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

Biology Plausible Cues Combination Model for Path Integration and Vision Information of Insects Navigation

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Background & Motivations

Insects are skillful navigators!

The desert ants can travel hundreds of meters for food, and return home directly with high accuracy.

Bees can develop efficient line routes around multiple food sources

The Monarch Butterflies can travel 3600km as the migrant

Toolkit for Navigation (desert ants case)

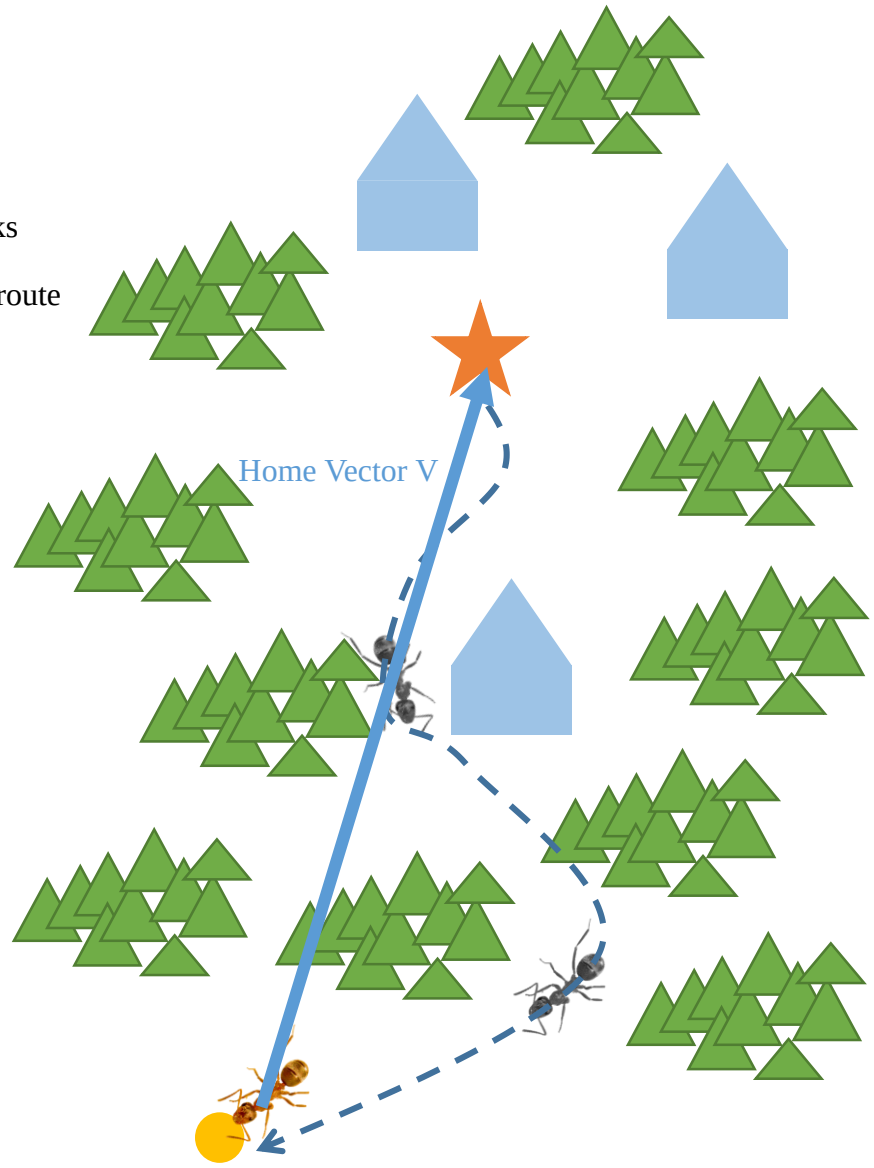
Nest

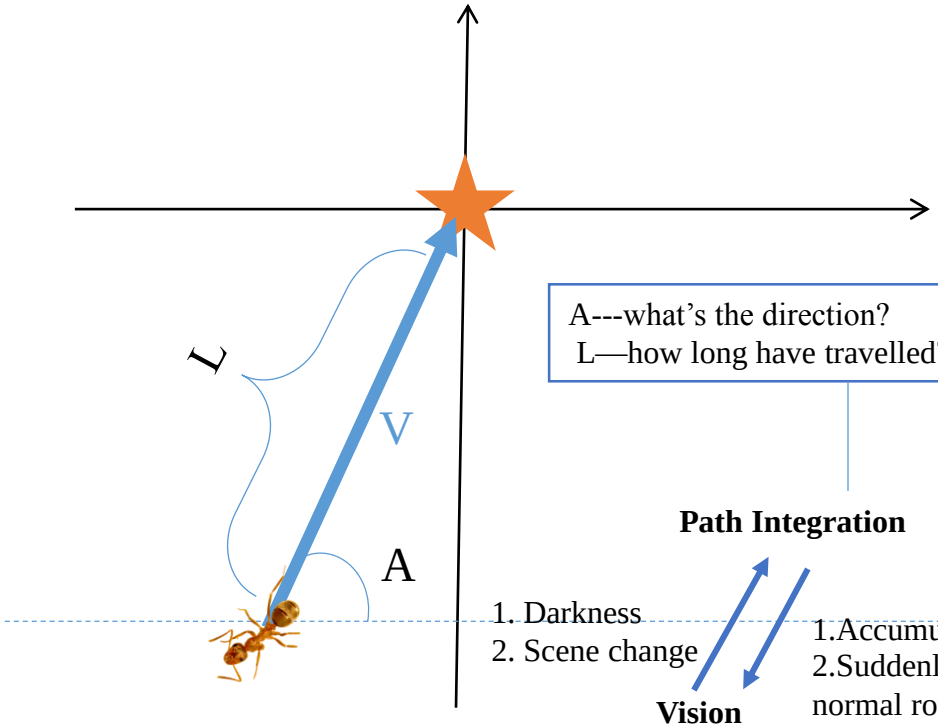
Tussock

Landmarks

Foraging route

food





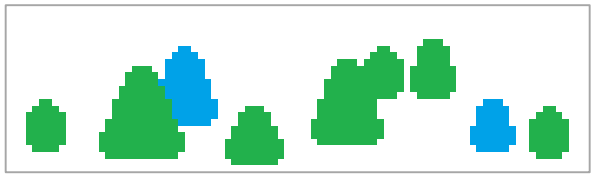
A---what's the direction?
L—how long have travelled?

Path Integration

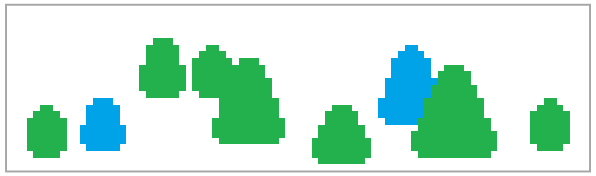
1. Darkness
2. Scene change

1.Accumulated errors
2.Suddenly displaced from the normal route

Vision



Left



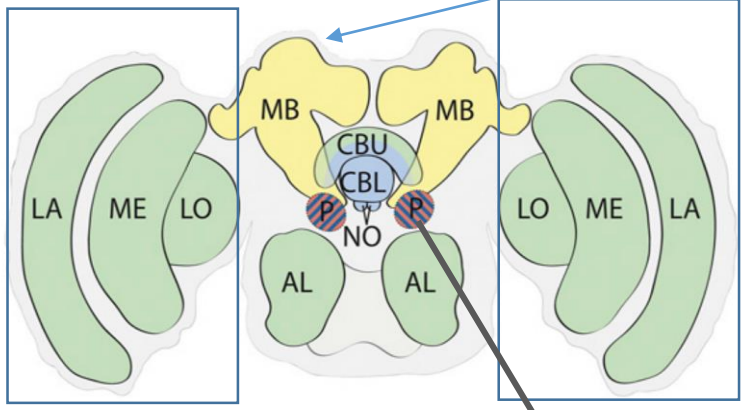
right

Which direction is the nest's direction?

Functional Anatomy of Insect Brain

Learning & Memory

Mushroom Body



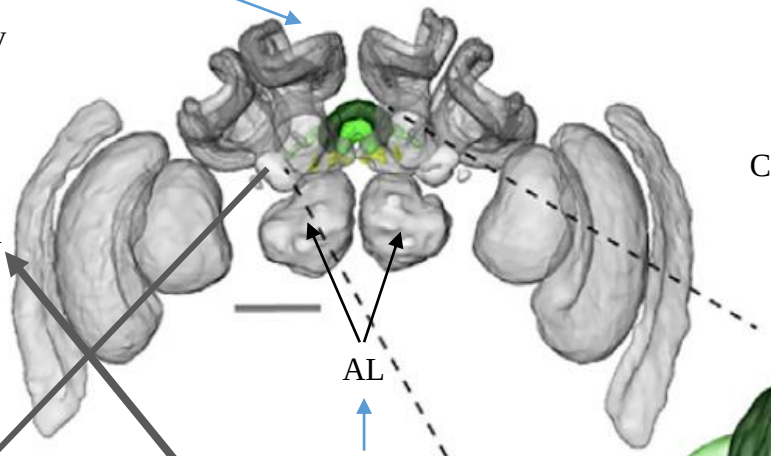
Optic Lobe

Optic Lobe

Vision (Low-layer process)

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

Retina



AL

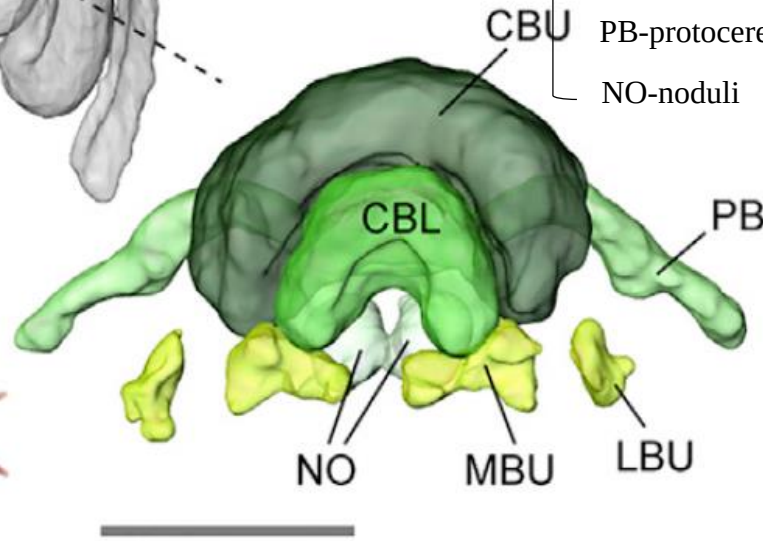
Primary Odor Process

P-Protocerebrum
(LAL-lateral accessory lobe is within)
A very anatomically complicated region

Integration, physiological state and so on

Spatial Tasks

CX (Central Complex)
- CBU-central body upper
  FB-fan-shape body
- CBL-central body lower
  EB-ellipsoid body
- MBU-medial bulb
- LBU-lateral bulb
- PB-protocerebral bridge
- NO-noduli



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

Thomas Stone, Barbara Webb, et.al, *An Anatomically Constrained Model for Path Integration in the Bee Brain*, Current Biology 27, 3069–3085, October 23, 2017

Path Integration-Sensory System

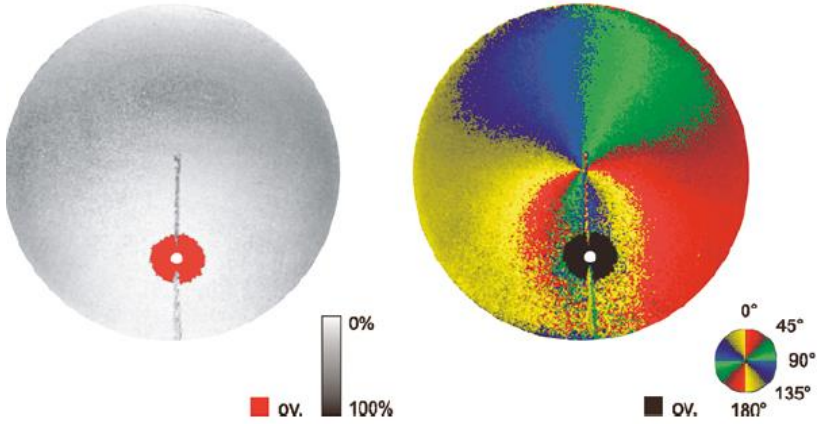
Theory calculation: $L = \int v\,dt$ $A = \int \omega\,dt$

We can also put them together by vectorization, then the Home Vector $\vec{V}(T) = \int_0^T \vec{v}(t)\,dt$

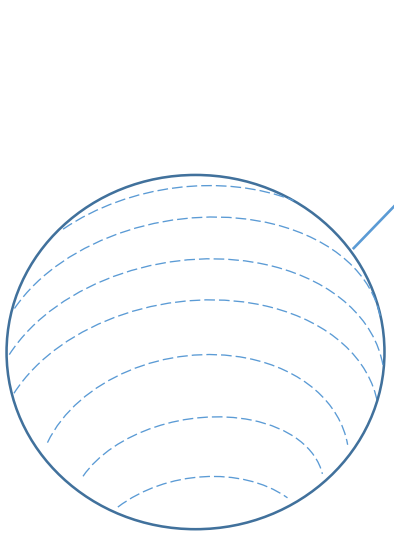
Where $\vec{v}(t)$ is a vector with magnitude and direction, so if the insects can get both value of the magnitude and direction, in theory, they can do Path Integration just as we do the Integral operation above.

Yes, they do!

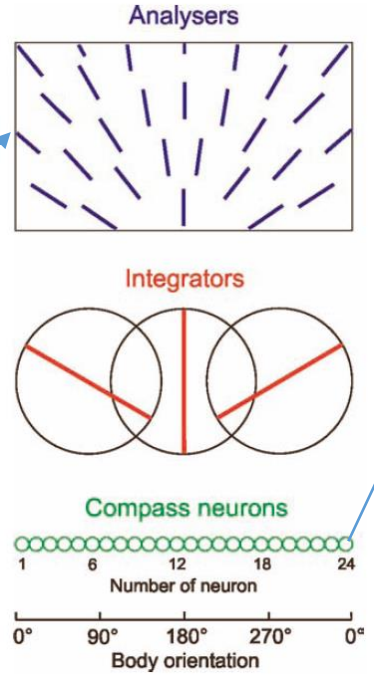
Sensory system

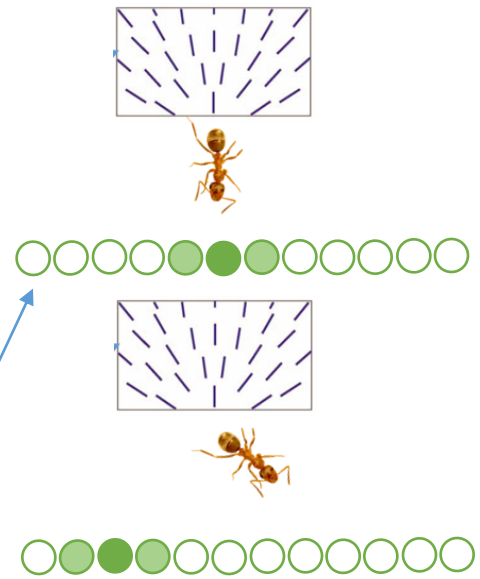


1.Skylight polarization when Elevation of sun: 41deg



2.Luminance contour



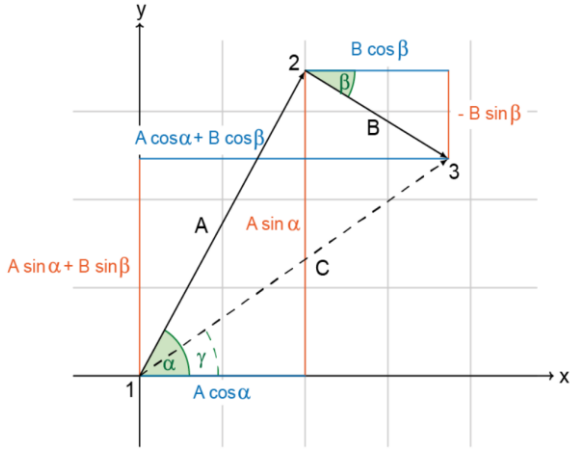


3.For magnitude of the velocity:

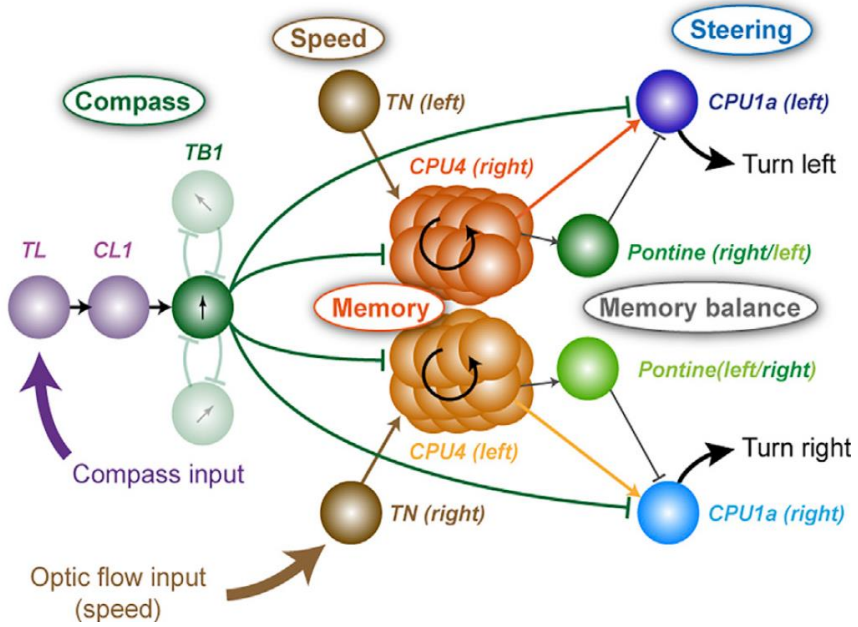
Ants: Step Count
Bees: Optic Flow (vision based)

R. Wehner. *Desert ant navigation: how miniature brains solve complex tasks,* J Comp Physiol A 189: 579–588, 2003

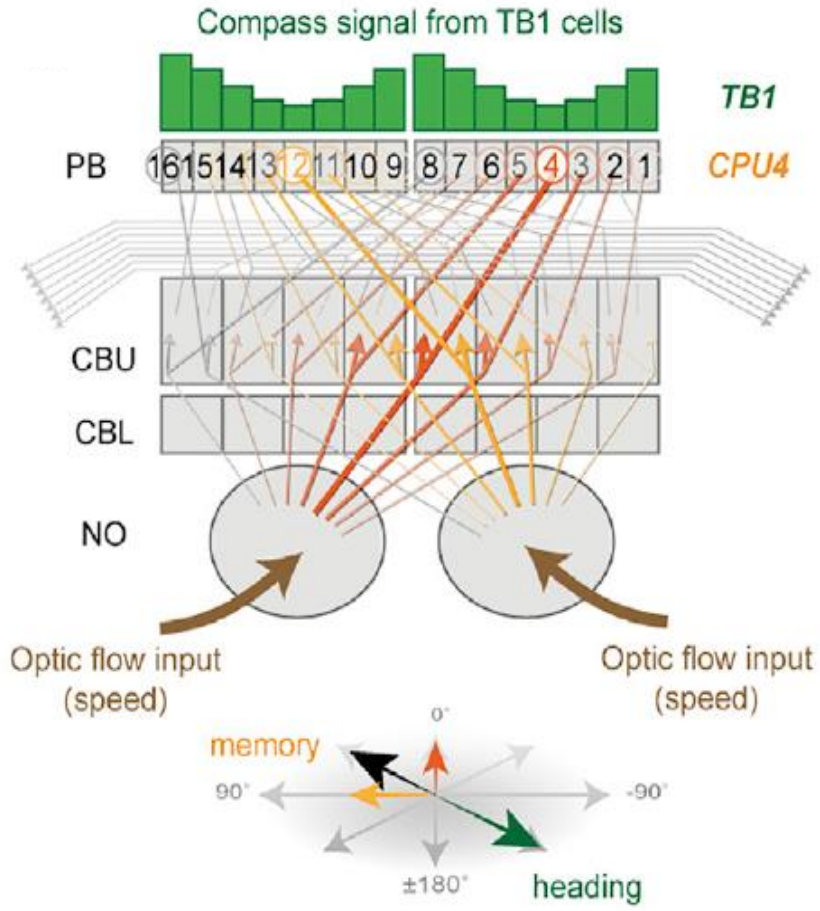
Path Integration-Integrator Modelling



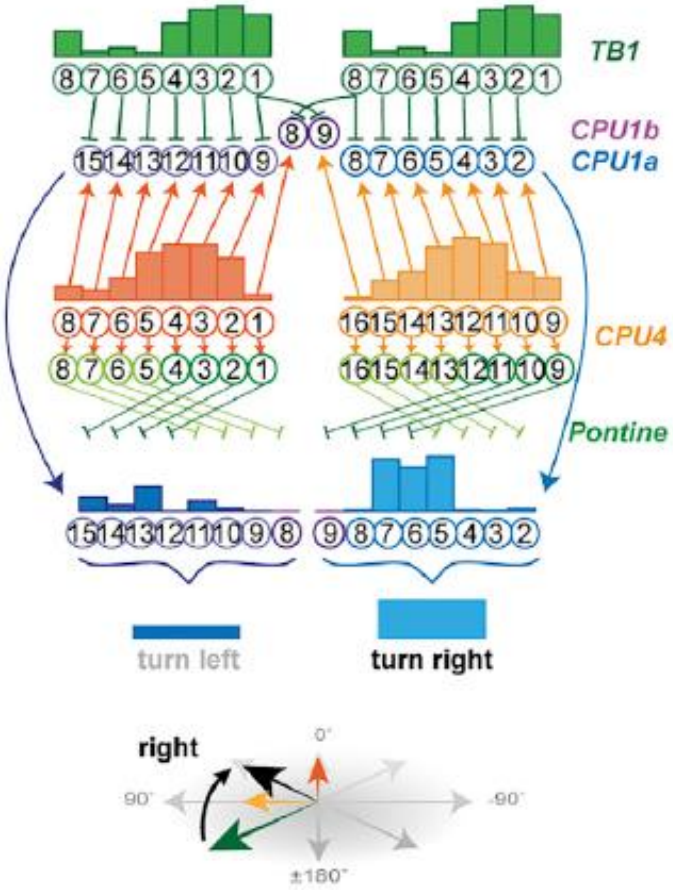
1.The Vector Addition underlines the method of accumulated activation for Path Integration



2.The Structure of Path Integration Model

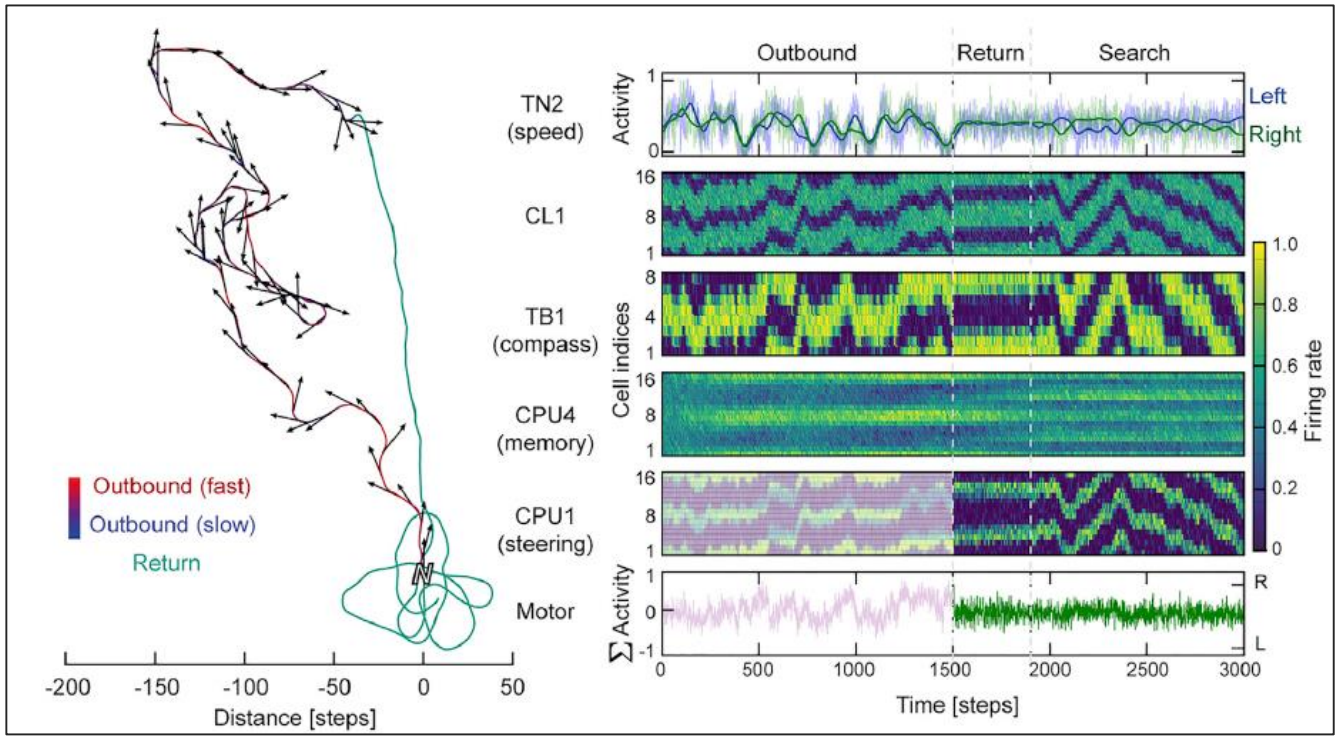


3.Outbound/Foraging: the memory established

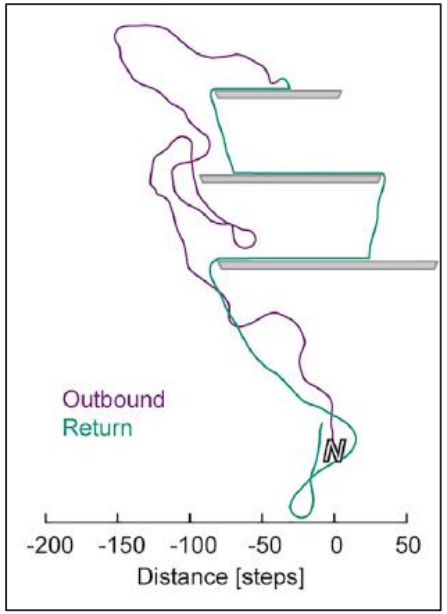


4.Inbound/homing: memory compared with heading to control the motor

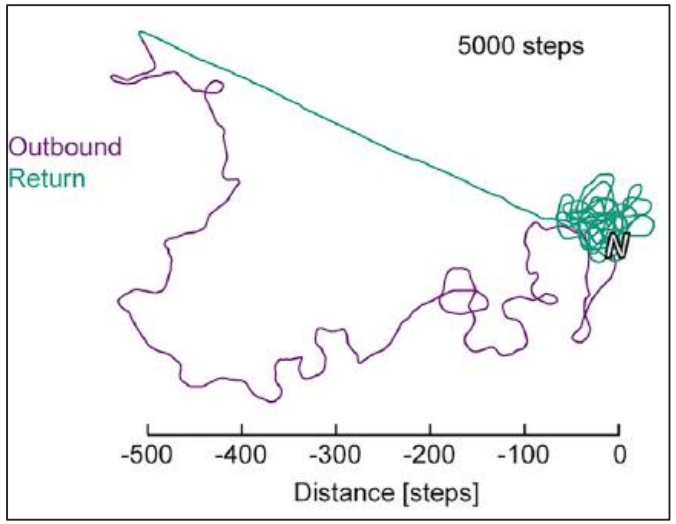
Path Integration-Integrator Modelling



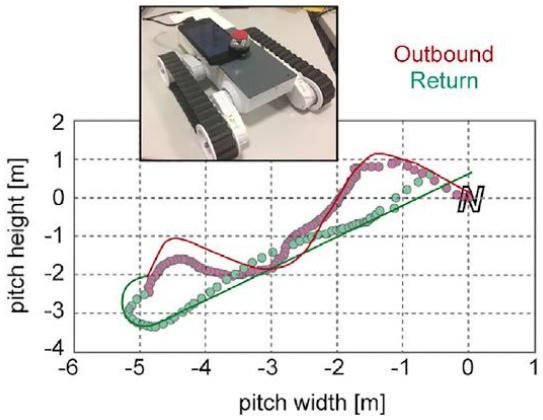
1.With Obstacles



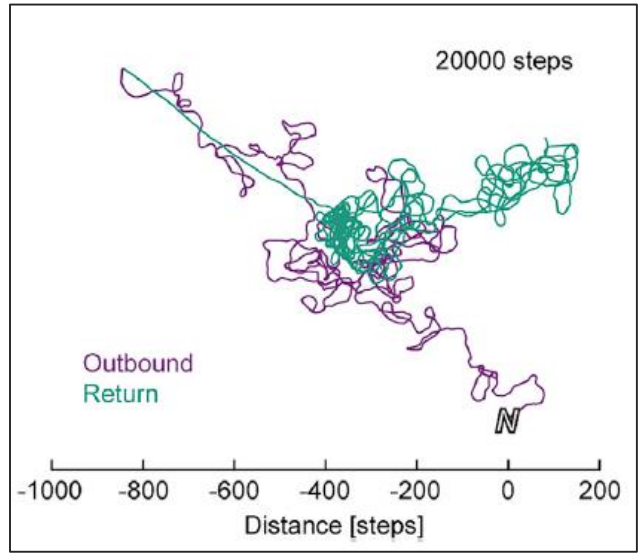
2. Long journey with 5000 steps



4.Robot Experiment



3.So long a journey with 20000 steps that exceed the capacity of the memory,

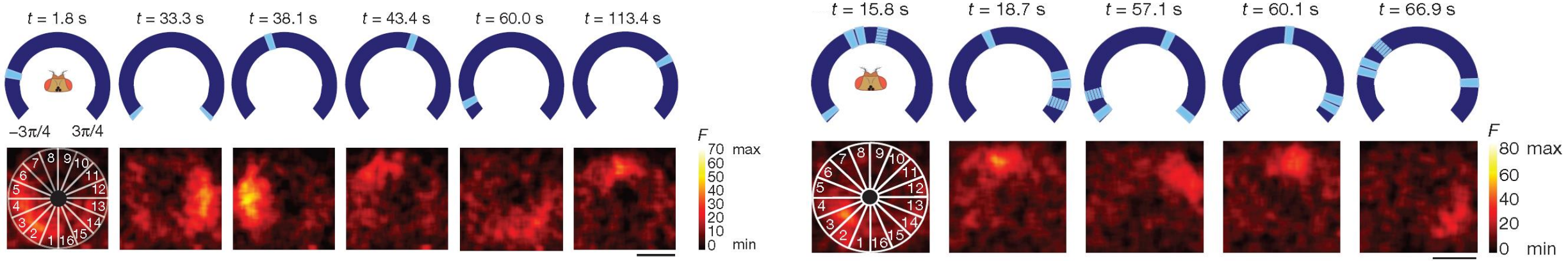


Thomas Stone, Barbara Webb, et.al, *An Anatomically Constrained Model for Path Integration in the Bee Brain*, Current Biology 27, 3069–3085, October 23, 2017

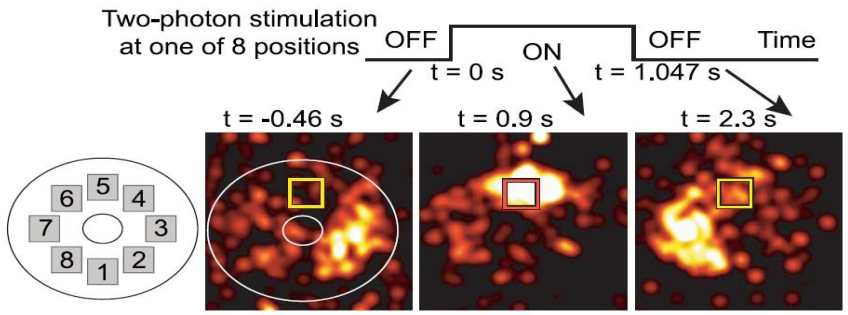
Landmark Based Vision-Sensory

How do insects capture the information of landmarks? – Just like humans, use eyes, but the insects have the **compound eyes.**

Some simple tasks can be done within Optic Lobe, but when the vision processing is related with complex tasks like navigation, other parts of the brain will get involved.



1. Landmark detecting, the different neurons in EB(CBL) in CX will firing due to single or multiple stimulus in different directions



2. If we removed the landmark stimulus, the activity will continue to maintain. We call this property **Attractor, which is related to the short memory of neurons.**

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

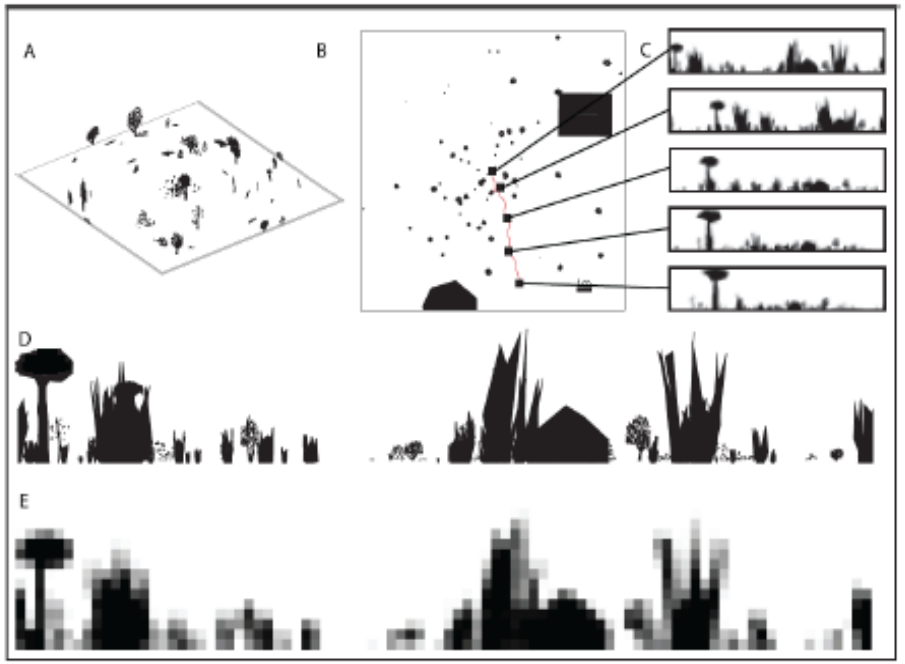
Landmark Based Vision-Process via Scene Familiarity

How do humans process the visual information? Too complicated question, by now, know little about it.

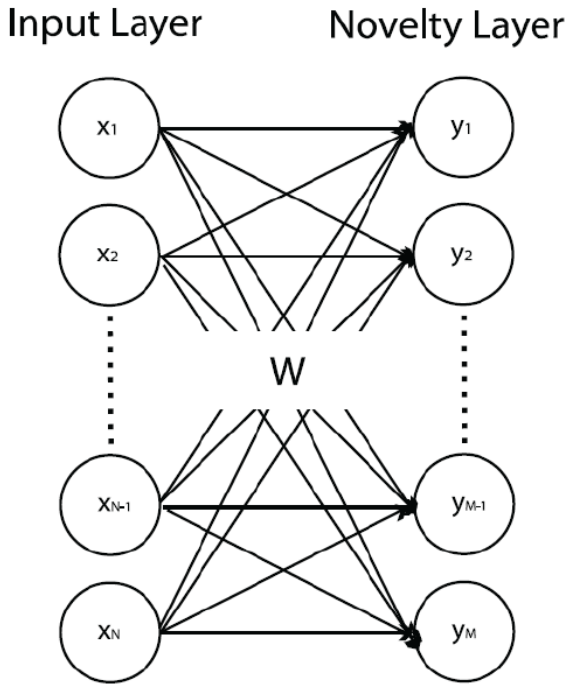
How do insects process the visual information for navigation? By now, know some about it. But far from enough.

An Neuron Network for Homing Using Vision.

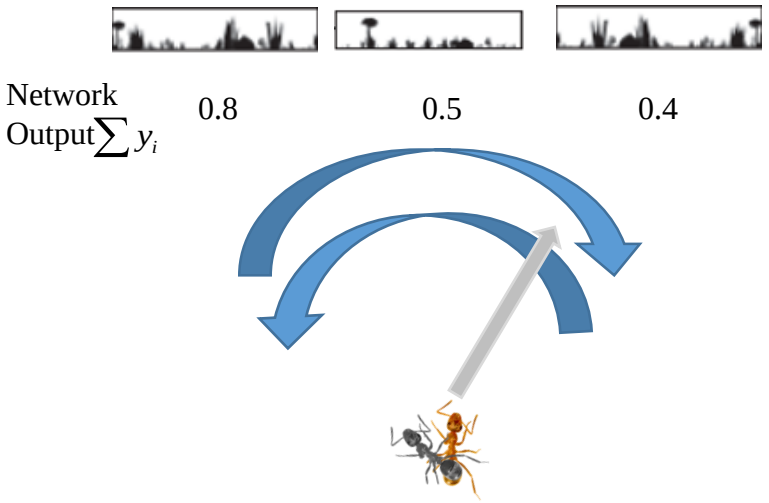
1. Generate many homing journeys and get the images of the scenes



2. Use these images to train a simple neural network



3. Searching and use the trained model to calculate the unfamiliarity and choose the direction with the smallest scene unfamiliarity.



4. Perform well but is not bio-plausible.(too many artificial ingredients)

Baddeley B, Graham P, Husbands P, Philippides A, *A Model of Ant Route Navigation Driven by Scene Familiarity*, PLoS Comput Biol 8(1), 2012.

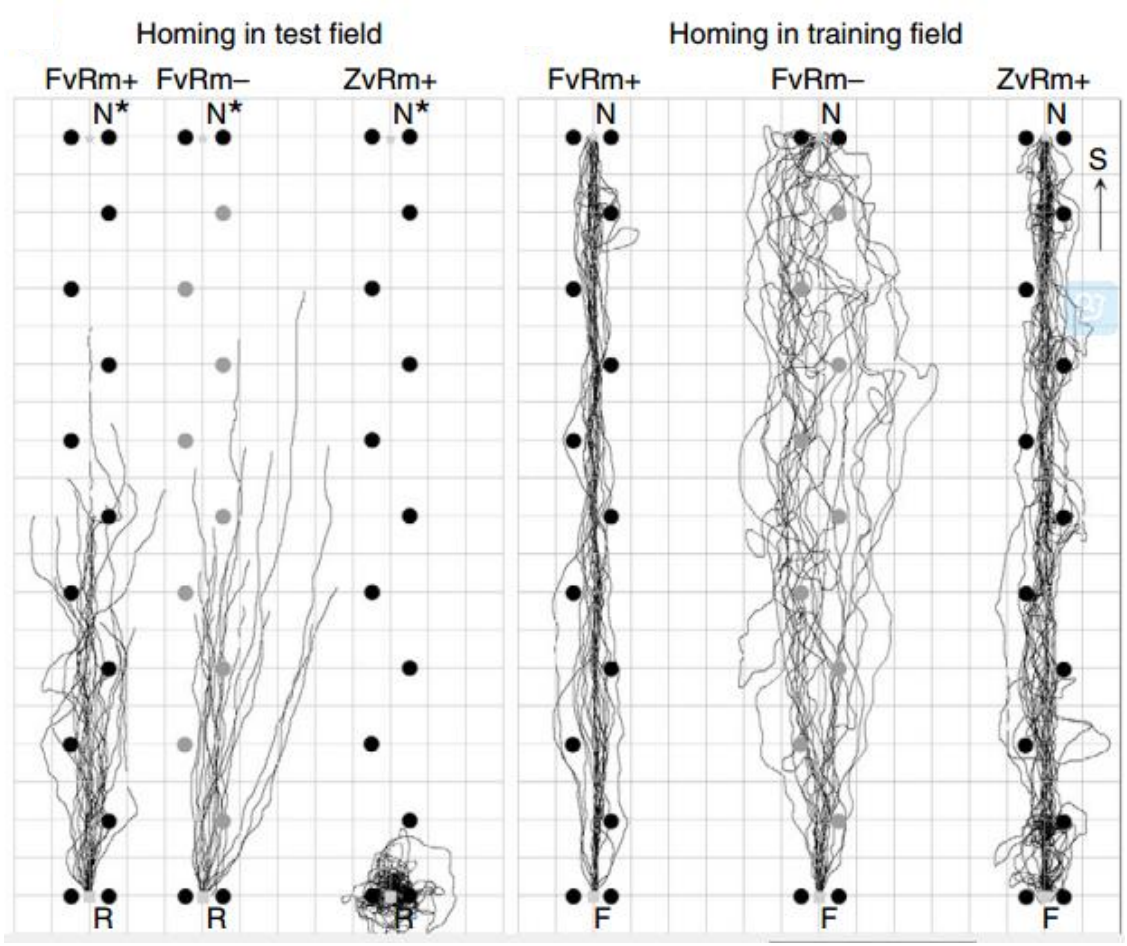
Questions for the Holonomic Insect Navigator

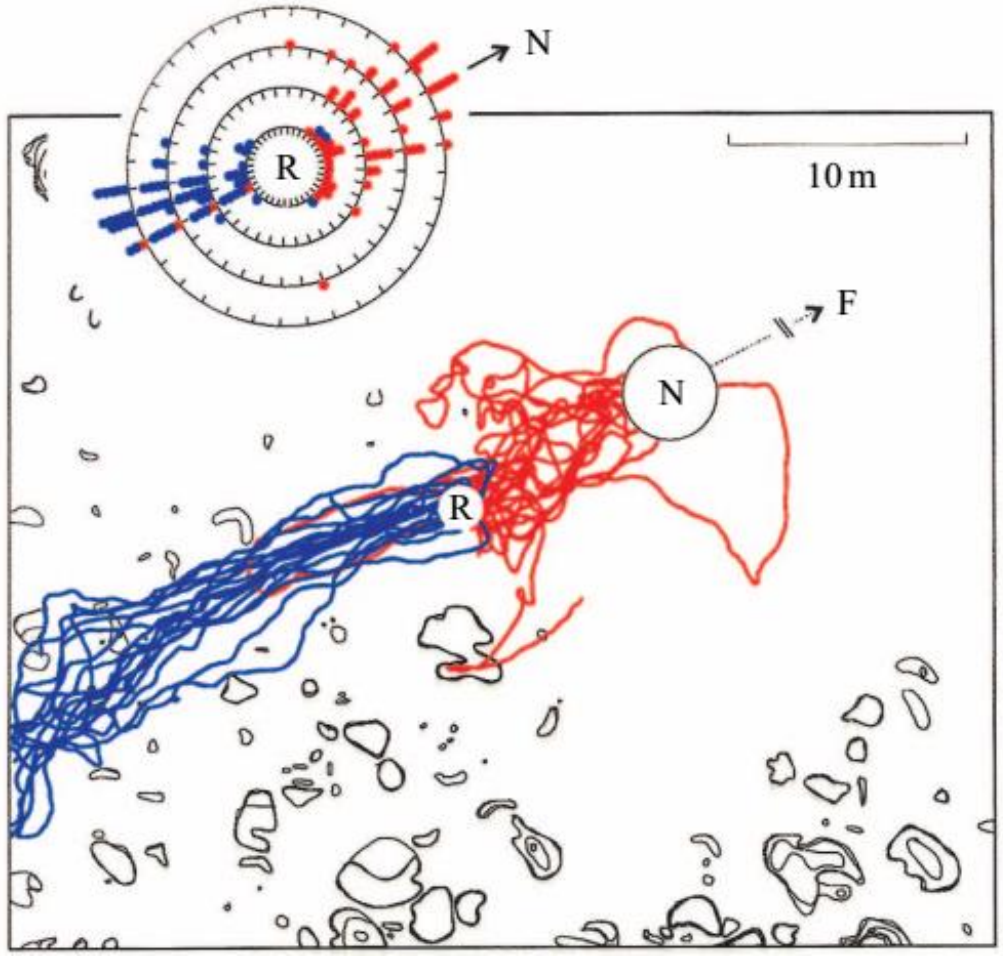
How do insects combine the information from Path Integration and Vision and thus get the holonomic navigator?

1. When the two information sources give two conflict signals, what the insect will choose?
2. When the insect lost one of the information, what's the effect will it take to the homing performance?
3. When the two cues are supplied with different certainty, can the insect make the optimal decision?

For these questions, many biology experiments have been done…

Biology Experiments for the Holonomic Insect Navigator

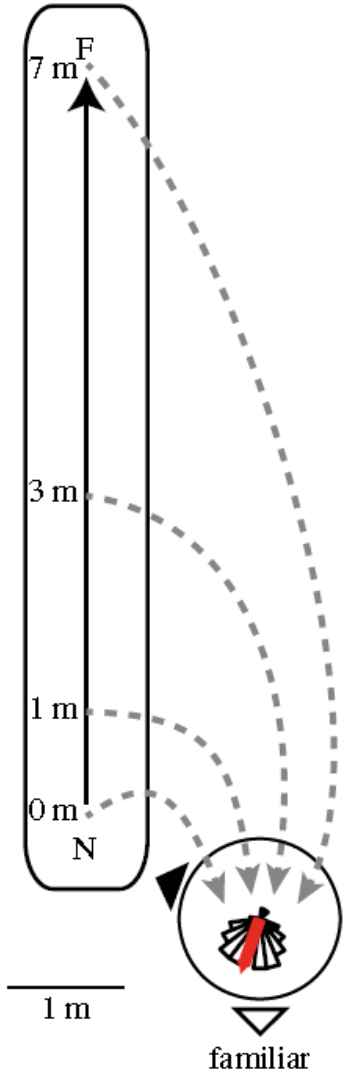


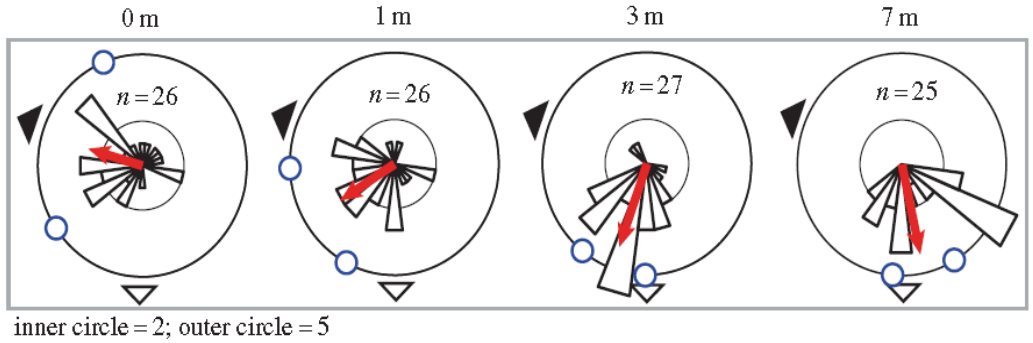


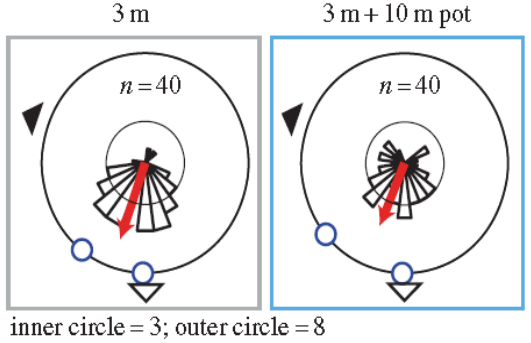
- In training field, have one of the two information, can successfully homing and having two will improve the efficiency. But in test field, PI seems to be more import.
- If landmark-based and vector-based information compete with each other, the former succeeds only in situations in which the ant's home vector is zero.

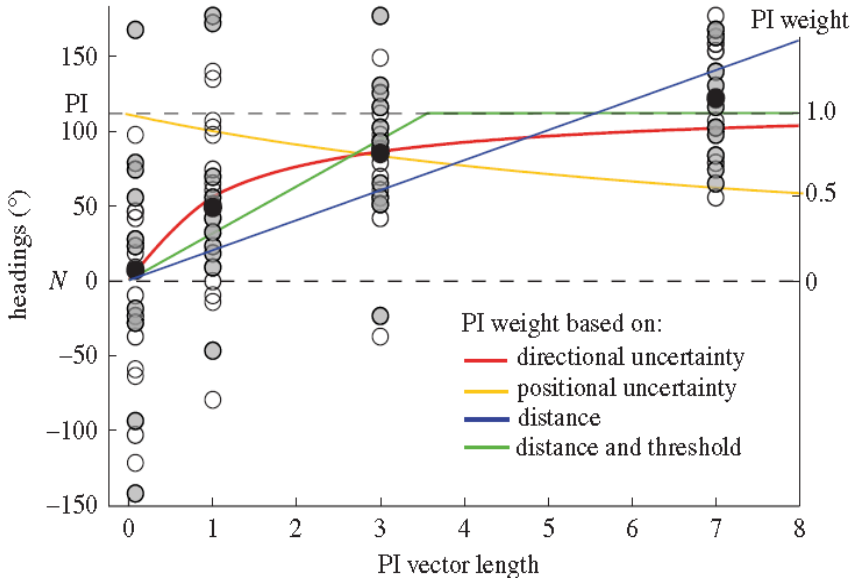
Ajay Narendra, *Homing strategies of the Australian desert ant Melophorus bagoti. II. Interaction of the path integrator with visual cue information,* J. Exp. Biol. 210, 1804-1812, 2007.

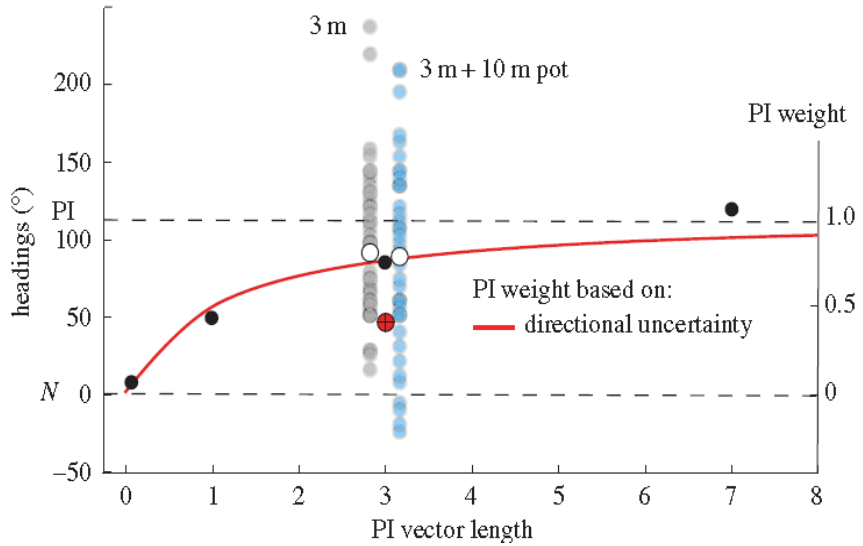
Biology Experiments for the Holonomic Insect Navigator







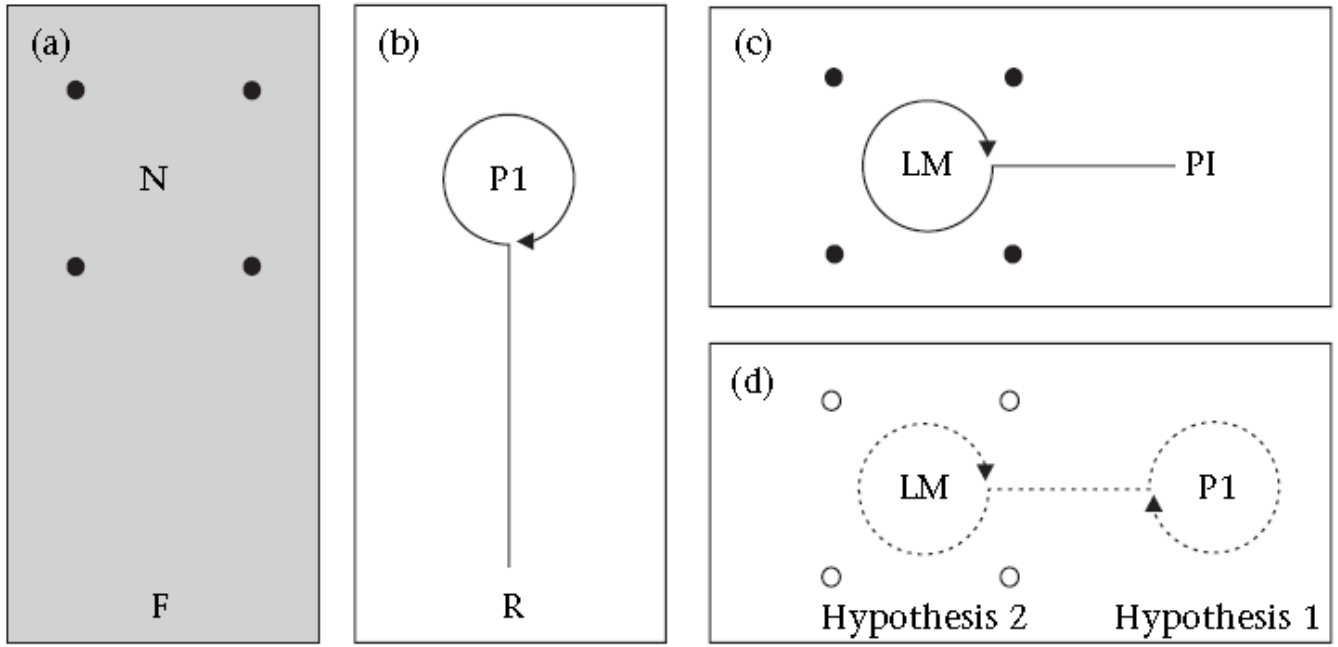


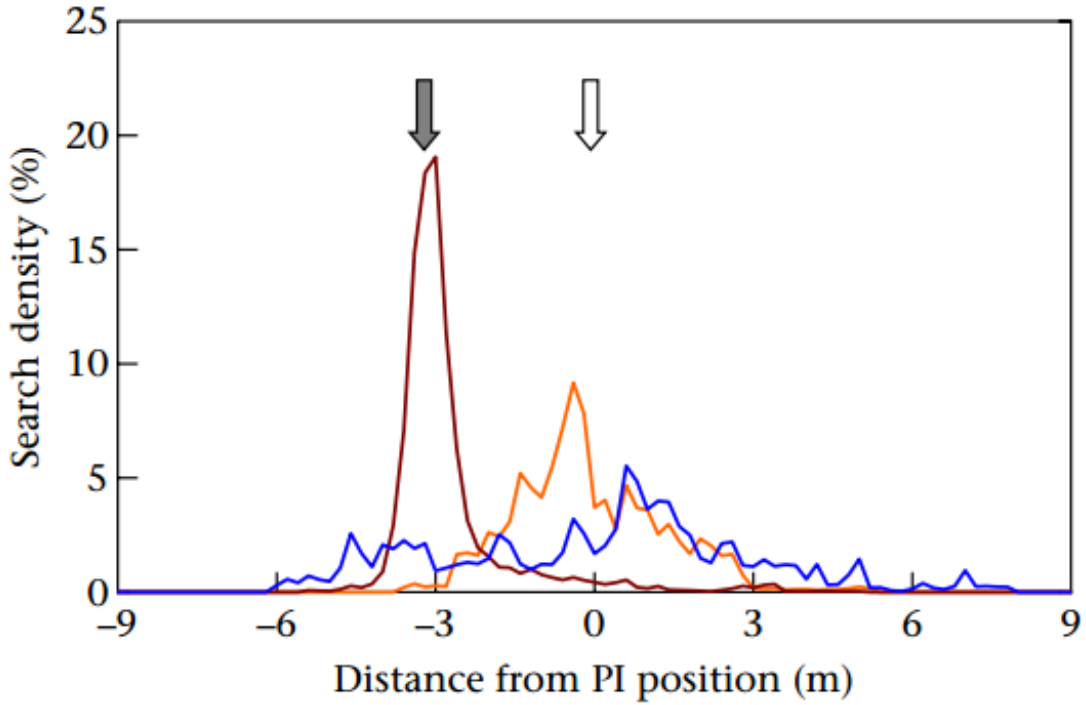


- The best fit is given by summing optimal weighting of the cues based on the directional variance of PI, which decreases proportionally with increasing distance.

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

Biology Experiments for the Holonomic Insect Navigator



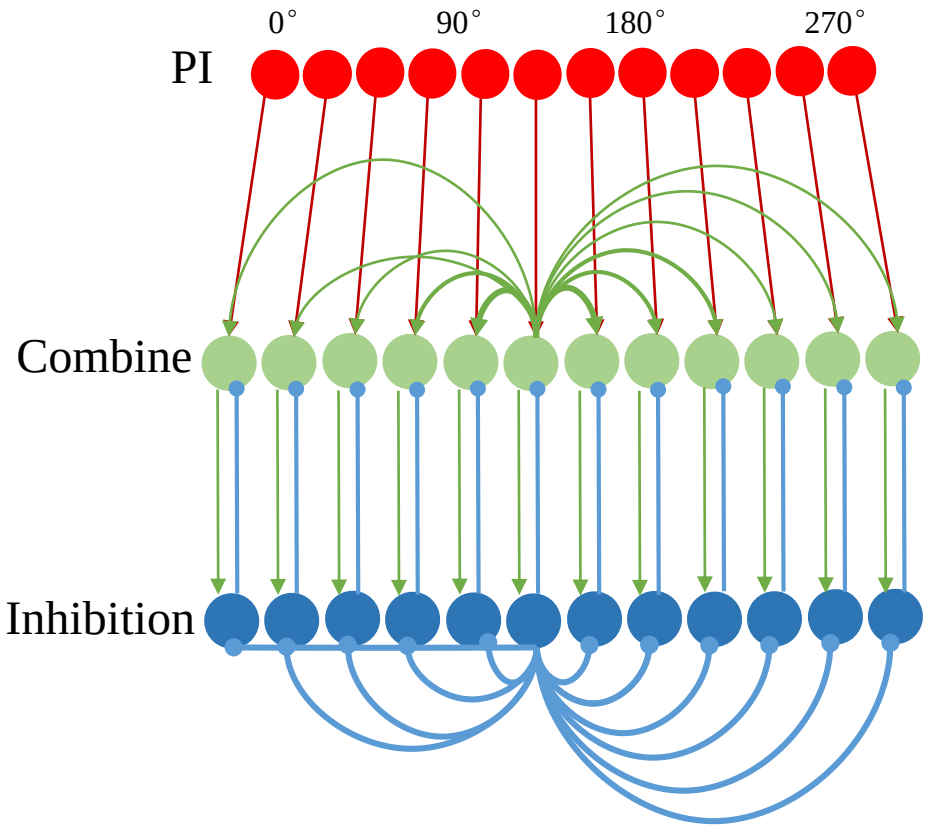


- In conclusion, even while the ants were narrowly searching around the fictive position of the nest within the landmark array, after the landmarks were removed, the centre of the search switched back to the position defined by the path integrator

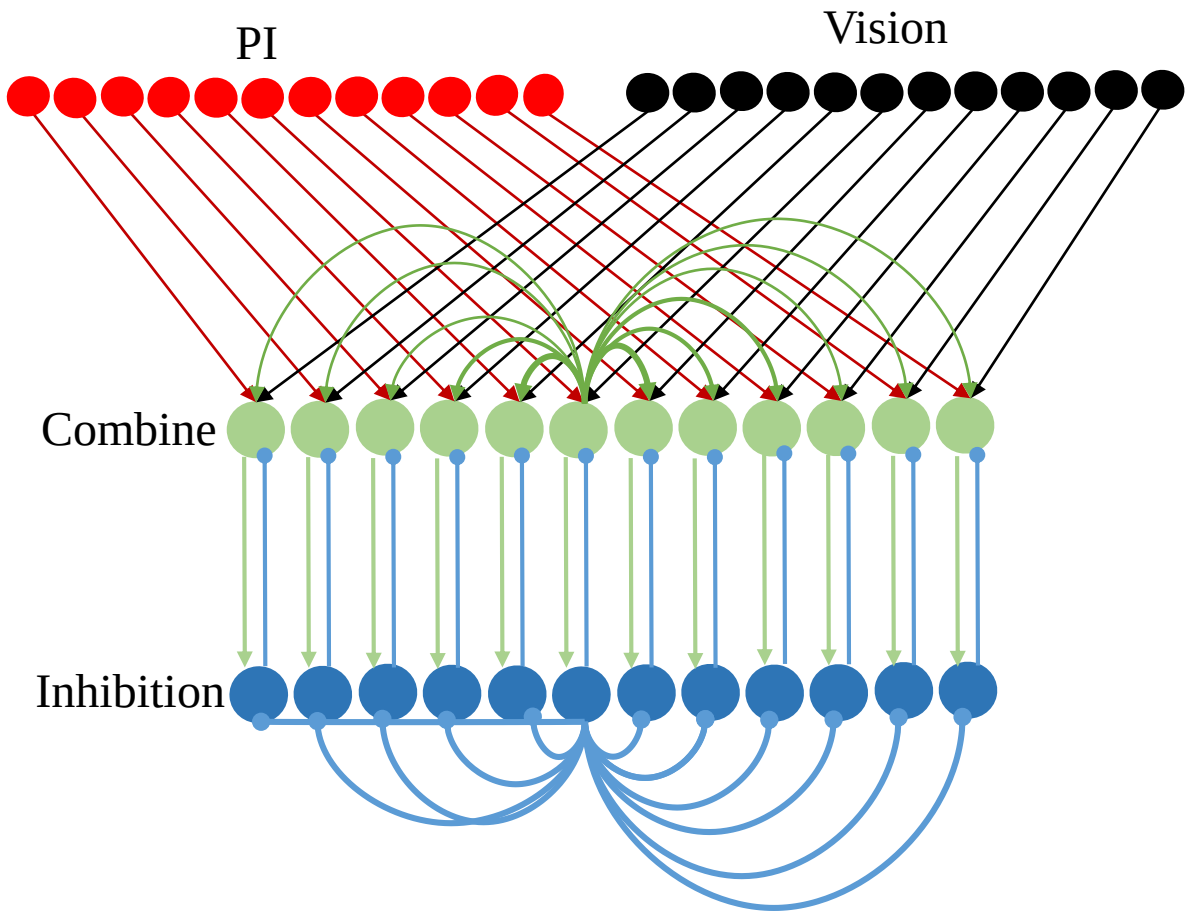
MARKUS KNADEN & R WEHNER, *Nest mark orientation in desert ants Cataglyphis: what does it do to the path integrator?* ANIMAL BEHAVIOUR, 70, 1349–1354, 2005

Cues Combination Model-General

How to build a neuron model to combine the PI and vision and the model can repeat the results of the biology experiments?



Outbound: PI model – Memory Established

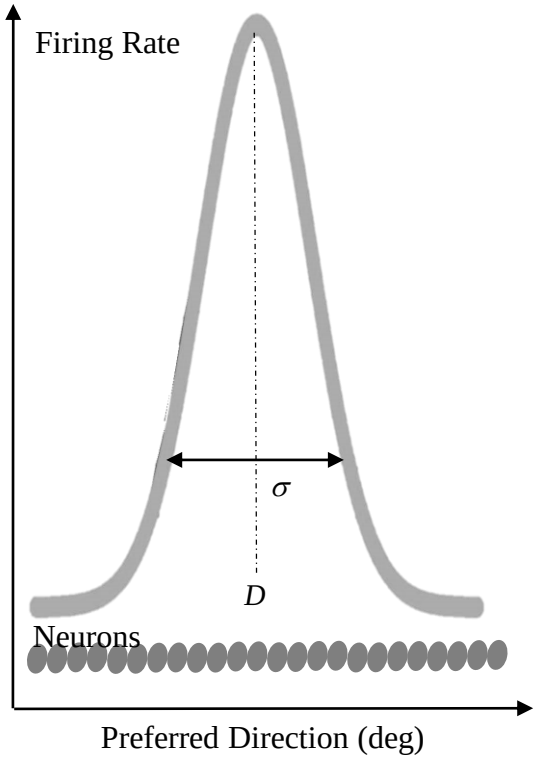


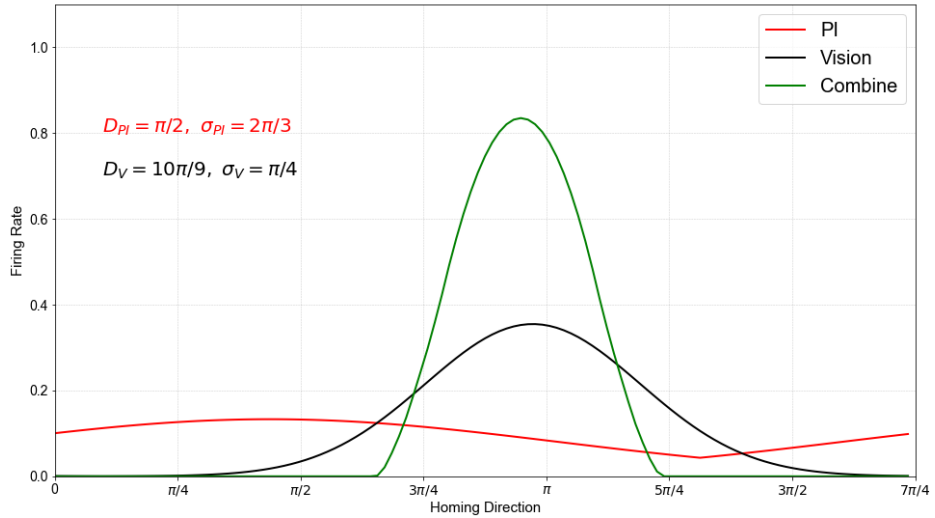
Homing: PI and vision cues are combined dynamically

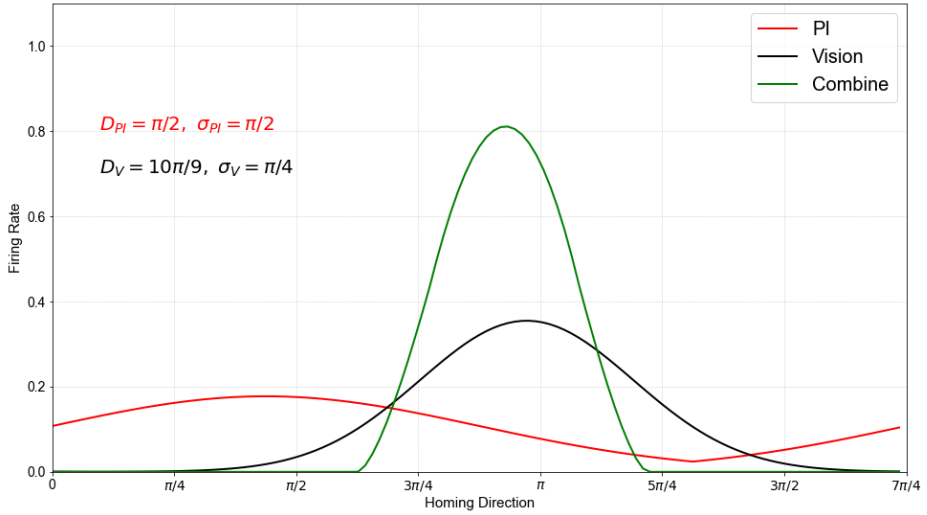
Neurons (labeled with preferred direction) → Excitation Connections —● Inhibition Connections

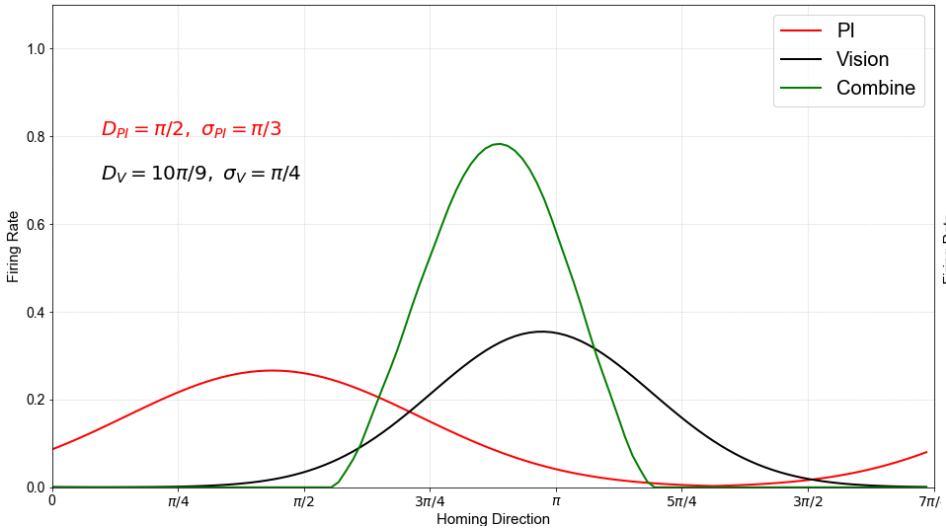
Cues Combination Model-General Results

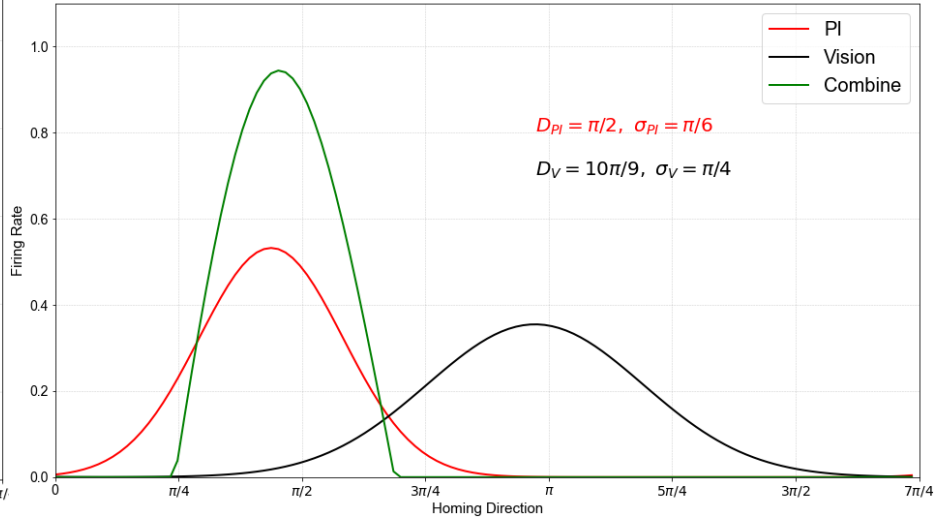
To focus on the properties of combination, now we just feed the ideal inputs to the model.
As inspired from the Compass Neurons in PI, we give the bell-shape (Gaussian Distribution) activation profile.
For accuracy and simplicity, we set the numbers of neurons in each population be the same N=120.





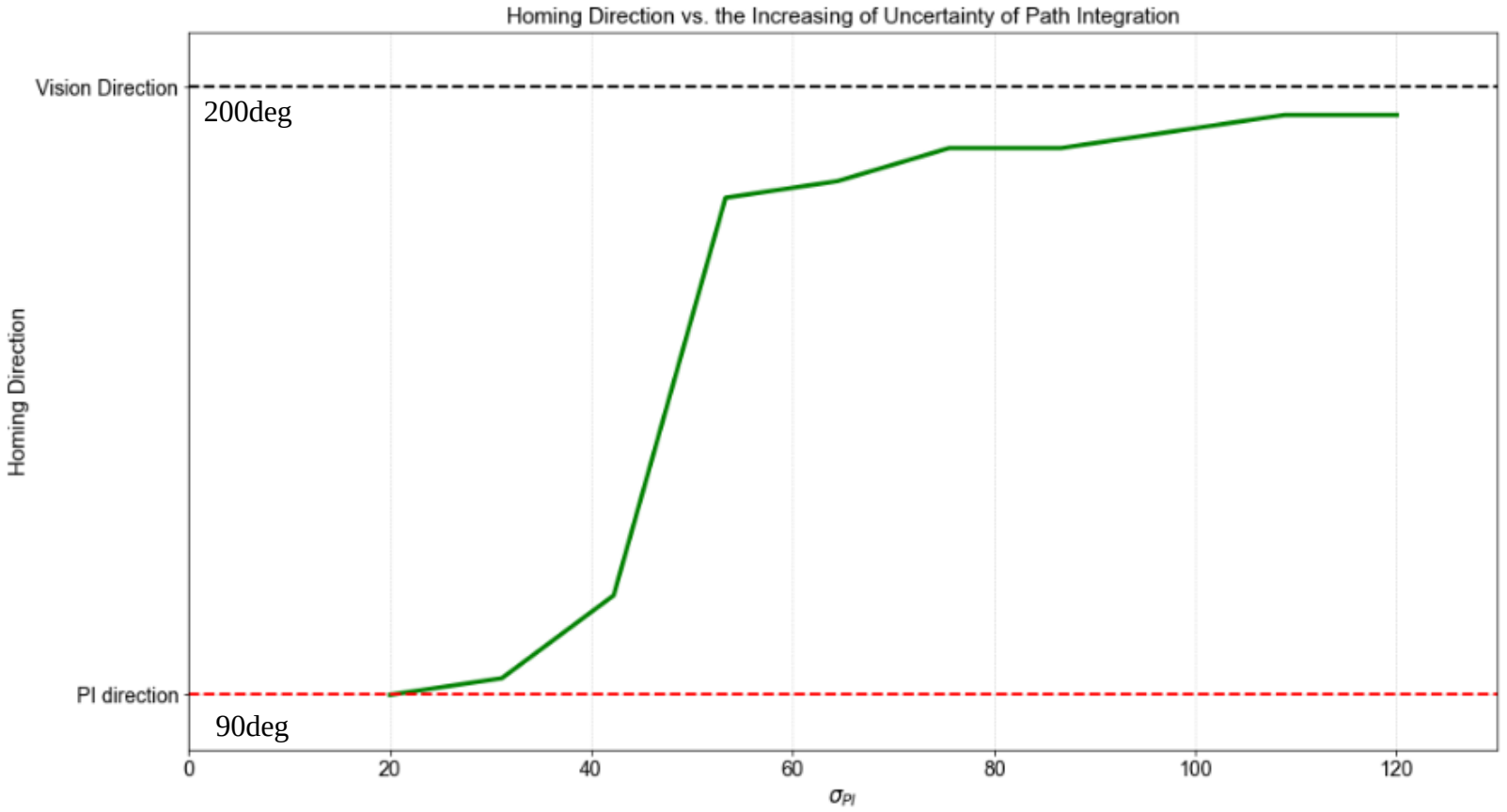


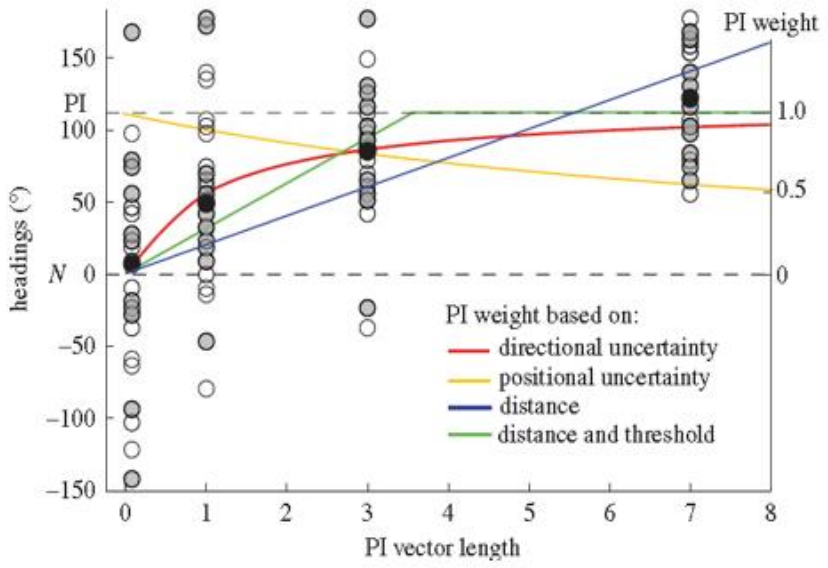




Cues Combination Model -General Results

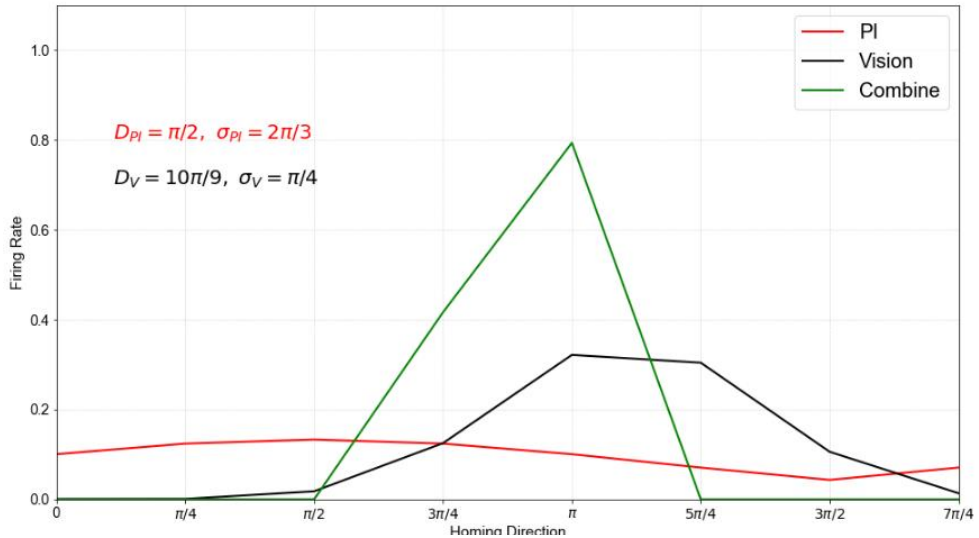
The results of this model is very similar with the biology experiments.

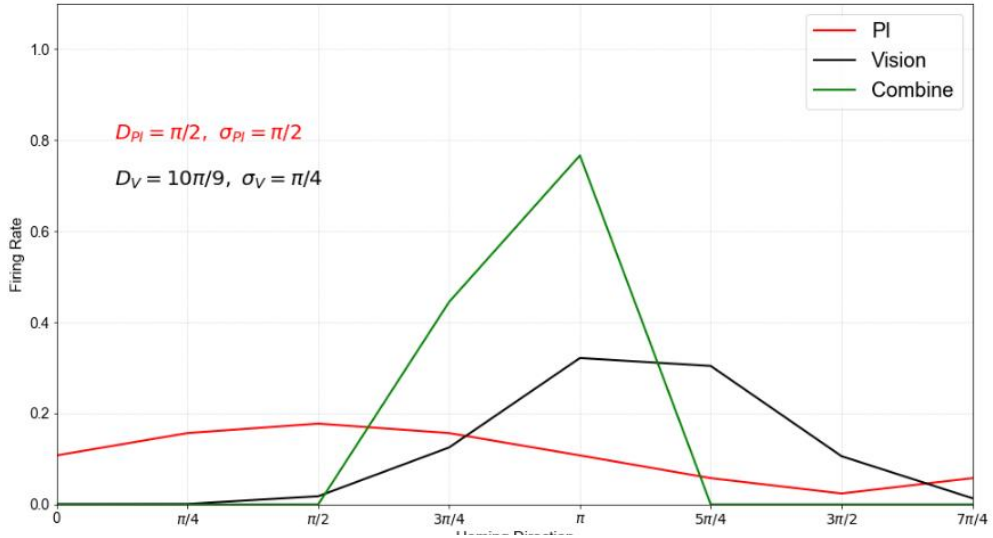


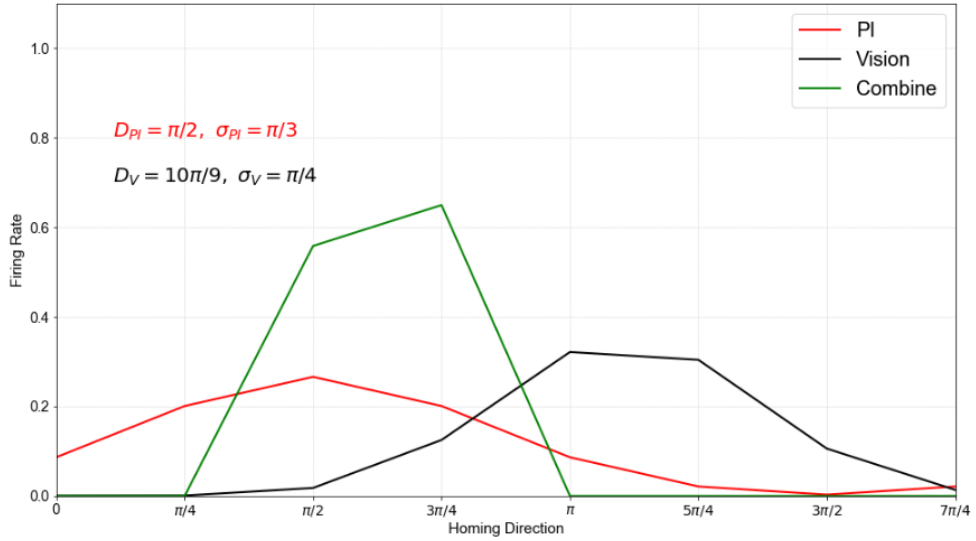


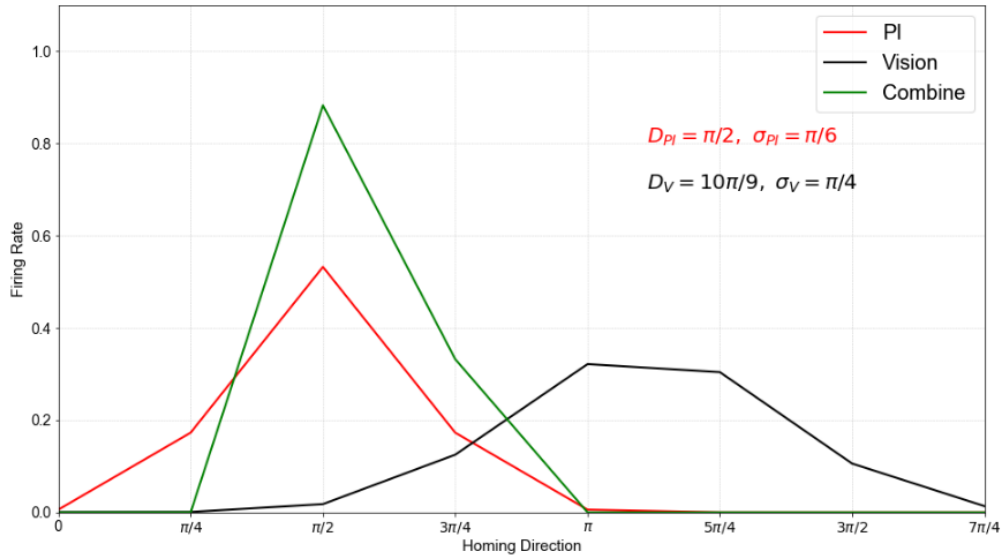
Cues Combination Model-Consider with the PI model

If we only have N=8 neurons to encode the 360 degree, just as the PI model introduced before, what's the impact?

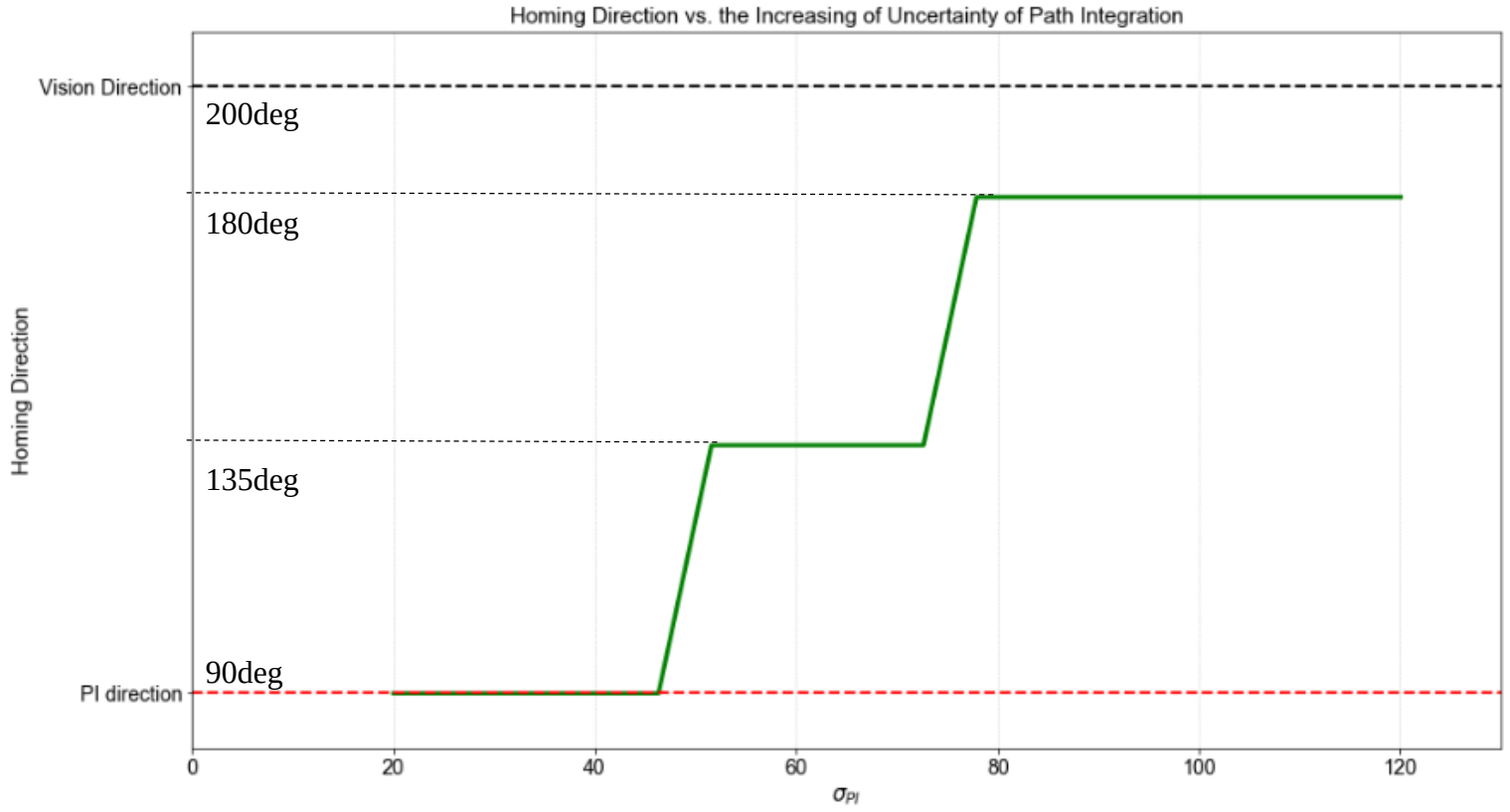








Cues Combination Model-Consider with the PI model

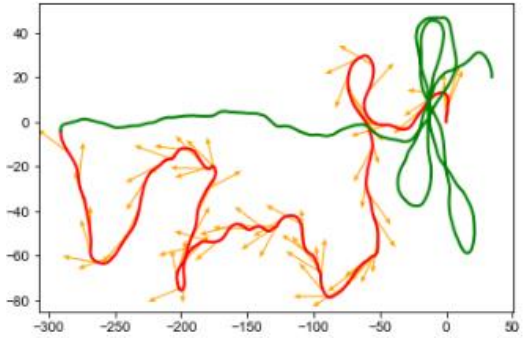


- The activation profile goes well, which reveals that this cues combination model is bio-plausible when consider it with the new published PI model.
- This curve looks a little strange mainly because using 8 neurons to encode 360deg, we only have 45deg accuracy.

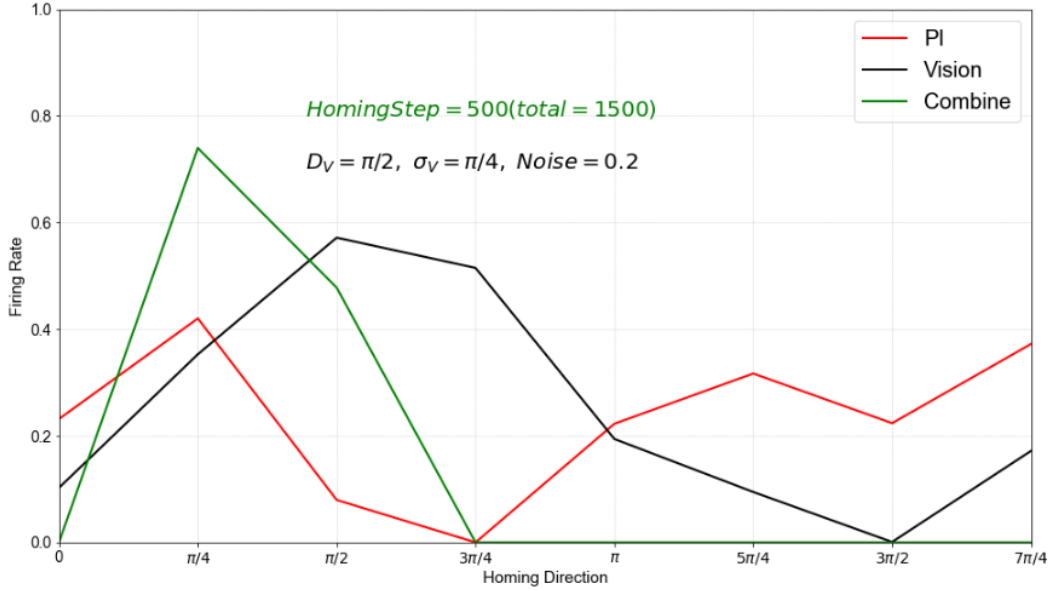
Cues Combination Model-Consider with the PI model

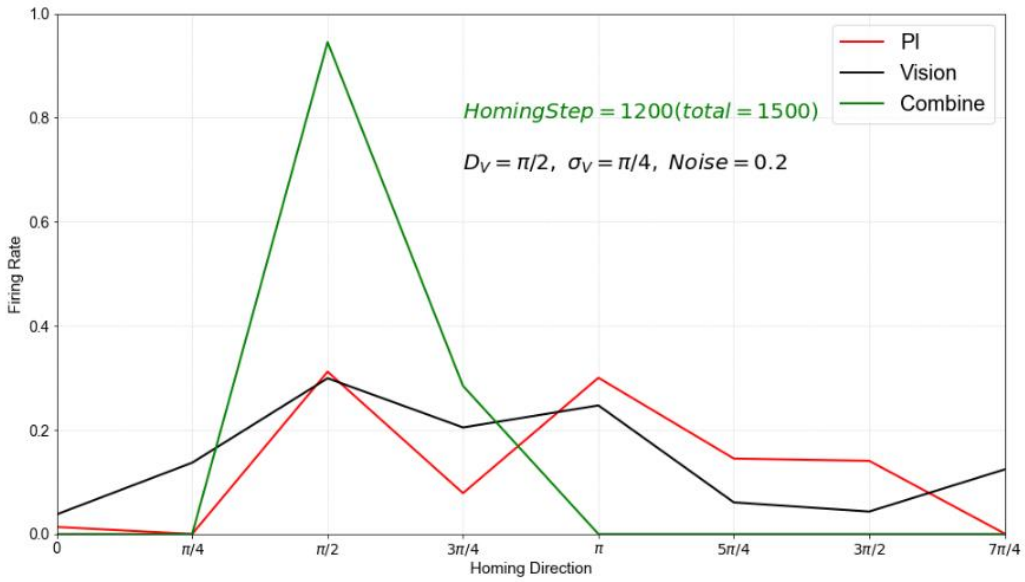
Here, we use the ideal bell-shape activation profile to feed the combination model, thus, if the input profile is not as standard we want, what will happed to this model?

Let's test it using the outputs of the *CPU4* (integrator cells) neurons from PI model as our PI input. For vision input, we add random noise.



Through the figures that show the input and output activation profiles, we can see that the model can still work with 'bad' inputs. However, we should find out what the integration actually do to the homing performance. So we should think the relationship between PI model and this Cues combination model mathematically and anatomically, which leads to the future works.

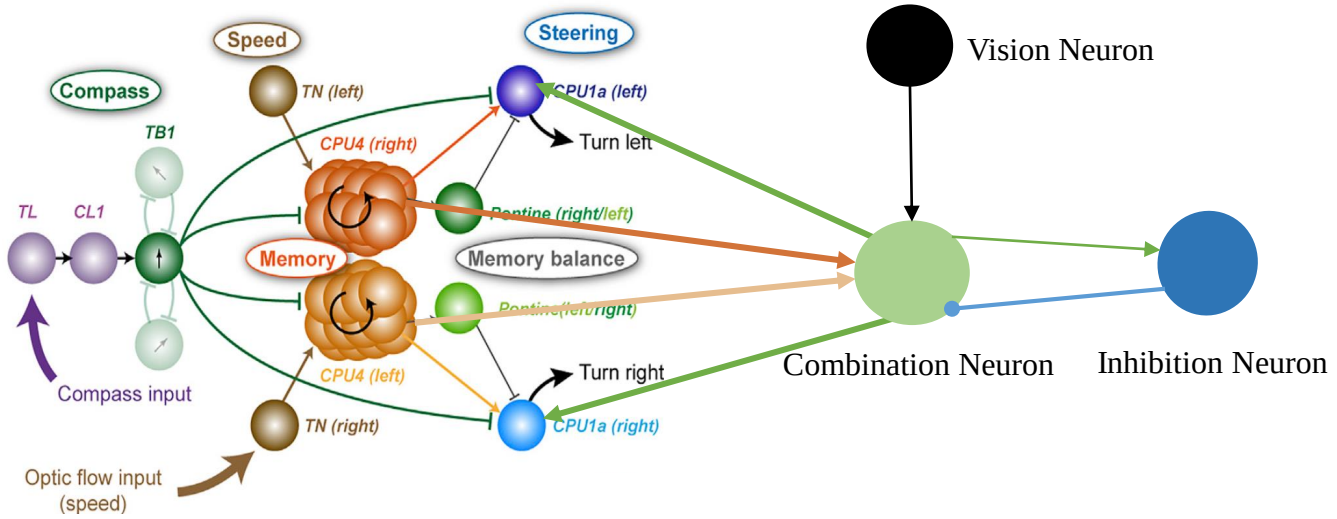




Cues Combination Model-Consider with the PI model

There are two hypothesizes for the roles that the PI model and our Cues Combination Model play in the Navigation System.

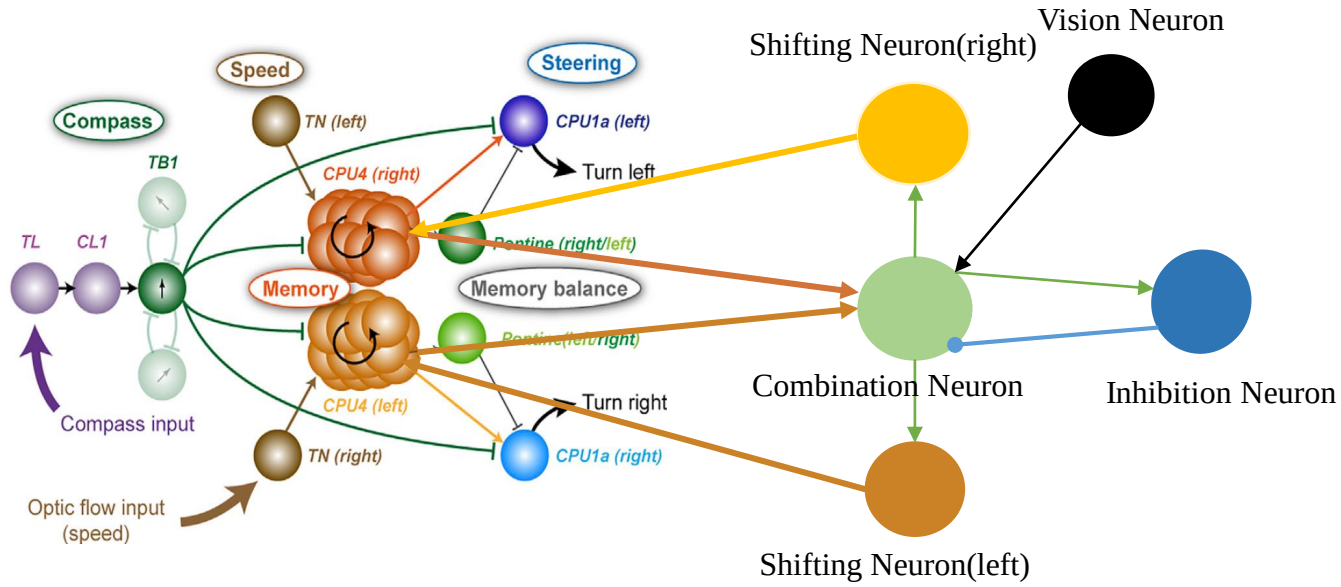
Hypothesizes 1



Which is right?

That depends on the actual performance and the real anatomy.

Hypothesizes 2



Conclusions

- Insects are skillful navigators with strong ability which enable them to accurately forage and home in various situations and environments.
- Path Integration and Visual Landmarks are the most crucial tools of the insect's toolkit for navigation.
- Path Integration and Visual Landmarks have their own advantages and flaws, so the smart insects should combine them optimally using their little brain.
- Many interesting biology experiments have showed the behavioral relationships between them.
- Now, we have a elegant and effective cues combination models with ring attractor properties, which can repeat the results of the biology experiments.
- The cues combination models are robust for small neurons using to encode the direction and they can still work with not-friendly inputs.
- We can implement the little model in Robots, run just like a *Kalman filter*, which is a classic signal integration method. Maybe, the model works even better. That's also what we will do in future works.

Know more about the neurons and the brain,

We know more about the human, We know more about ourselves!

Artificial Intelligence?

Maybe the key lies in the Intelligence, not the artificial!

European Commission

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

Q & A

Thank You!

Xuelong Sun

Friday， 01 Dec 2017
TsingHua University, Beijing

UNIVERSITY OF LINCOLN