How could the mushroom body and central complex combine for visual homing in insects?

THE UNIVERSITY of EDINBURGH informatics

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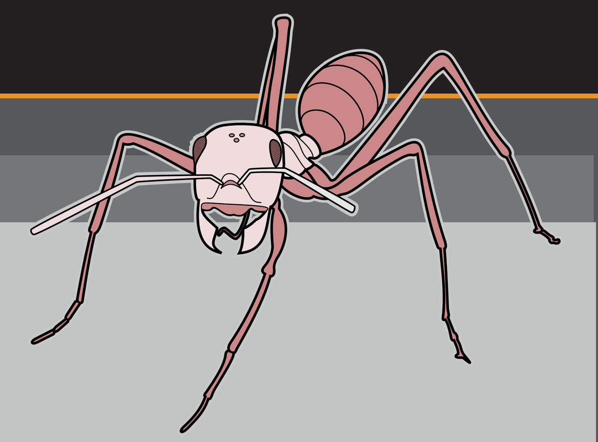
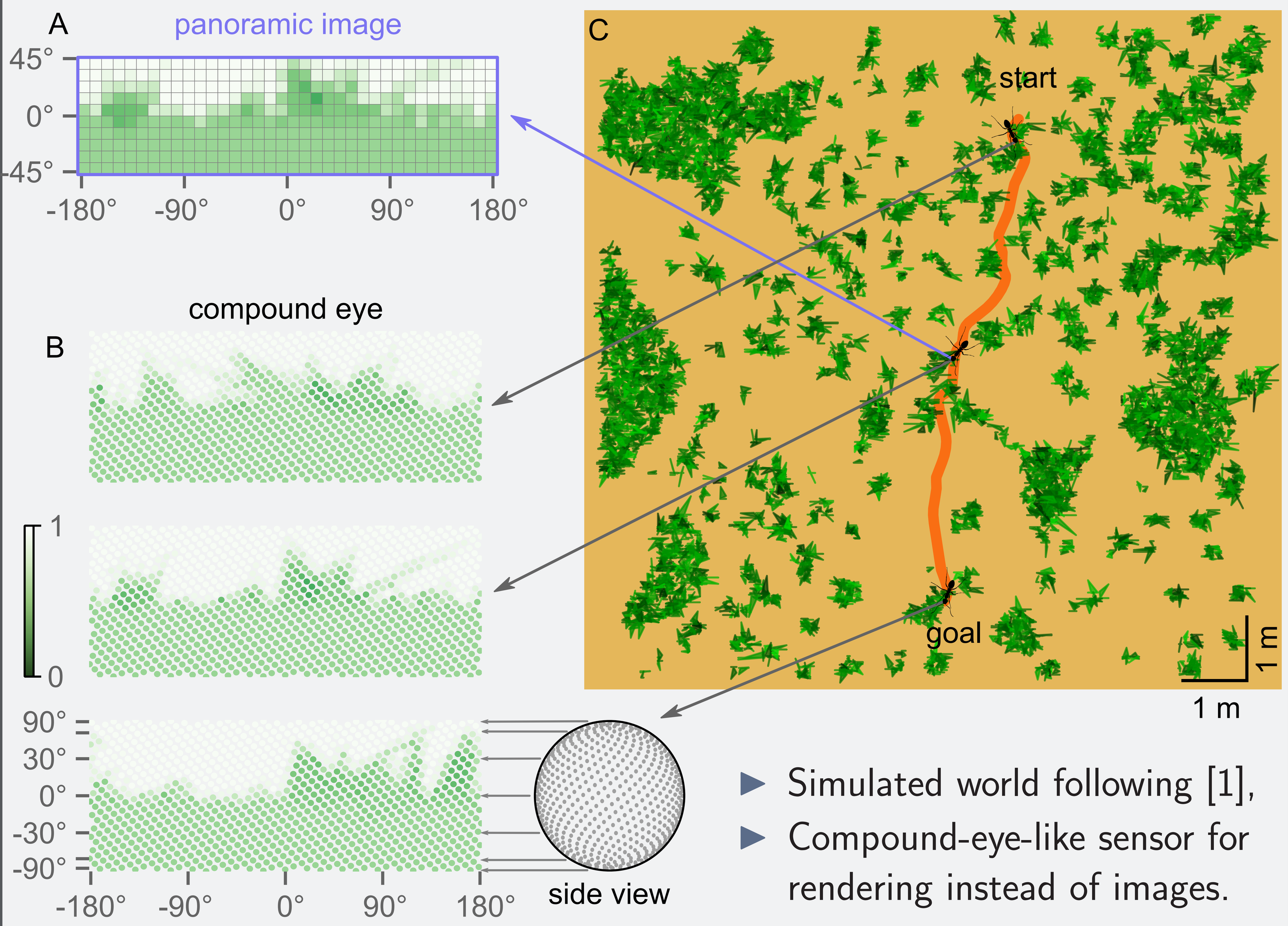


Introduction

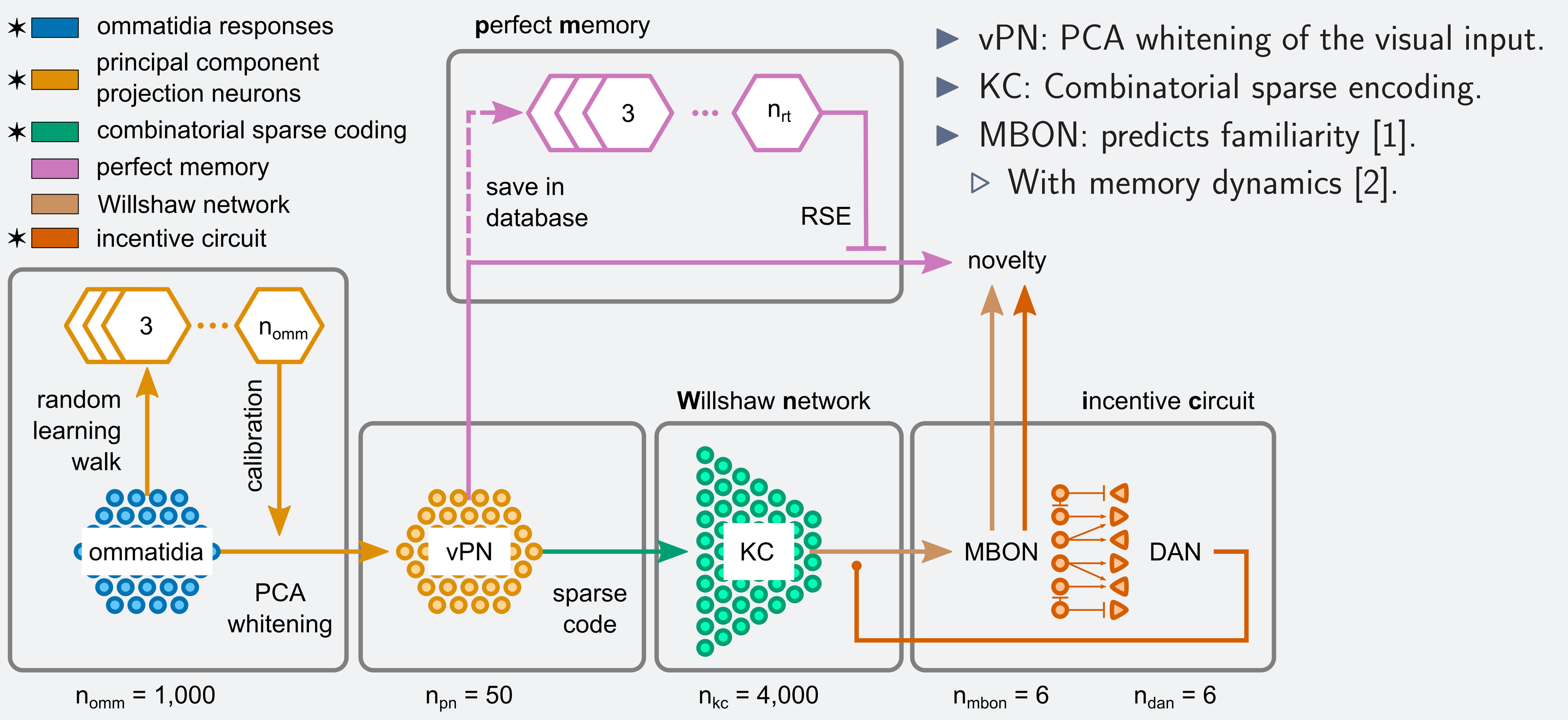
- Desert ants use their visual memory to follow familiar routes and find their nest, and this is usually assumed to be processed by their *mushroom bodies* (MB).
- We take a computational approach to the problem, which we bound in the natural behaviour of the animal.
  1. Therefore, we developed a compound-eye-like rendering system to capture views from a simulated world, and use them to train an MB model, following [1].
  2. To reduce the correlation amongst views, we propose that the *visual projection neurons* (vPN) might perform PCA whitening, and the *Kenyon cells* (KCs) a combinatorial encoding.
  3. We tested the performance of the incentive circuit [2] in predicting the familiarity of given views, which suggested that consecutive familiar views increase the confidence of the animal.
- Following [3], we suggest that the increasing confidence can be used by the *central complex* (CX), along with input from the *lateral horn* (LH), to shape the behaviour of the animal.

Methods: simulation and the compound eye



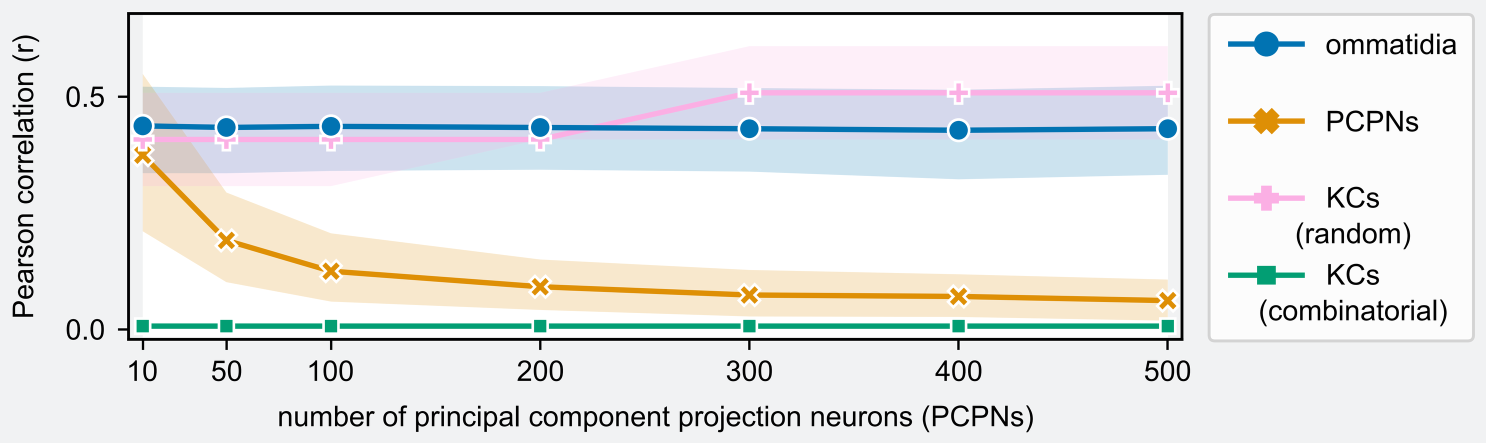
- Simulated world following [1].
- Compound-eye-like sensor for rendering instead of images.

Methods: visual processing pipeline



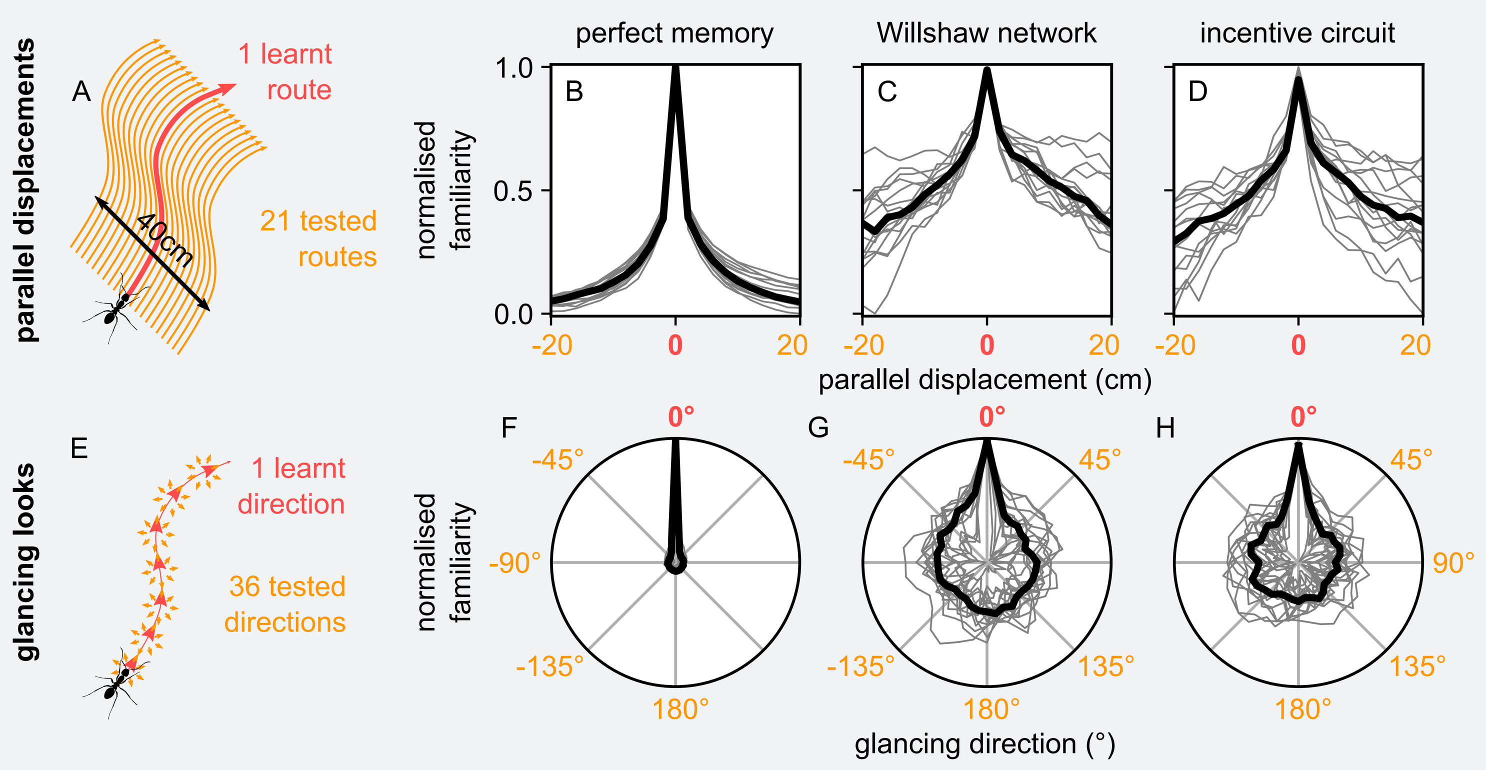
- vPN: PCA whitening of the visual input.
- KC: Combinatorial sparse encoding.
- MBON: predicts familiarity [1].
  - With memory dynamics [2].

Results: processing by the visual projection neurons and Kenyon cells



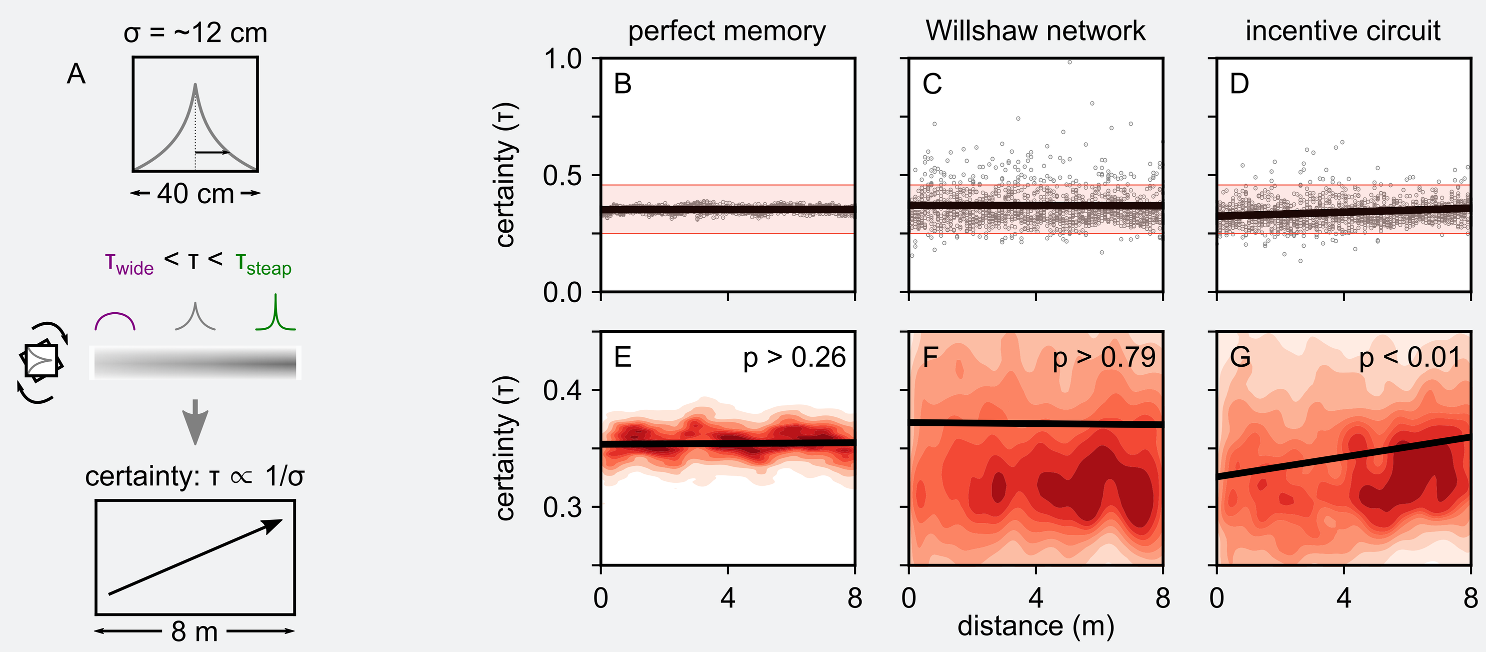
- PCA whitening and combinatorial encoding reduce correlation among views.

Results: calculating the familiarity



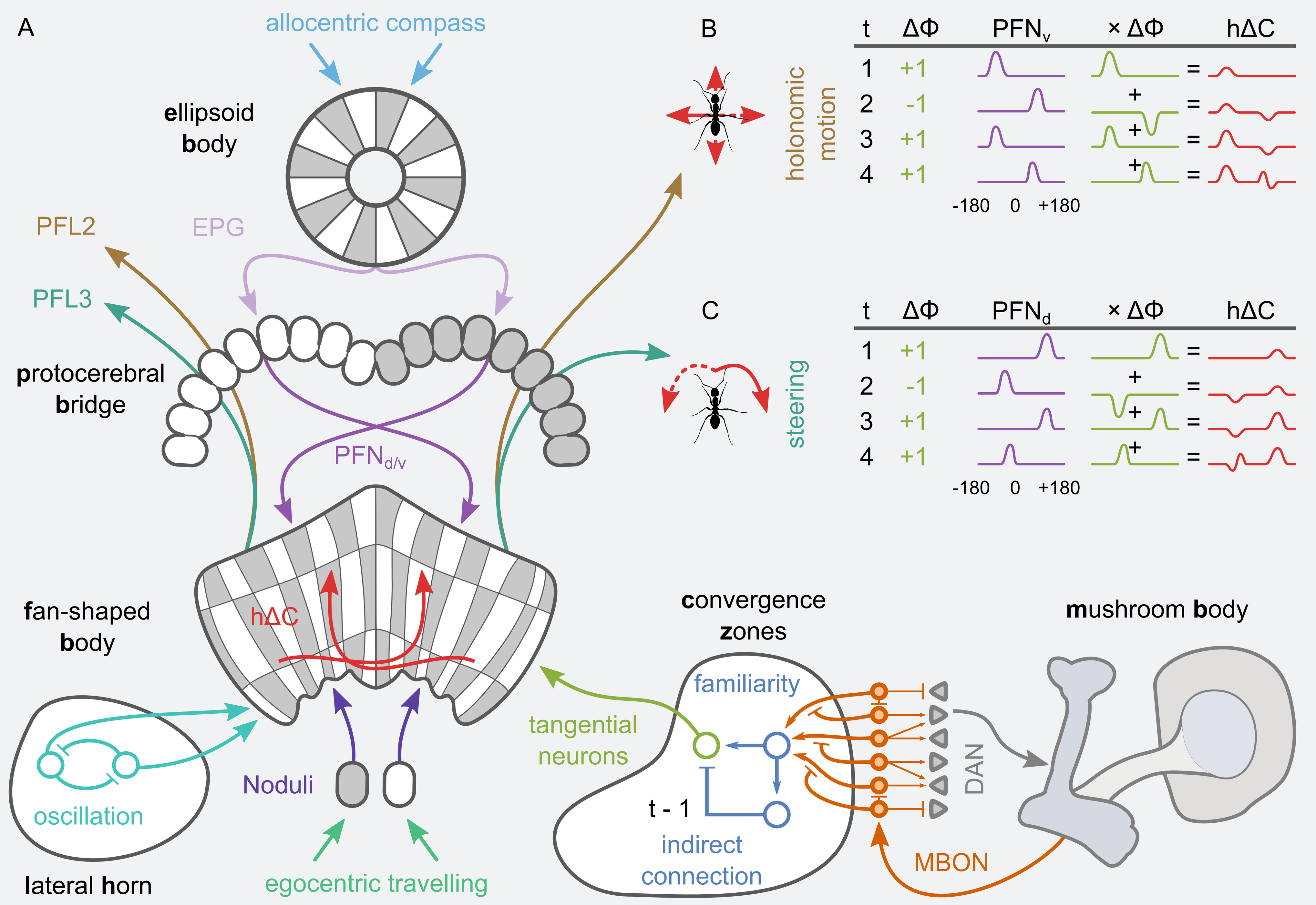
- **parallel displacements:** train on a route, test on its parallel routes.
- **glancing looks:** train on a route, test on different glances.

Results: the increasing confidence



- **Confidence:** the steepness of the familiarity distribution around a route.
- Only the incentive circuit increases the confidence along familiar routes.
  - Page's trend test: $p < 3 \cdot 10^{-6}$.

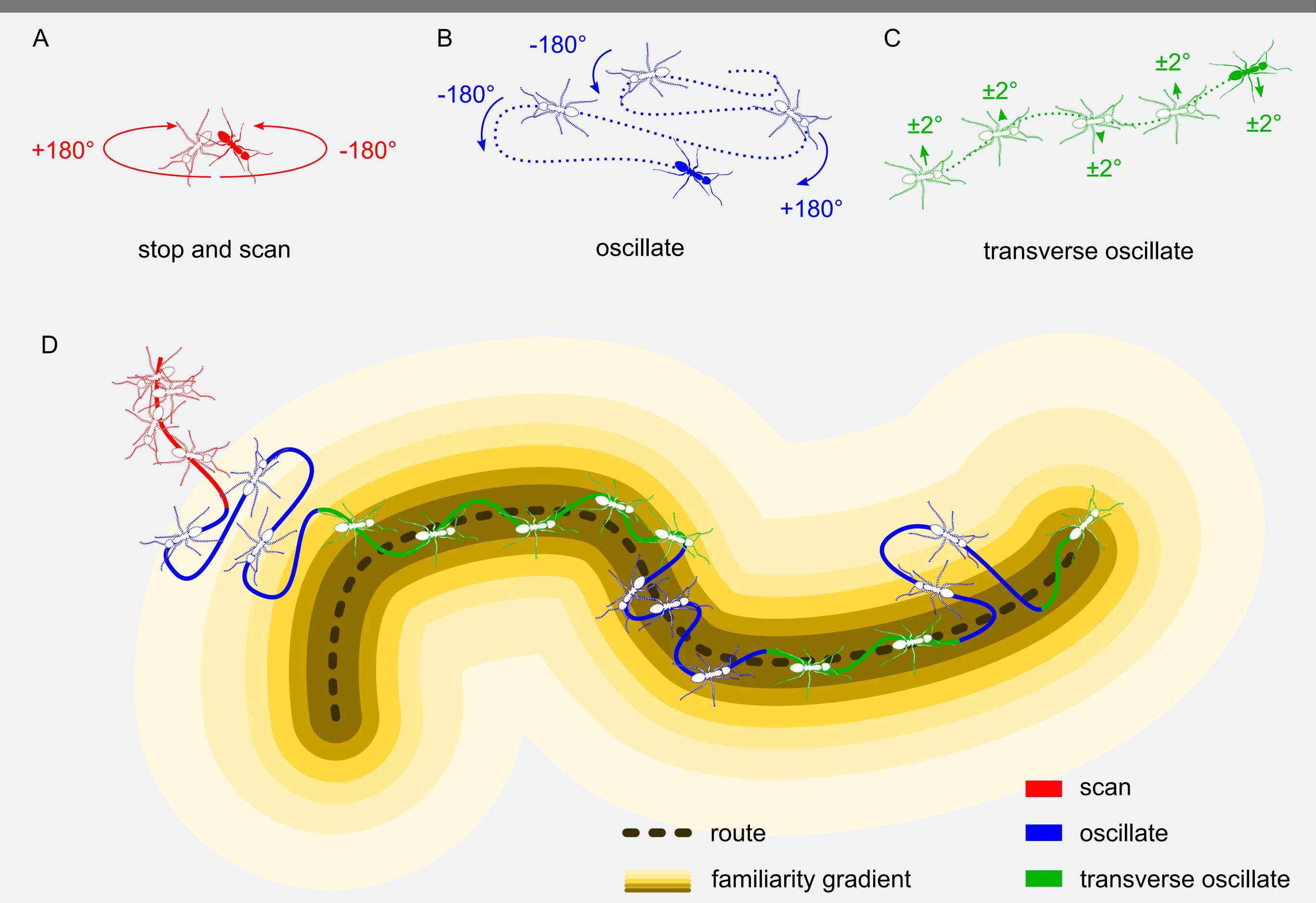
Discussion: interaction of the mushroom body with the central complex



- The LH provides the innate oscillating behaviours to the FB.
  - These are: *stop-and-scan*, *oscillate*, and *transverse oscillate*.
- Active LH neurons shift the activity bump of different groups of PFNs (v: holonomic, or d: steering) [3].
- The MB selects which of those will affect the PFNs.
- Increasing or decreasing familiarity causes switching of behaviours.

Discussion: an example of switching oscillations

- Differential familiarity causes switches in the behaviour.
  - Increasing familiarity gears-up towards transverse oscillating.
  - Decreasing familiarity gears-down towards stop-and-scan.
- Stop-and-scan samples an overall familiar direction and enables the oscillations.
- Based on the familiarity, following the result direction might enable stop-and-scan or transverse oscillations.



References

[1] P. Ardin, F. Peng, M. Mangan, *et al. PLOS Computational Biology*, vol. 12, no. 2, p. e1004683, 2016.

[2] E. Gkanias, L. Y. McCurdy, M. N. Nitabach, and B. Webb *eLife*, vol. 11, p. e75611, 2022.

[3] C. Lyu, L. F. Abbott, and G. Maimon *Nature*, vol. 601, no. 7891, pp. 92–97, 2022.

Conclusion

- PCA whitening and combinatorial encoding effectively reduced the correlation of the visual inputs.
- MBONs can affect flexible behaviours, but the LH and CX are also needed for implementation.