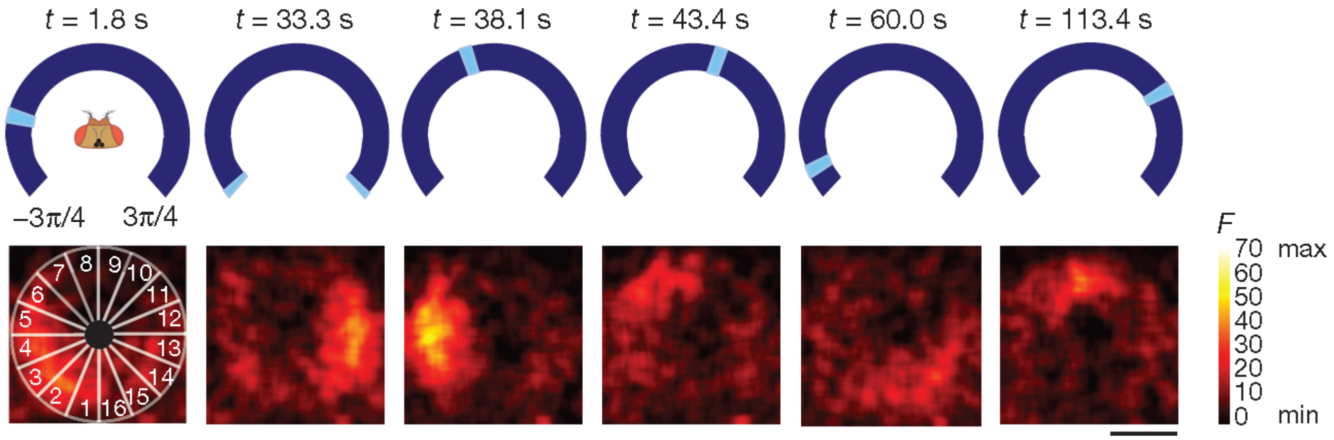
How to do it in a biology plausible way? Shall we get inspiration from animals to robot applications?

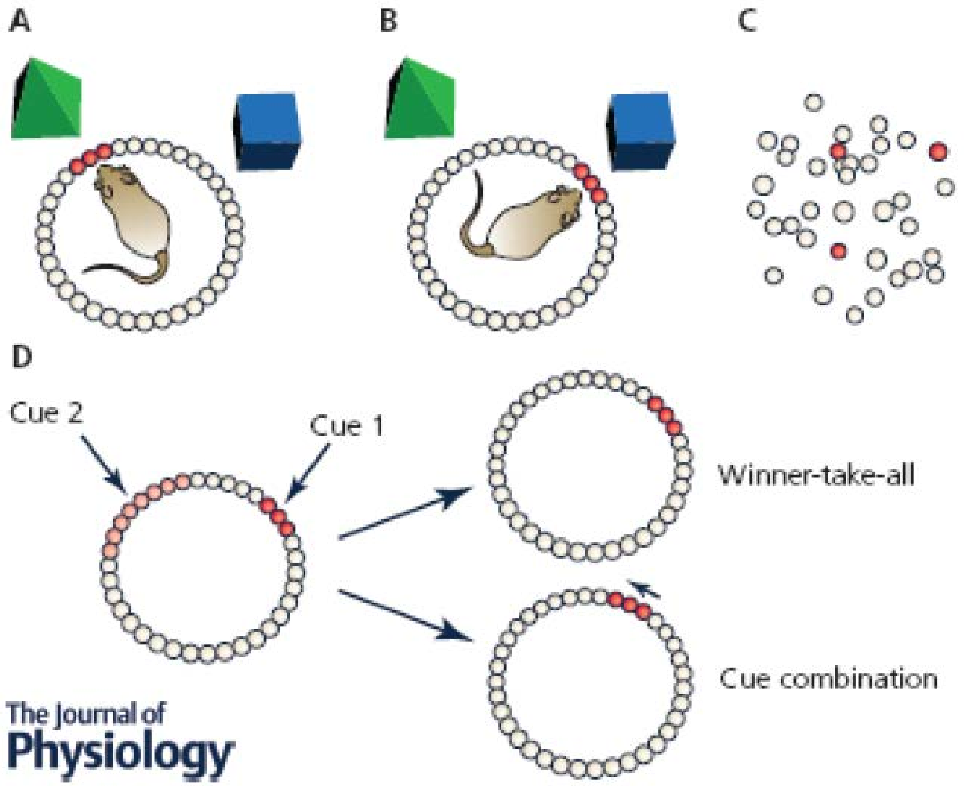
Ernst, M. O., & Knoblich, G. (2006). A Bayesian view on multimodal cue integration. Human body perception from the inside out, 131, 105-131.

Heading Direction System and Ring Attractor

Rodents encode the heading direction using neurons (although not arrange in a ring physically (c))

Insects encode the heading direction using ring neurons



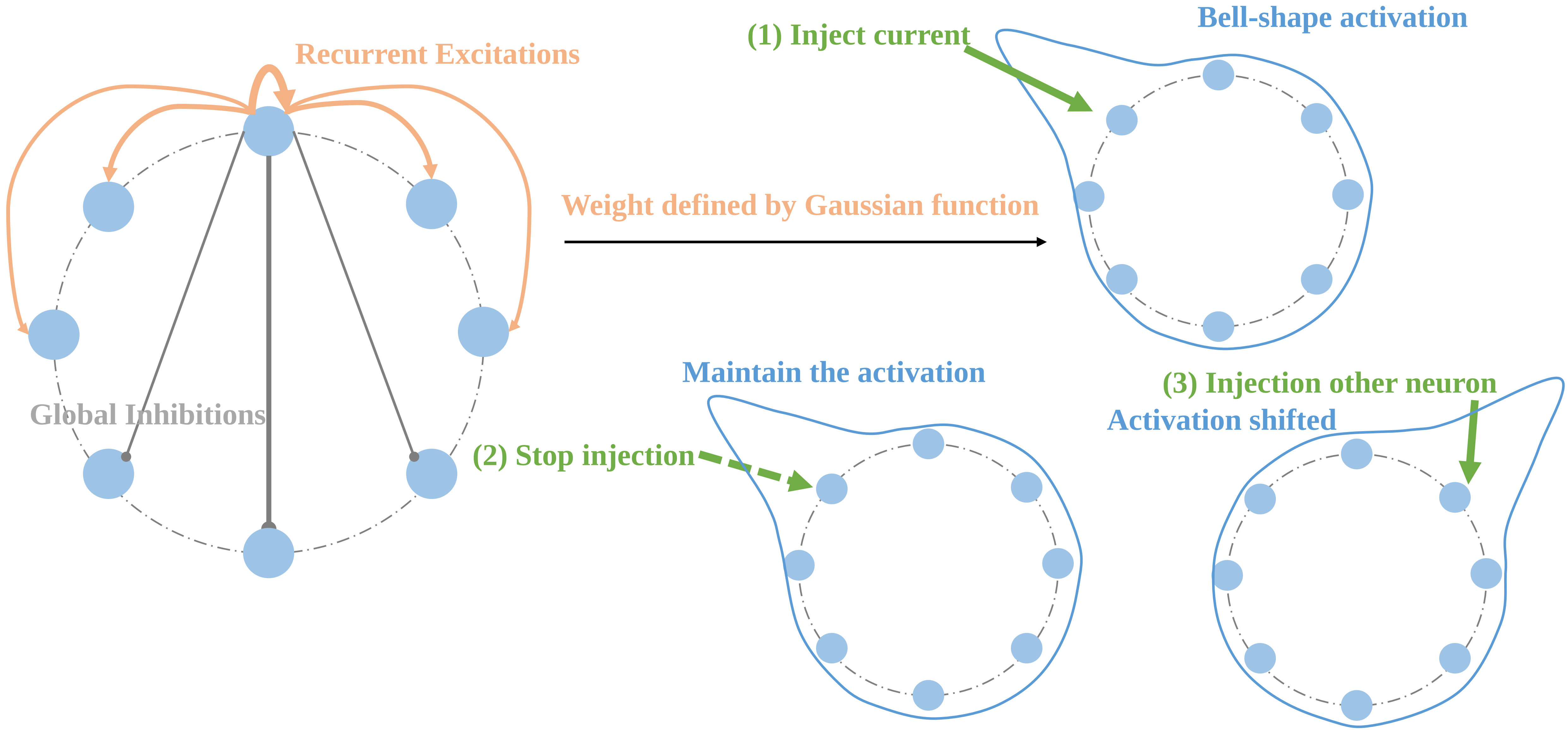


Both have the **ring attractor** properties

Seelig JD, Jayaraman V, *Neural dynamics for landmark orientation and angular path integration*, Nature 521(7551):186–191, 2015.

Jeery, K. J., Page, H. J., Stringer, S. M. (2016). Optimal cue combination and landmark-stability learning in the head direction system. The Journal of physiology, 594(22), 6527-6534

Ring Attractor Network



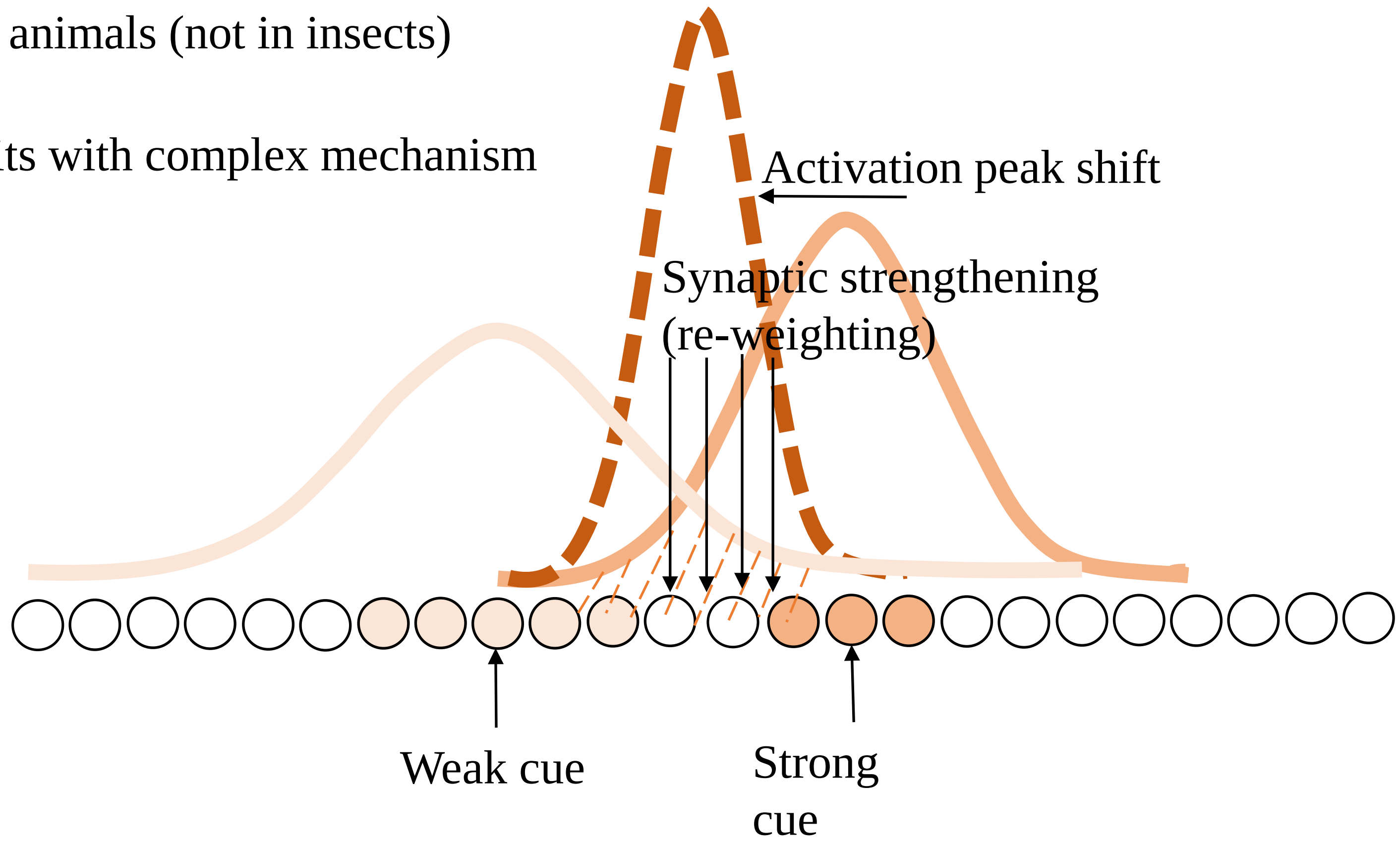
Touretzky, D. S. (2005). Attractor network models of head direction cells. Head direction cells and the neural mechanisms of spatial orientation, 411-432.

Existing Method – Re-weighting mechanism

1. Constrained by the biological evident of rodent animals (not in insects)

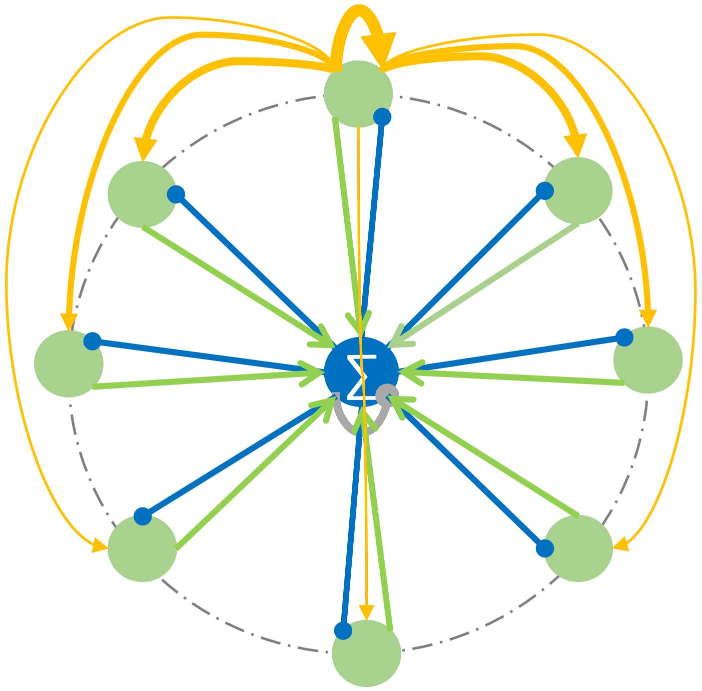
2. Neurons should have learning ability and circuits with complex mechanism

3. Other possibilities in insects?



Jeery, K. J., Page, H. J., Stringer, S. M. (2016). Optimal cue combination and landmark-stability learning in the head direction system. The Journal of physiology, 594(22), 6527-6534

Our Model – Ring attractor without re-weighting



Touretzky ring attractor

- Integration Neurons
- Uniform Inhibition Neurons
- Excitation Connections
- Inhibition Connections

All neurons are CTRNN neurons, so the membrane potential c_i

$$\tau \frac{dc_i}{dt} = -c_i + I_i$$

I_i is the total current injected to the neuron

$$I_i = \sum_{j=1}^{n} W_{ij} O_j + X_i = \sum_{j=1}^{n} W_{ij} g(c_i) X_i$$

$$g(c_i) = \max(0, \theta + c)$$

W is the connection weights, and the recurrent excitation weights is defined by the Gaussian function

$$W_{ji}^{E \to E} = e^{\frac{-d_{ji}^2}{2\sigma^2}}$$

d_{ji} is the difference between the preference of i and j neuron

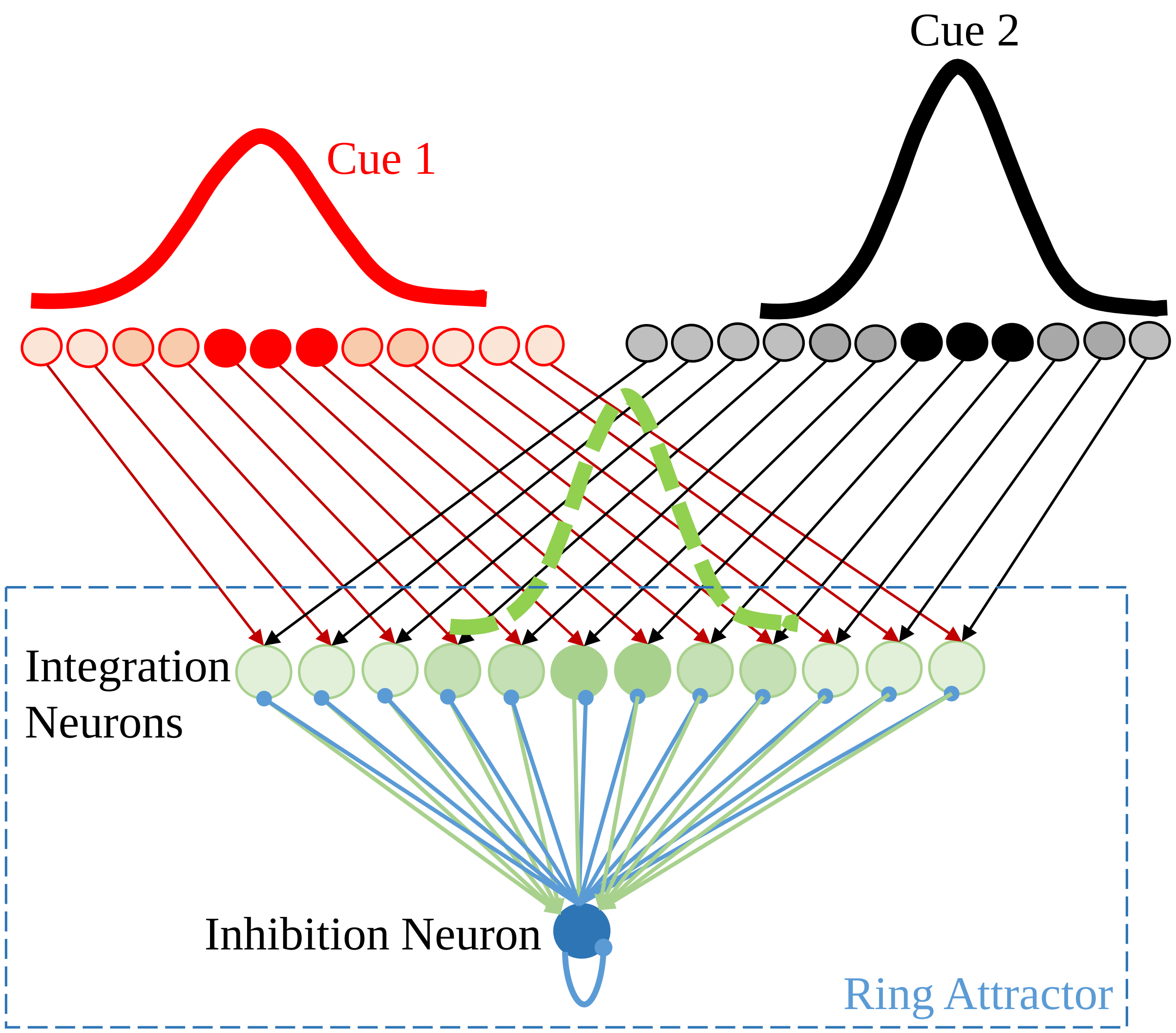
g is the activation function to guarantee the nonlinear property

X_i is the external input

The uniform inhibitory neuron sums all the integration activations and feedback the same inhibition to all the neurons

Touretzky, D. S. (2005). Attractor network models of head direction cells. Head direction cells and the neural mechanisms of spatial orientation, 411-432.

Our Model – Signals Processing



Cues are defined by the Gaussian function as:

$$F(i) = \frac{K}{\sqrt{2\pi}\sigma} e^{\frac{-(p_i-u)^2}{2\sigma^2}} + \xi N(0,1)$$

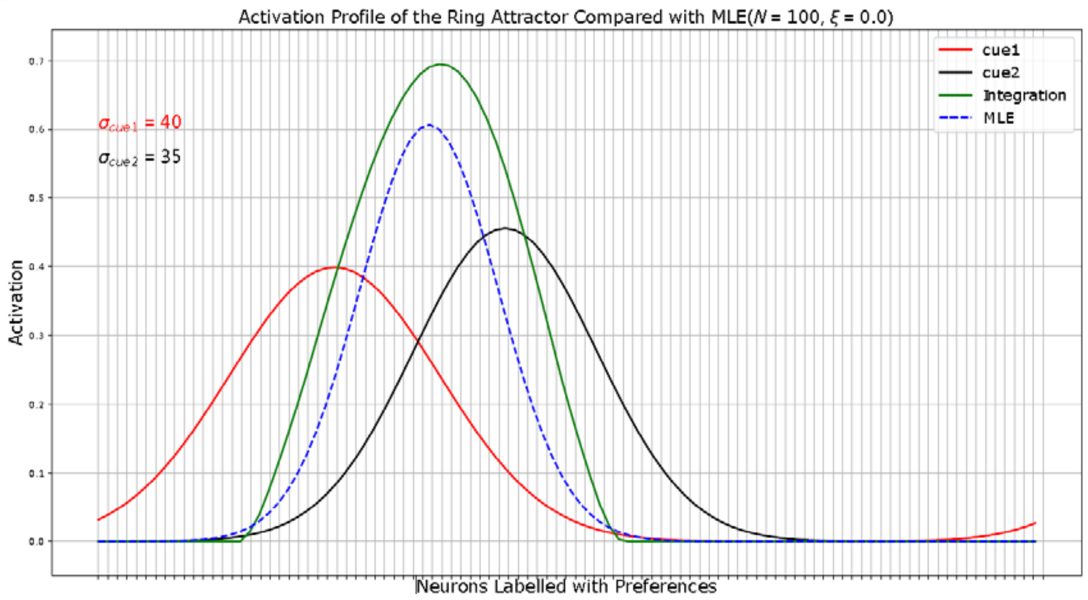
We input the two cues at the same time, so the time evolution equation of the membrane potential of the integration neurons becomes:

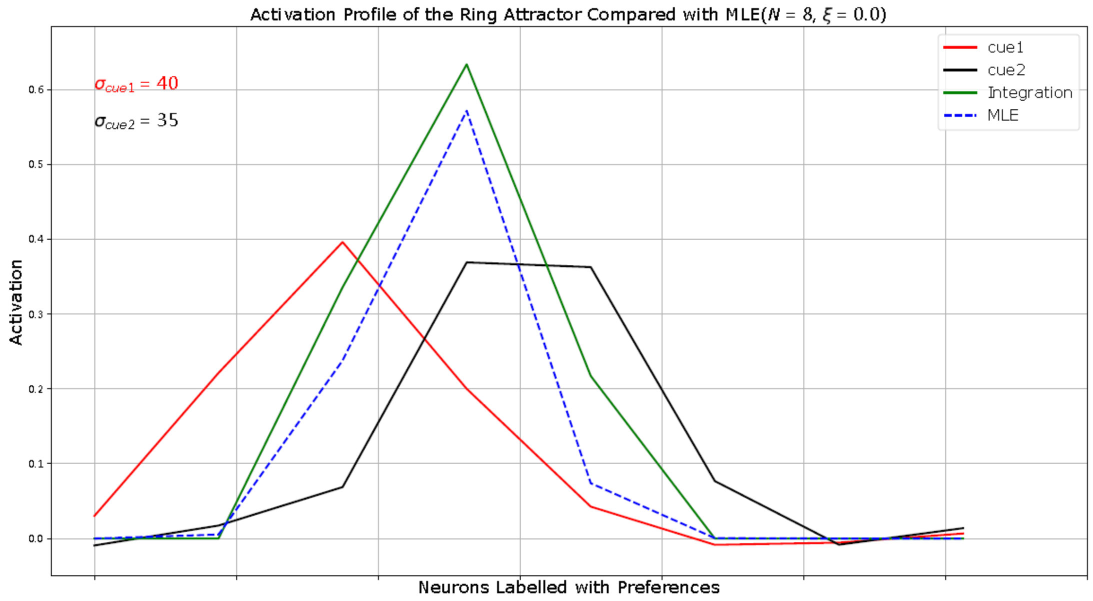
$$\tau \frac{dc_i}{dt} = -c_i + g(\sum_{j=1}^{n} W_{ji}^{E\to E} c_j + X1_i + X2_i + W^{I\to E} u)$$

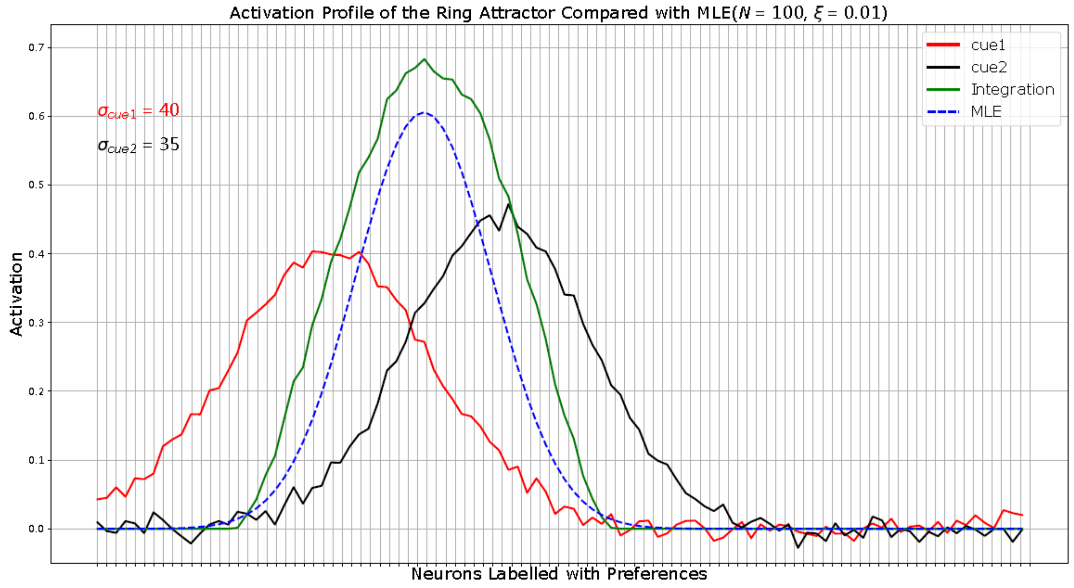
And the time evolution equation of uniform inhibition neuron is:

$$\tau \frac{du}{dt} = -u + g(W^{I\to I} u + W^{E\to I} \sum_{k=1}^{n} c_k)$$

Model Testing – Activation Profiles



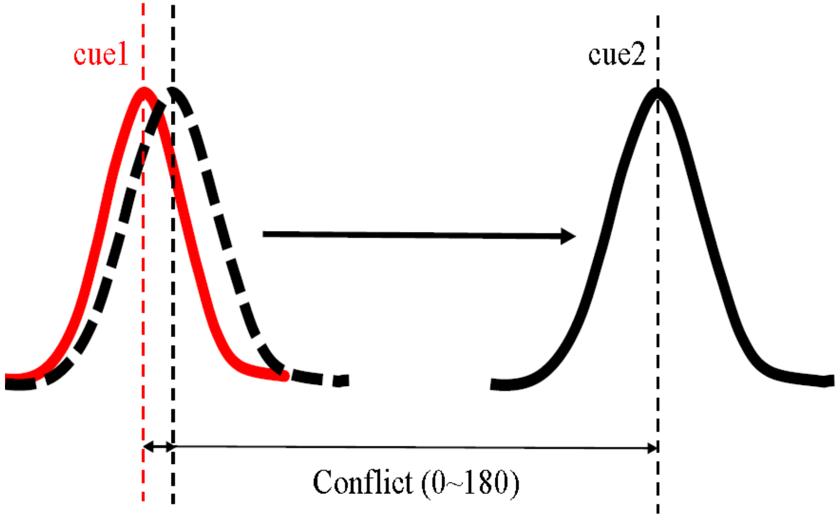


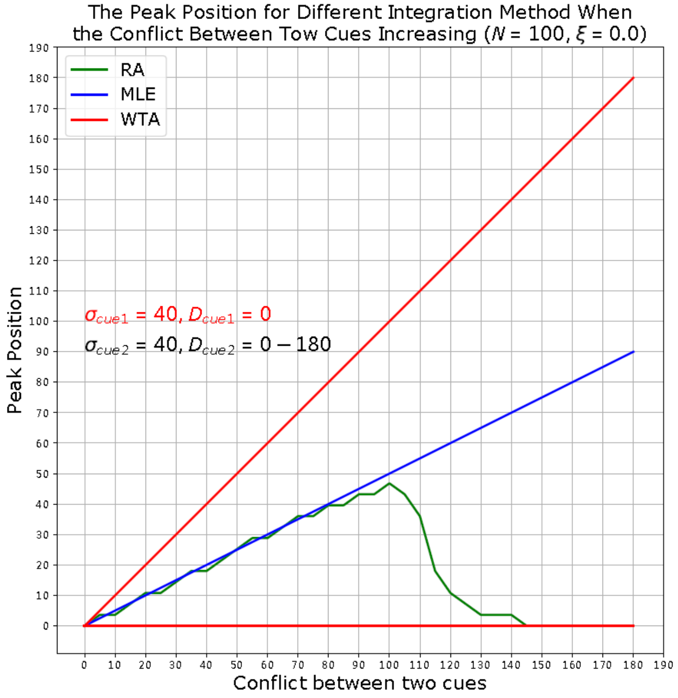


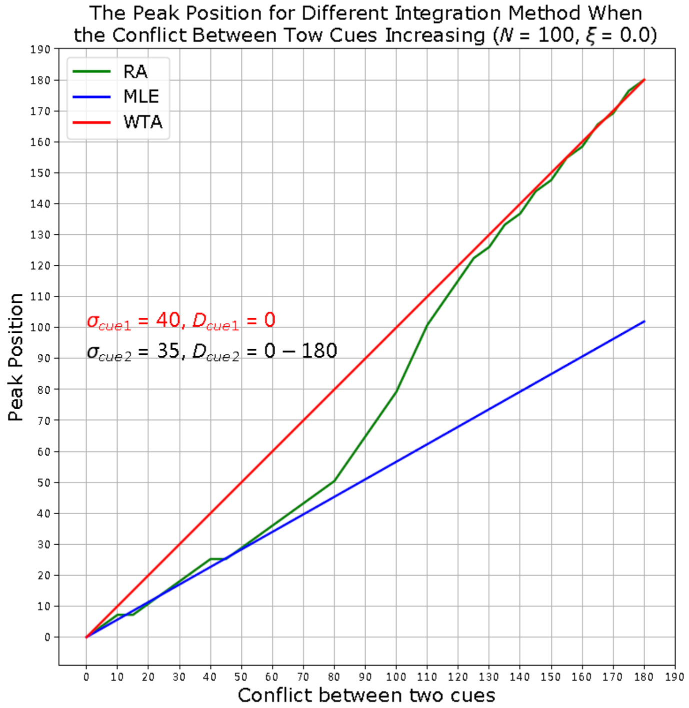
(1) Integration of conflicting cues by a ring attractor network shows that the response approaching the optimal integration.

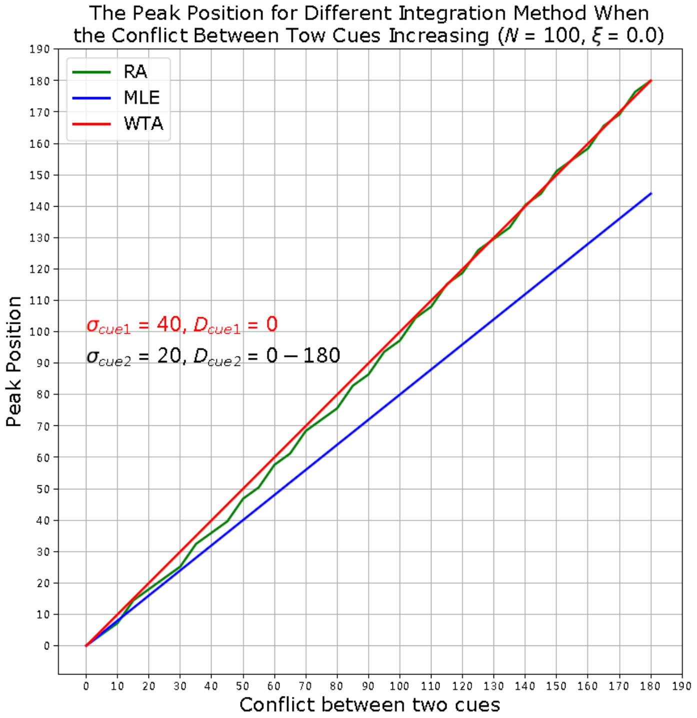
(2) The model remained stable despite the white noise and obvious loss of resolution in the Gaussian functions.

Model Testing – Increasing the conflicts of input cues





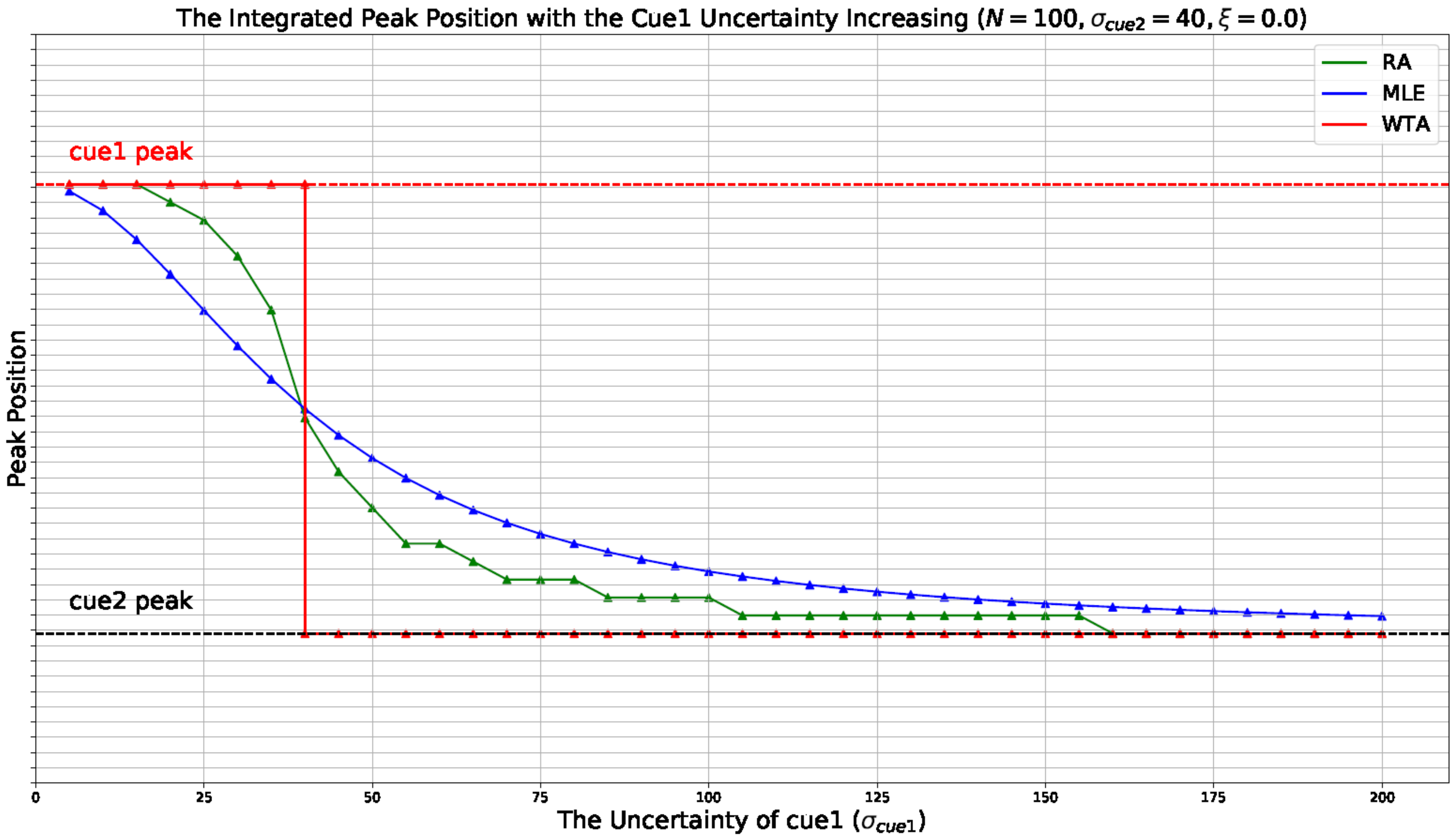




(1) Within a range of cues conflicts, the ring attractor model perform the optimal (or approximately) cues integration, when the two cues are enough different, the model shifts to the winner-take-all scenario.

(2) The difference between the uncertainty of two cues also strongly affect the model output.

Model Testing – Altering the uncertainty of one cue

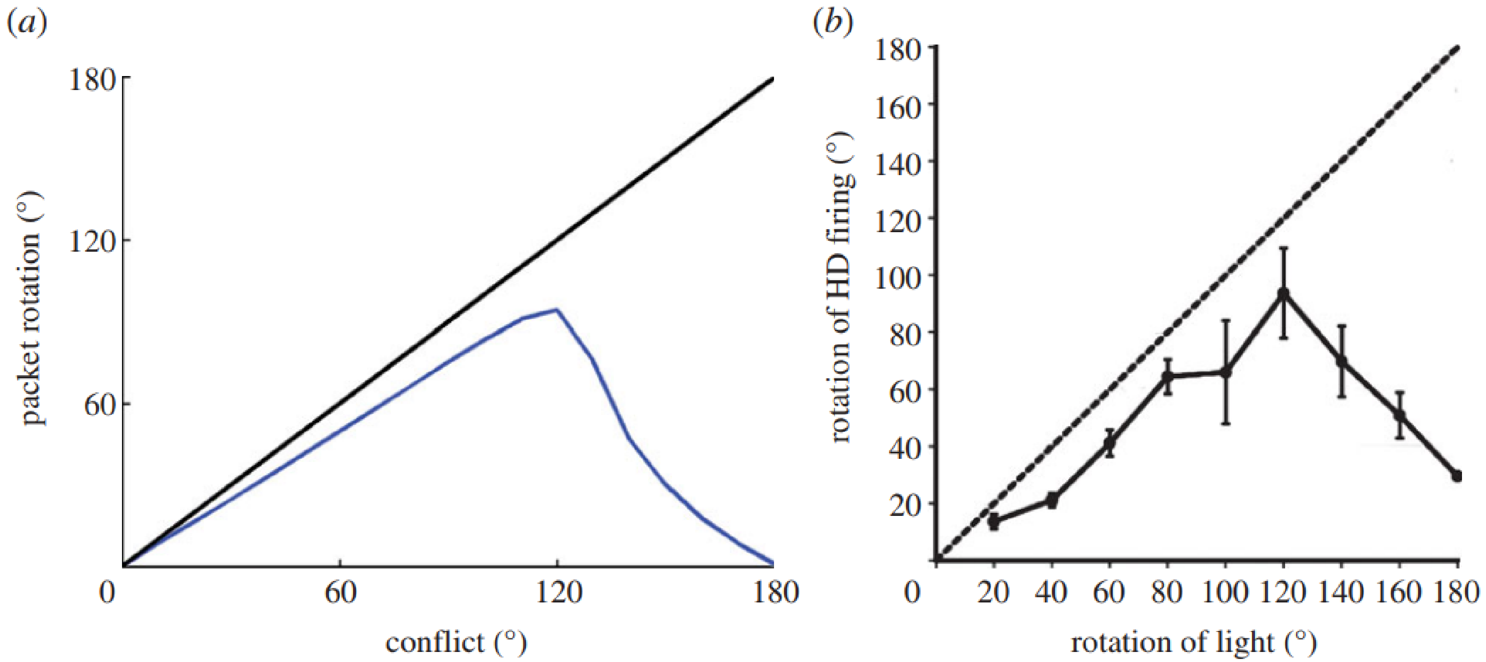


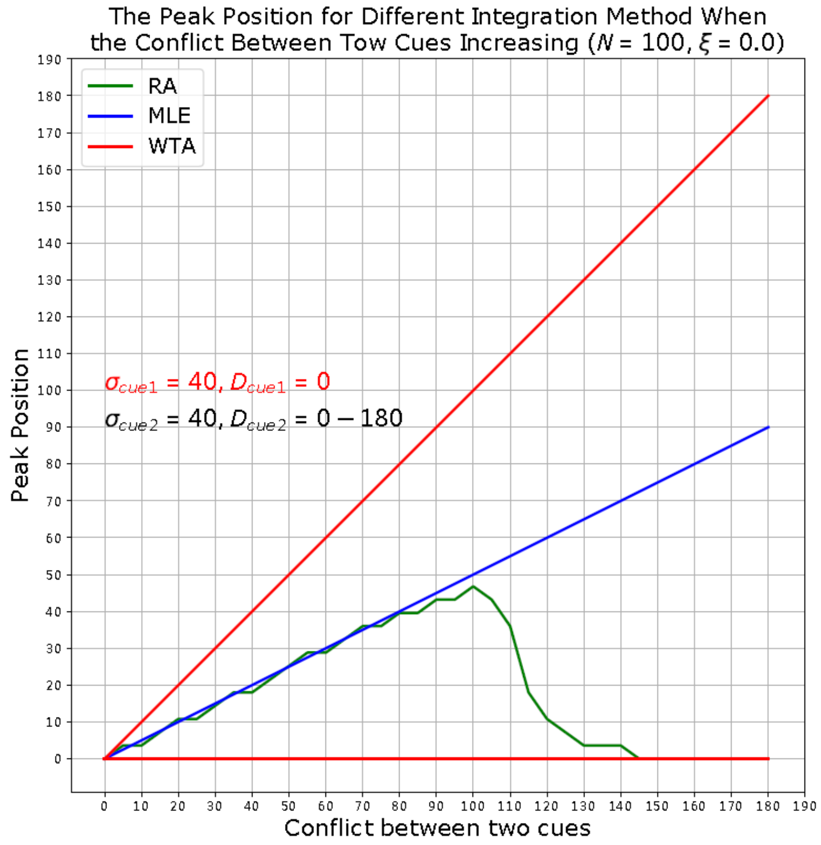
Although not acting in a truly optimal manner the switch from WTA to weighted-average and back again follows the general profile of the MLE prediction.

Discussion- Insect’s performances?

The re-weighting model

The rat’s data



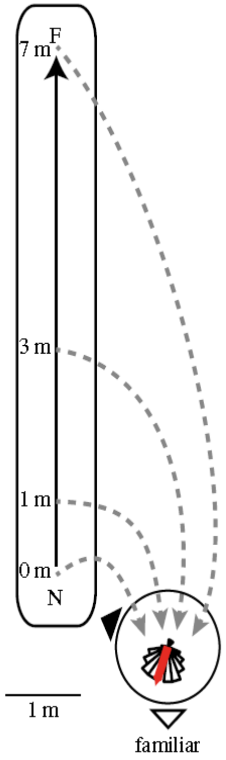


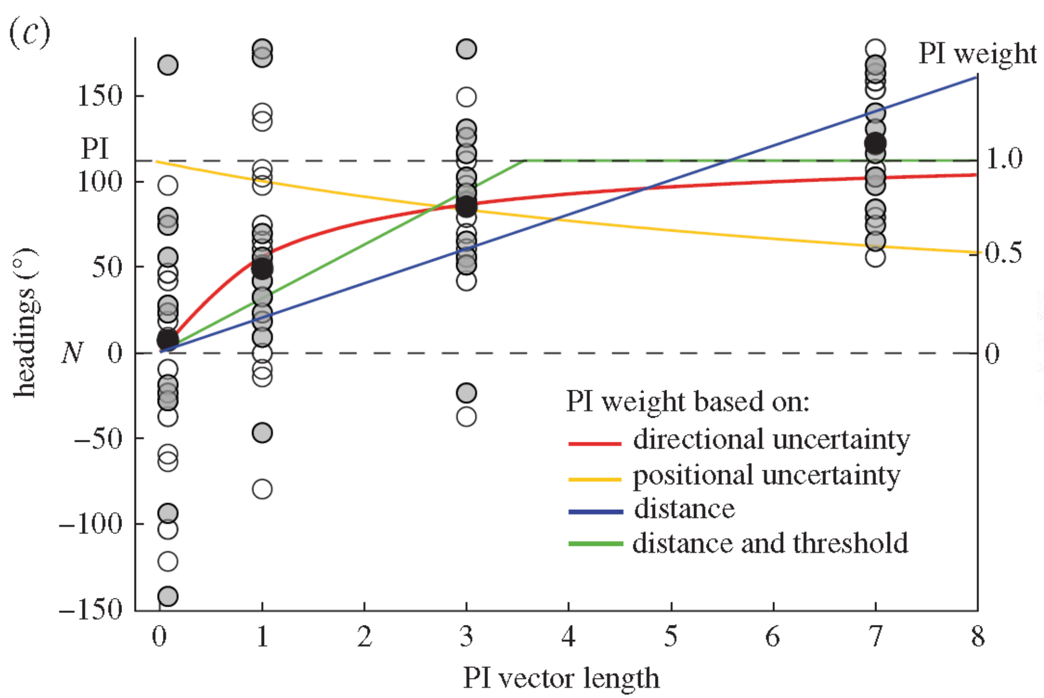
Have very similar performances as the re-weighting model and also the biological experiments.

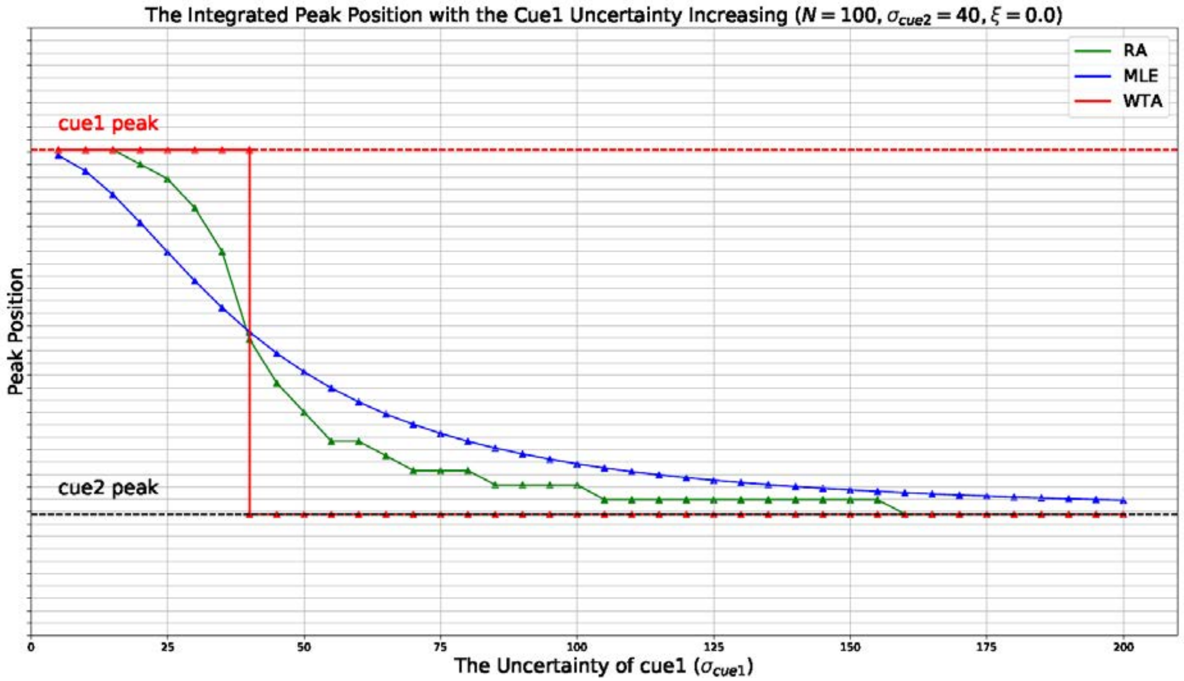
Page, H. J., Walters, D. M., Knight, R., Piette, C. E., Jeery, K. J., & Stringer, S. M. (2014). A theoretical account of cue averaging in the rodent head direction system. Philosophical Transactions of the Royal Society B: Biological Sciences, 369(1635), 20130283.

Knight, R., Piette, C. E., Page, H., Walters, D., Marozzi, E., Nardini, M., ... &Jeery, K. J. (2014). Weighted cue integration in the rodent head direction system. Philosophical Transactions of the Royal Society of London B: Biological Sciences,369(1635), 20120512.

Discussion- Insect’s performances?



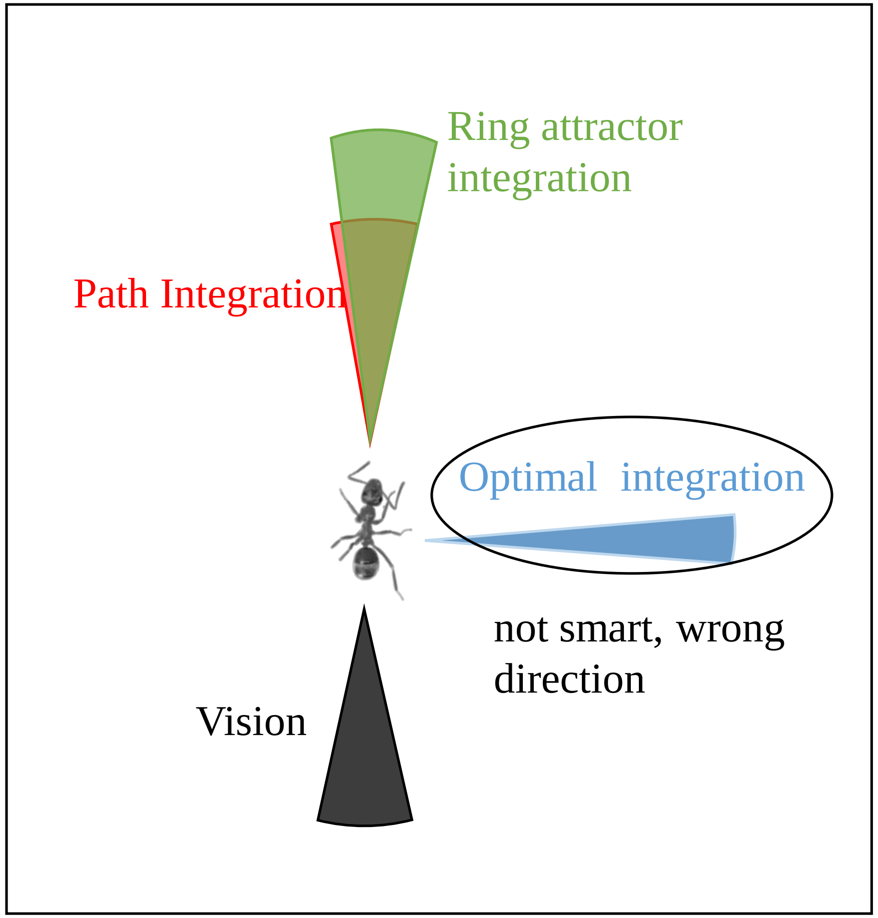


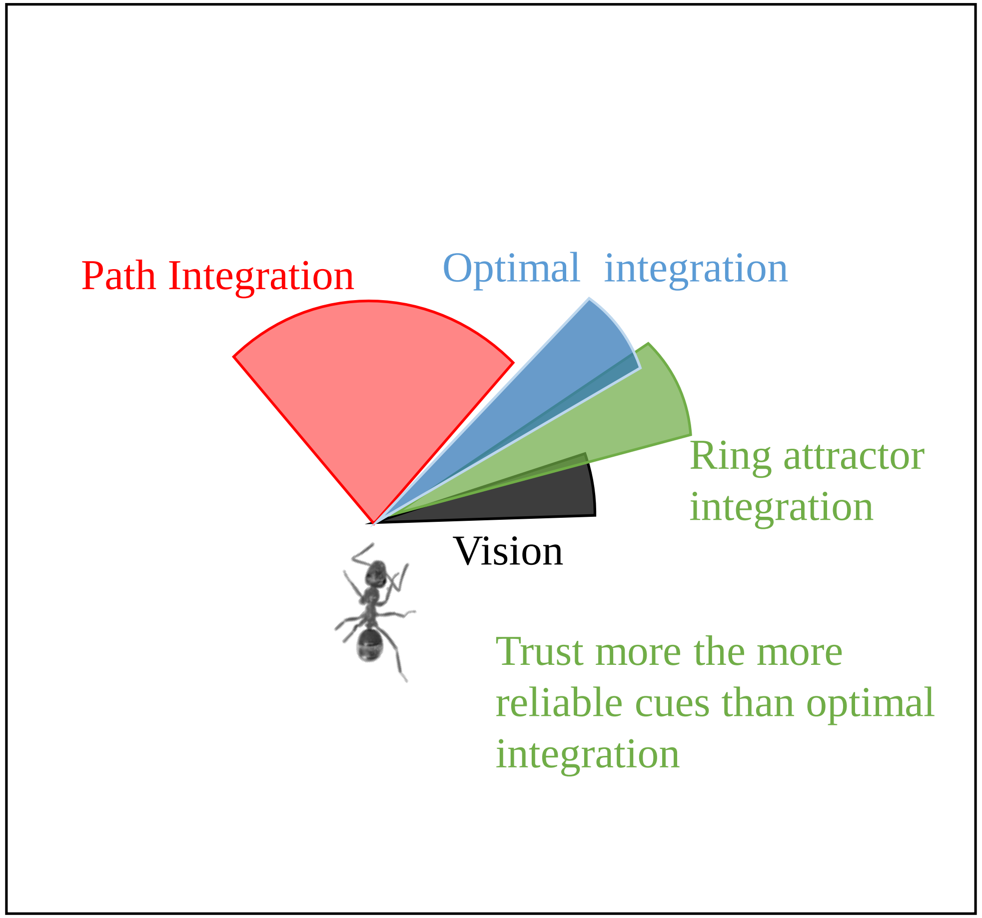


The tendency is very similar, some of the differences may be caused by the parameter setting.

Wystrach A, Mangan M and Webb B, *Optimal cue integration in ants.* Proc. R. Soc. B 282: 20151484. 2015.

Discussion-Is optimal integration the best way?





The smartest way is when two cues are closed enough, we do the optimal integration and when two cues are disparted, choose the more reliable one and if they are identically reliable, arbitrarily select one.

Ring attractor possesses this capacity with only a very simple network structure.

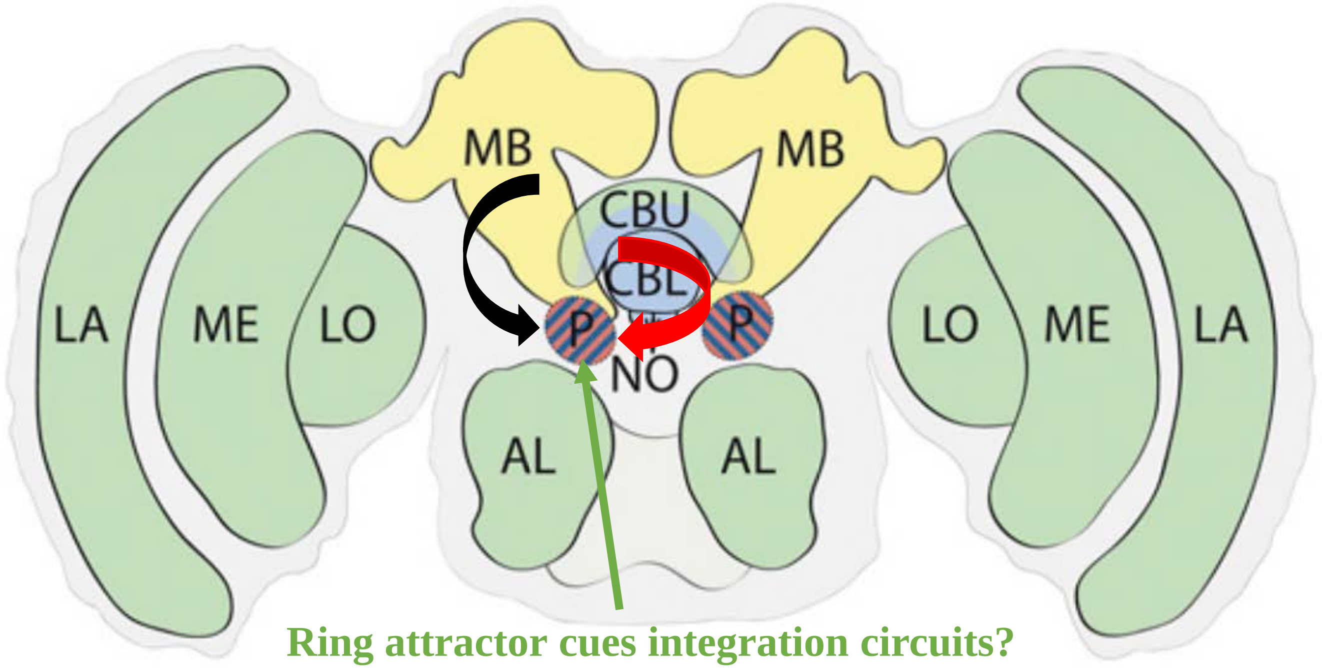
Discussion- Application for biomimetic model of insects

(1) Information integration in the LAL

Insect brain:

MB mushroom body
CBU central body upper
CBL central body lower
NO noduli
P protocerebrum (with LAL in it)
LAL lateral accessory lobe
AL antennal lobe

Optic Lobe
- LA-Lamina
- ME-Medulla
- LO-Lobula



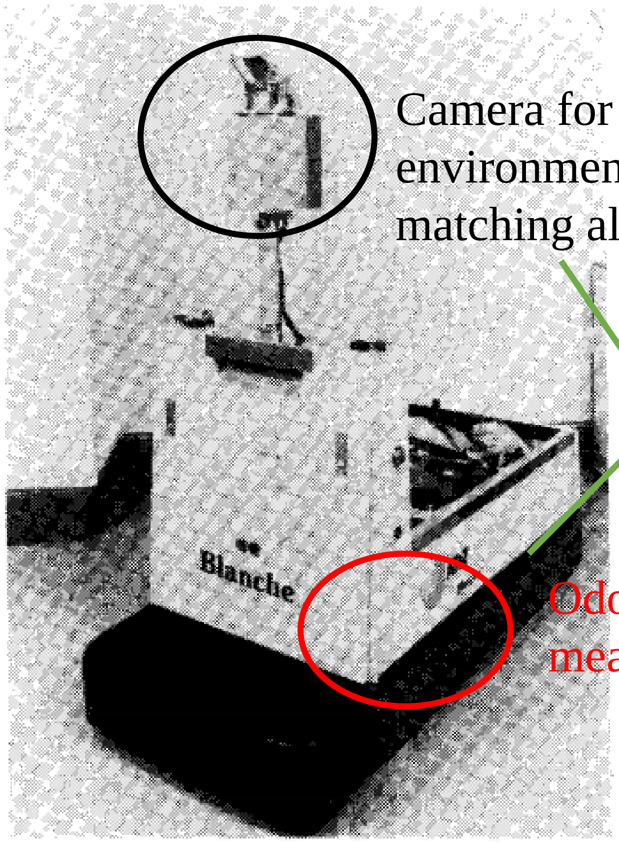
(2) Other areas that needs information combining. Ring attractor network may be a ubiquitous circuits in animals' brain.

Andrew B. Barrona, Colin Kleinb, *What insects can tell us about the origins of consciousness*, Proceedings of the National Academy of Sciences, 113 (18), 2016

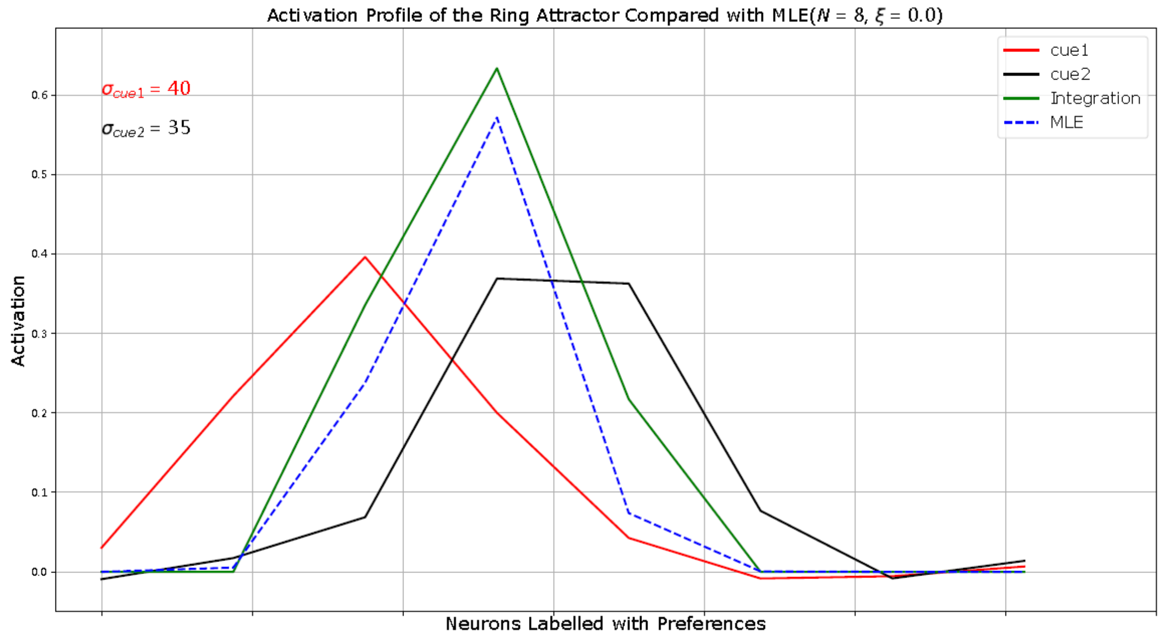
Discussion- Robot application

Sensory Fusion

(1) Can do the optimal-like integration



(2) Cost very little computing resources (8 neurons can still work well), make it possible for applying Bayesian method on small, cheap robot platforms



Cox, I. J. (1991). Blanche-an experiment in guidance and navigation of an autonomous robot vehicle. IEEE Transactions on robotics and automation, 7(2), 193-204.

Kam, M., Zhu, X., & Kalata, P. (1997). Sensor fusion for mobile robot navigation.Proceedings of the IEEE, 85(1), 108-119.

Conclusions

- Our implementation of the classic ring attractor can perform optimal-like cue integration when presented with conflicting cues.
- The network output is also shown to be robust to noise on the sensory input and reduction in size to the 8 neurons that encode direction in insects.
- Sweep tests showed both the variance and distance between conflicting cues strongly affect the network properties.:

  (1) With equal or small differences in variance of cues the network performs a weighted average for small cue conflicts, but switches to a winner-take-all response for larger conflicts.

  (2) larger differences the network switches to WTA responses at much small conflicts.
- Simple ring attractor network possesses the capacity of smartly switching from optimal integration to winner-take-all shows a similar properties of animals' behavior supported by some biological experiments.
- With the advantage of small size and simple structure, it can be applied in small and cheap robot needing sensory fusion.

Q & A

Thank You!

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