Insect solutions to olfaction and visual navigation

BRANDY School
Val di Sole

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Olfaction

- “Odors” are typically complex mixtures of chemicals, e.g., the smell of coffee contains dozens of components above detection threshold:

Chemical components in Coffee Aroma

Odor component	$\mu g/l^*$	Odor component	$\mu g/l^*$
Acetaldehyde	4700	3-Hydroxy-4,5-dimethyl-2(5H)-furanone	80
Methylpropanal	760	(E)-P-Damascenone	1.6
2-Methylbutanal	870	Guaiacol	120
3-Methylbutanal	570	4-Ethylguaiacol	48
2,3-Butanedione	2100	4-Vinylguaiacol	740
2,3-Pentanedione	1600	Vanillin	210
2-Ethyl-3,5-dimethylpyrazine	17	2-Furfurylthiol	17
2-Ethenyl-3,5-dimethylpyrazine	1.0	Methional	10
2,3-Diethyl-5-methylpyrazine	3.6	3-Mercapto-3-methylbutyl formate	5.7
2-Ethenyl-3-ethyl-5-methylpyryzine	0.2	2-Methyl-3-furanthiol	1.1
3-Isobutyl-2-methoxypyrazine	1.5	3-Methyl-2-buten-1-thiol	0.6
4-Hydroxy-2,5-dimethyl-3(2H)-furanone	7200	Methanethiol	170
2(5)-Ethyl-4-hydroxy-5(2)-methyl-3(2H)-furanone	800		

*in coffee brew

Mayer et al. *Eur Food Res Technol* (2000)

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Olfaction

- “Odors” are typically complex mixtures of chemicals, e.g., the smell of coffee contains dozens of components above detection threshold:
- Animals (and humans) can, however, also recognize the components in a mixture (to some extent)

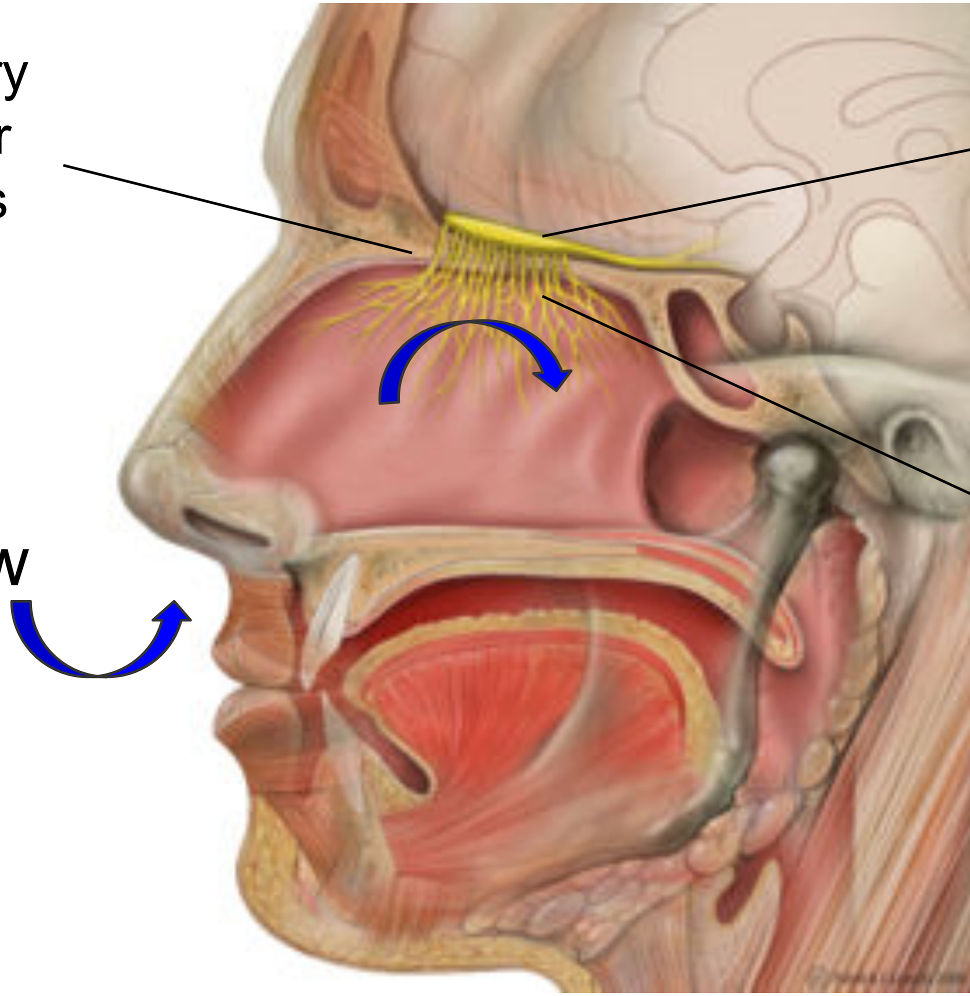
Odours mix in complex plumes

Marc Weissburg et al. J Exp Biol 2012;215:4175-4182

The Journal of Experimental Biology

- Odours travel from their source to your nose in complex plumes
- Odour molecules from different sources mingle with each other – but don't fully mix

Olfactory system - humans



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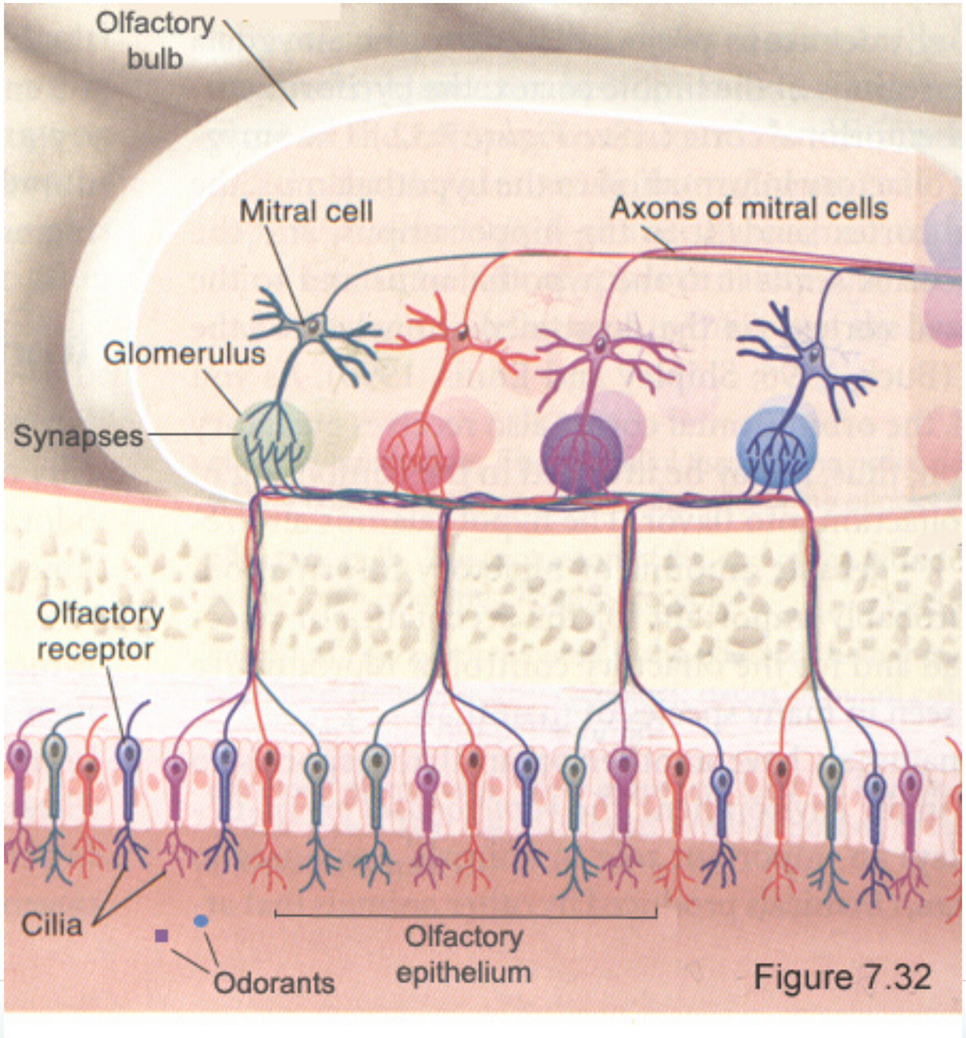
Olfactory transduction pathway (mammal)



Stages

- Mucus, odor binding proteins
- Olfactory receptor neurons
- Mitral cells/ granule cells in the olfactory bulb
- Piriform cortex

chemical

"electrical"

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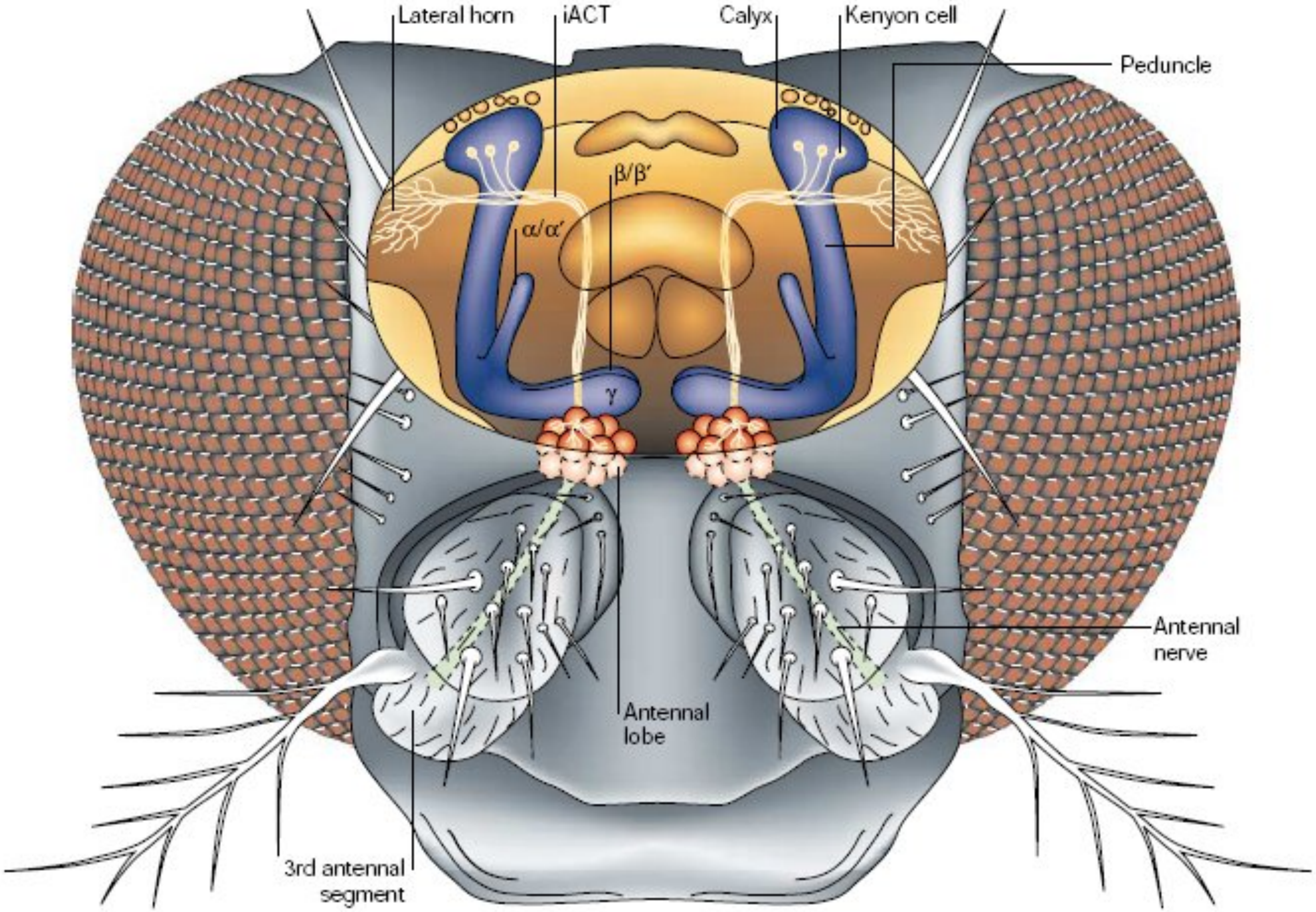
Olfactory system – insects



Heisenberg, Nat Rev Neurosci 4, 266 (2003)

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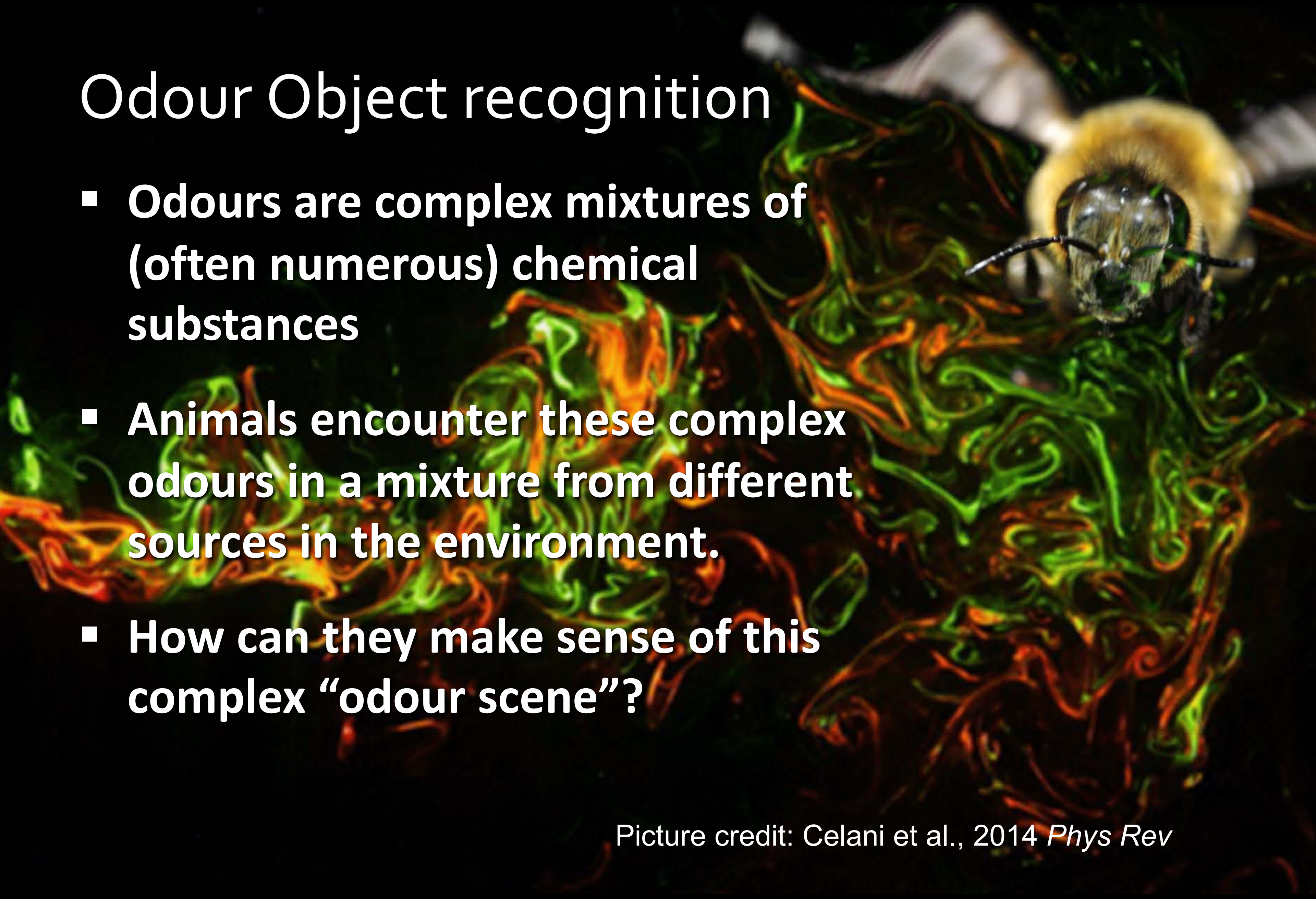
Principles of olfactory systems

- Large number of olfactory receptor types
- Each olfactory receptor neuron (ORN) expresses one specific type
- All ORNs of the same type converge onto the same glomerulus
- Olfactory receptors typically have a broad response profile
- Individual odorants activate more than one receptor type

Olfactory responses are encoded in overlapping pattern of glomerular activity patterns

Odour Object recognition

- **Odours are complex mixtures of (often numerous) chemical substances**
- **Animals encounter these complex odours in a mixture from different sources in the environment.**
- **How can they make sense of this complex “odour scene”?**



Picture credit: Celani et al., 2014 *Phys Rev*

Related problem in the auditory system: Cocktail party problem

→ Concurrent sound segregation

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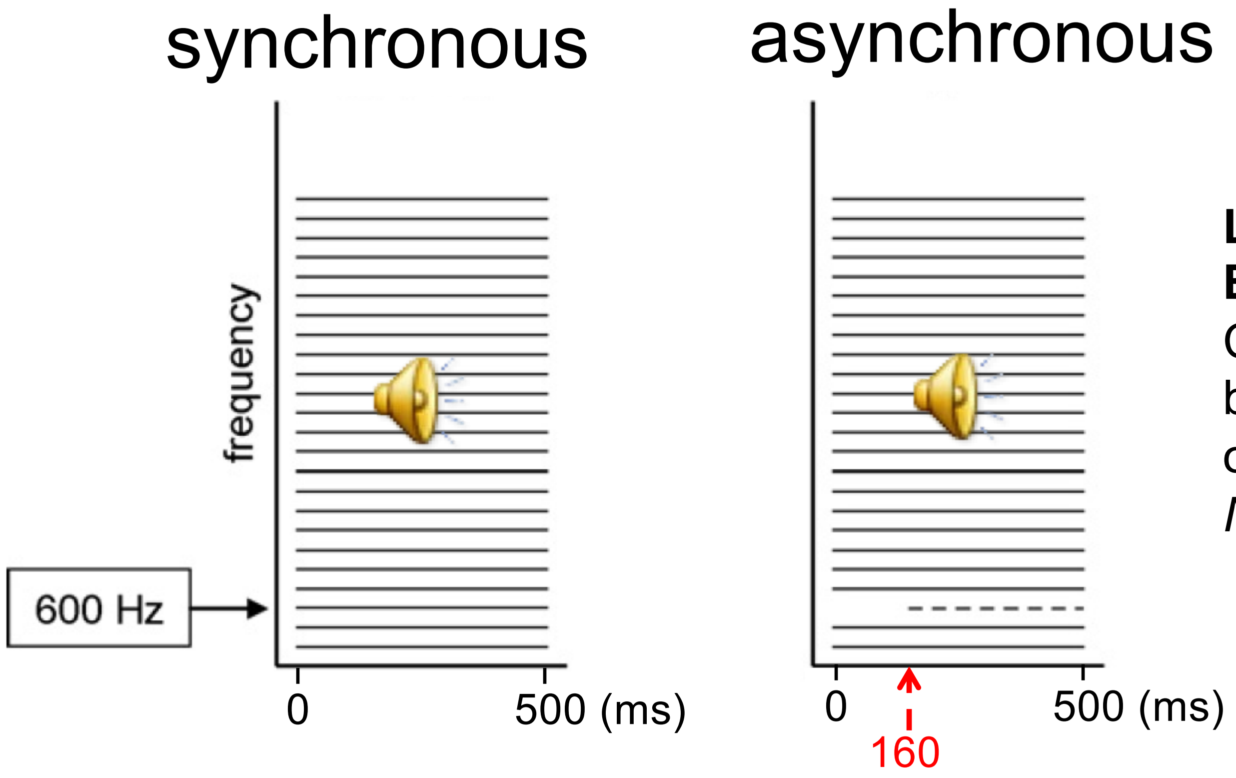
Demo



Lipp, Kitterick, Summerfield, Bailey, Paul-Jordanov (2010) Concurrent sound segregation based on inharmonicity and onset asynchrony. *Neuropsychologia* **48**:1417-25

Did you smell
the difference?

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Well, of
course I did!

No, you
didn’t!

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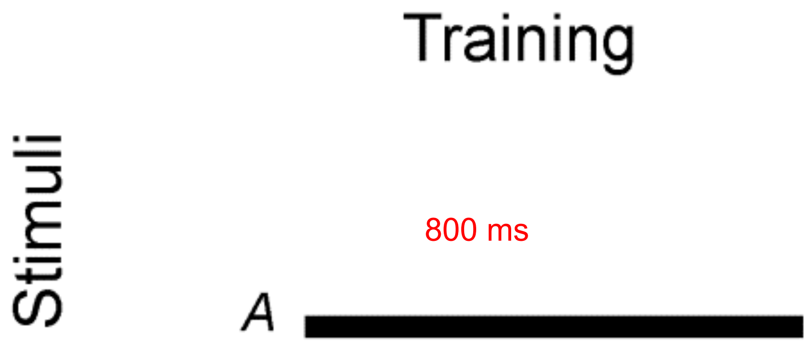
Conditioned Proboscis Extension Response (PER)

Concurrent odor segregation?



Szyszka, Stierle, Biergans, Galizia (2012) **The Speed of Smell: Odor-Object Segregation within Milliseconds**. *PLoS ONE*, 7(4)

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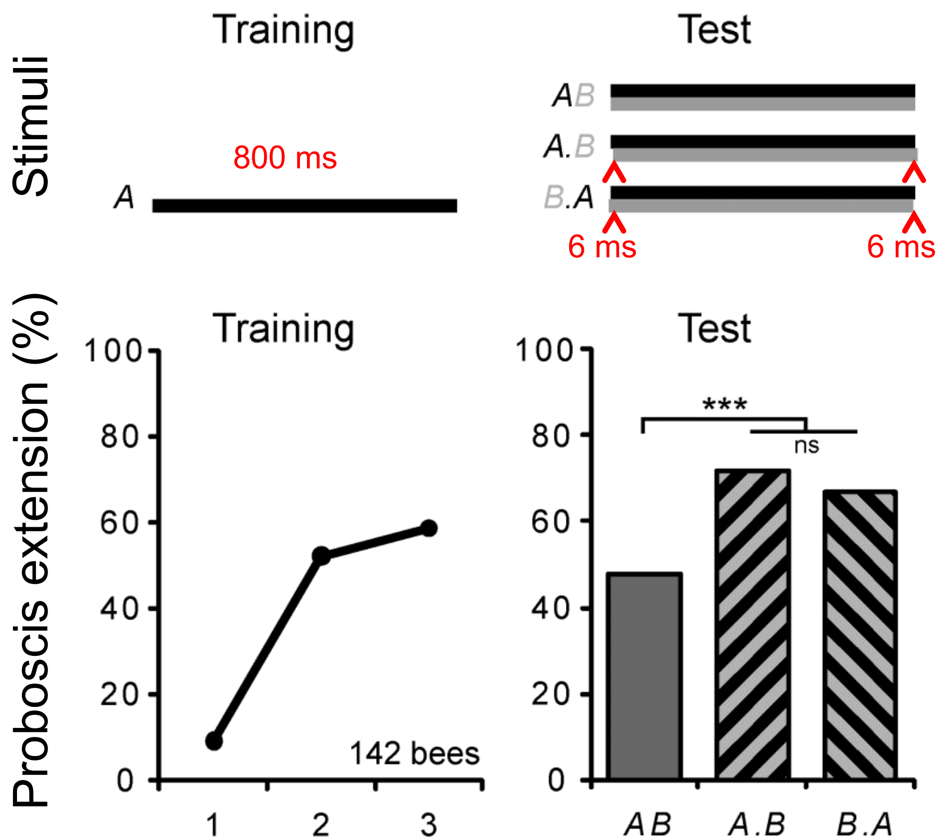
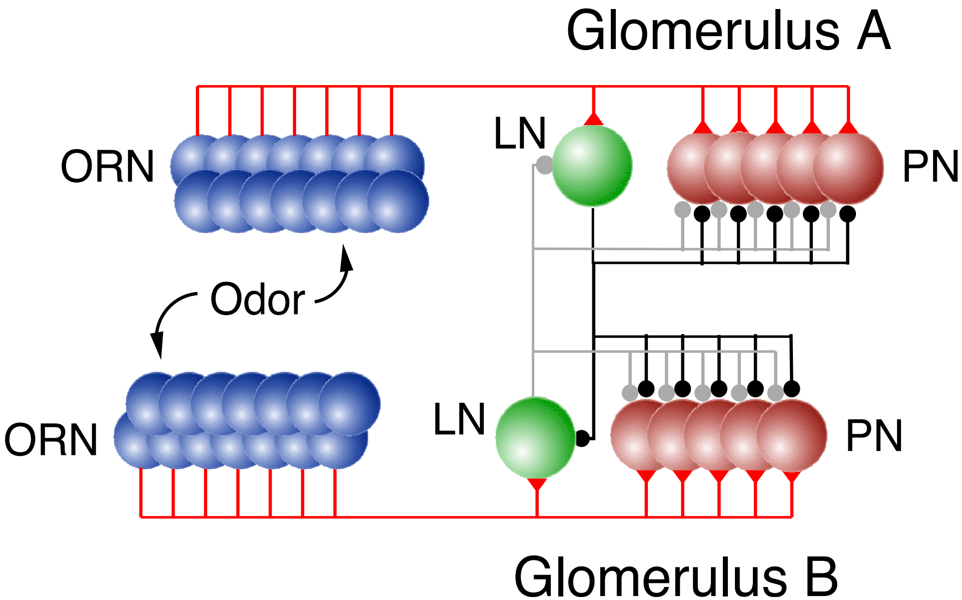
Bees use onset asynchrony



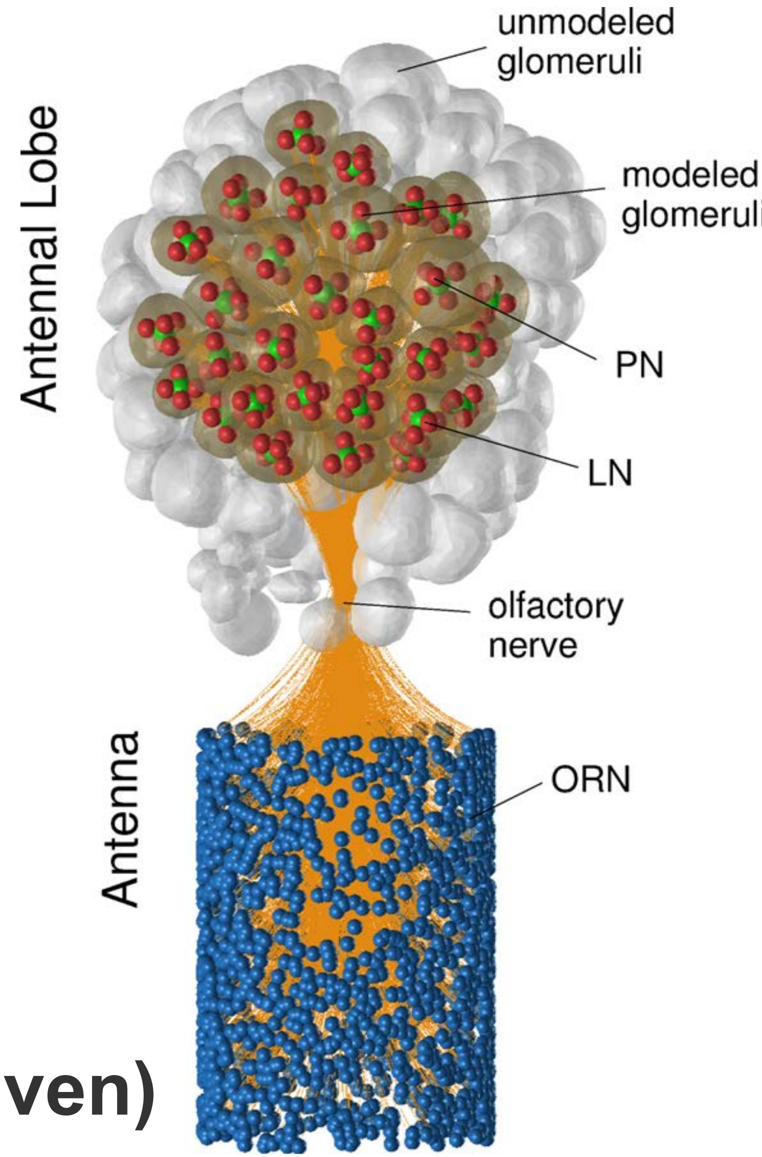
A= nonanol or hexanol
B= hexanol or nonanol

Szyszka, Stierle, Biergans, Galizia (2012) The Speed of Smell: Odor-Object Segregation within Milliseconds. *PLoS ONE*, 7(4)

Circuit (hypothesis driven)



Model “anatomy” (data driven)



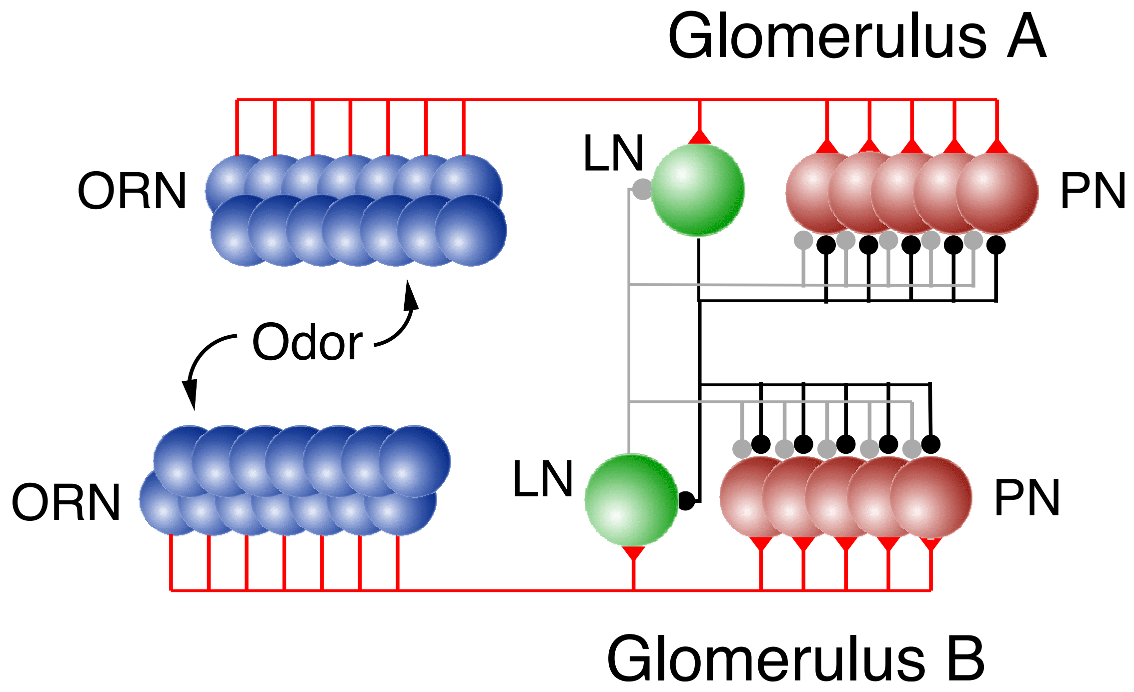
Hypothesis driven part

Hypothesis: Inhibitory winner-take-all circuit breaks the symmetry so that A.B and B.A can be distinguished from AB and each other.

Odour A: $LN_{max}(A)$

Odour B: $LN_{max}(B)$

Odours A+B: $LN_{max}(AB)$



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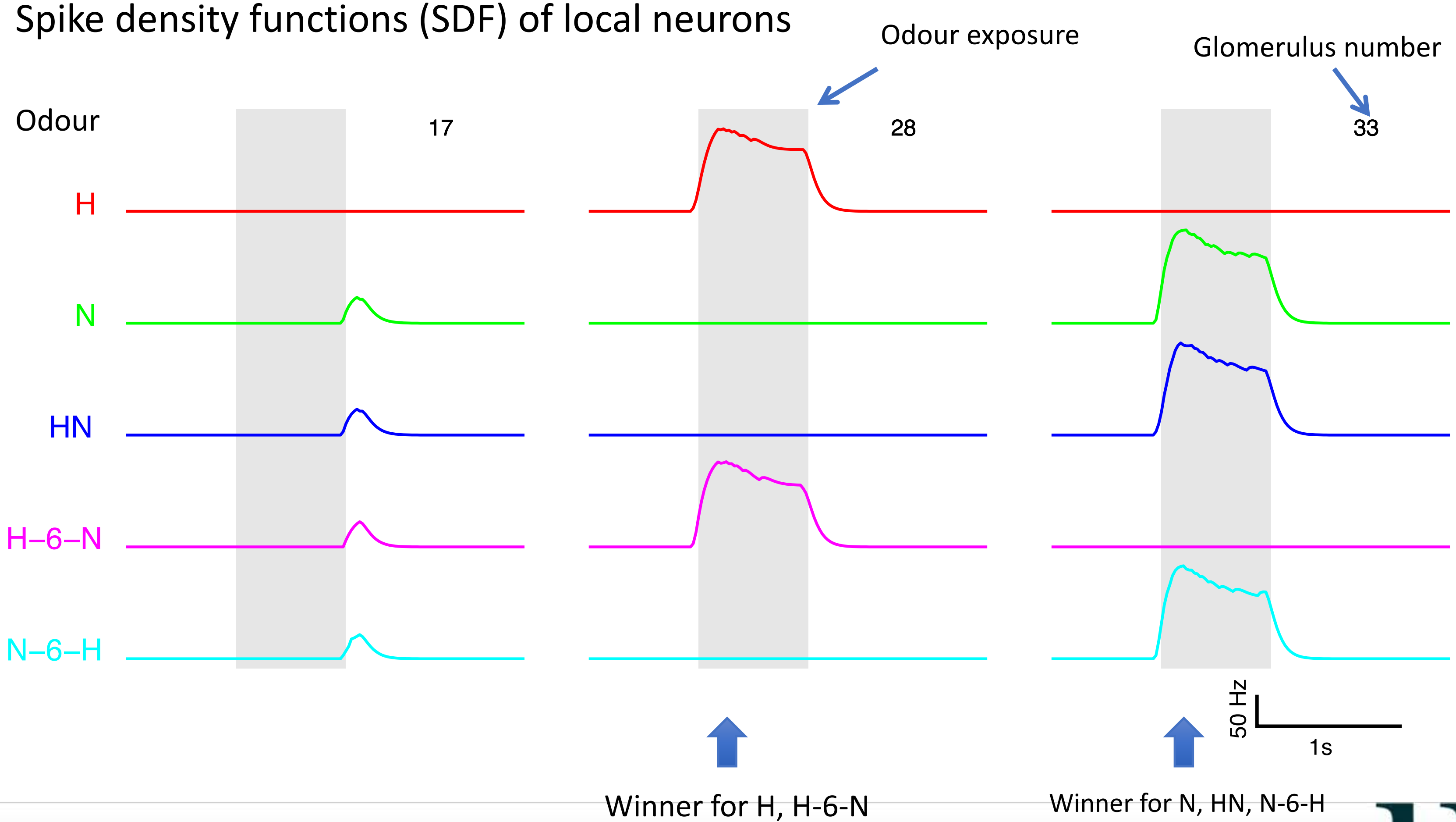
The inhibitory circuit: Winner-take-all

Spike density functions (SDF) of local neurons



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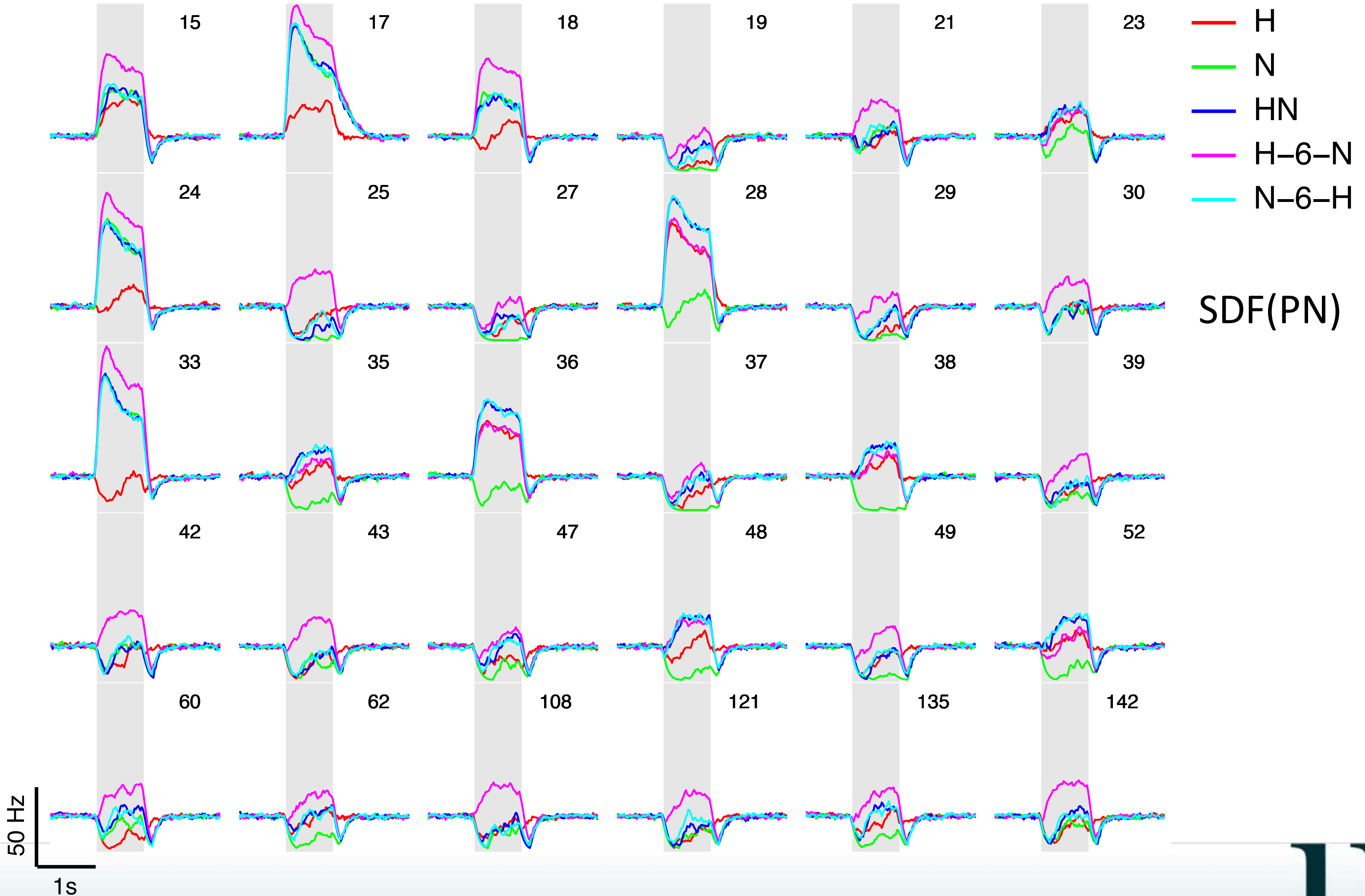
PN activity patterns



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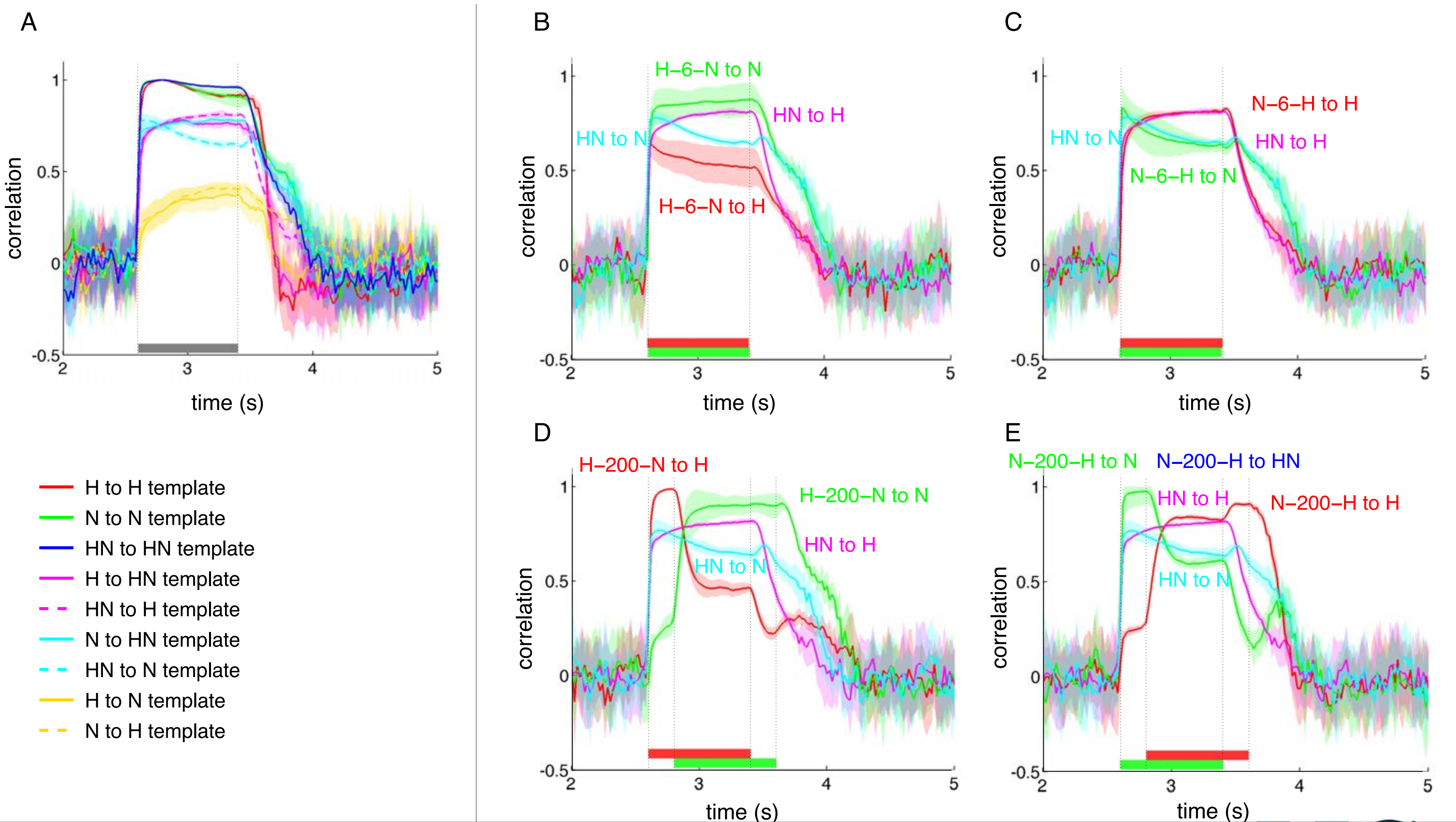
Template-correlation functions



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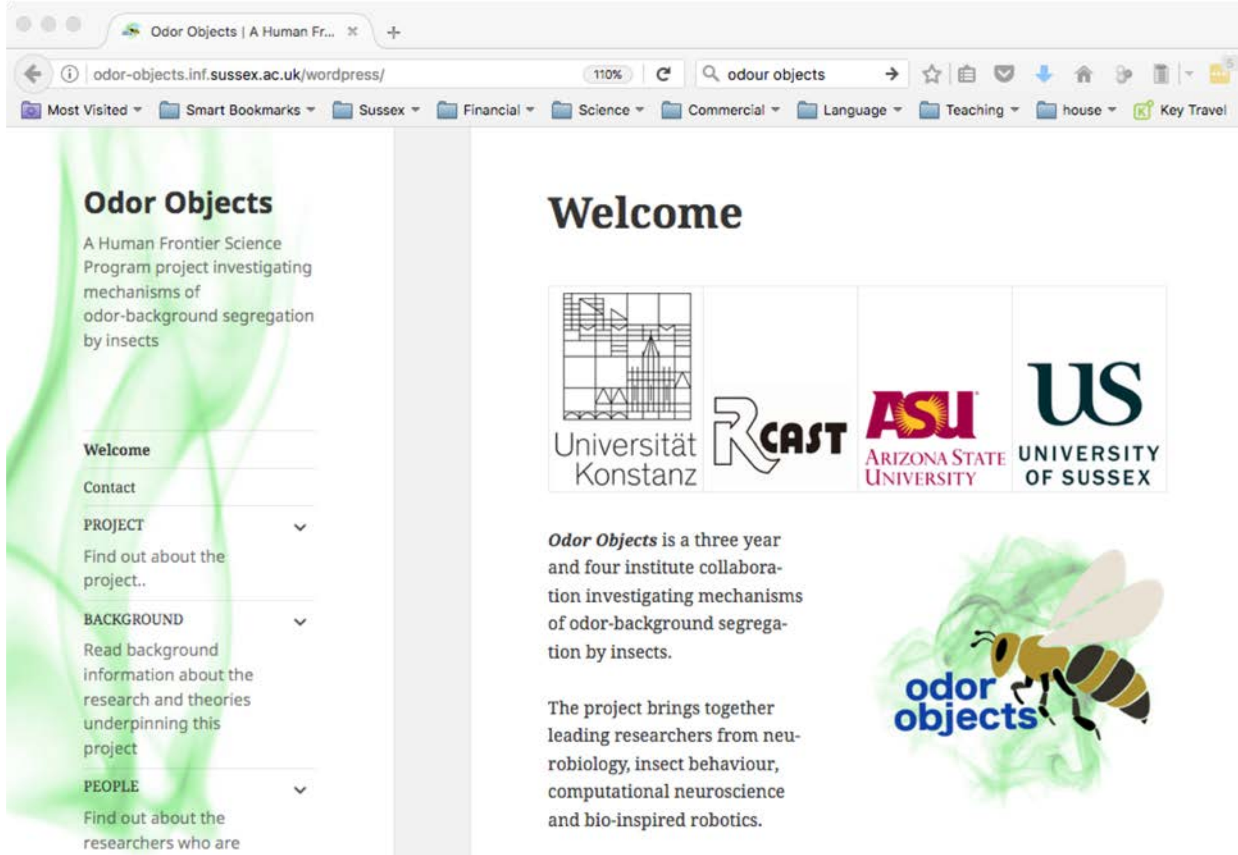
“Odor Objects” project

odor-objects.org



HUMAN FRONTIERS
SCIENCE PROGRAM

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Navigation in Ants and Bees

- Bees can memorize routes over long distances (km)
- Bees and ants can do path integration
- Bees can communicate food locations (waggle dance)

brains on BOARD

What if we could design an autonomous flying robot with the navigational and learning abilities of a honeybee?

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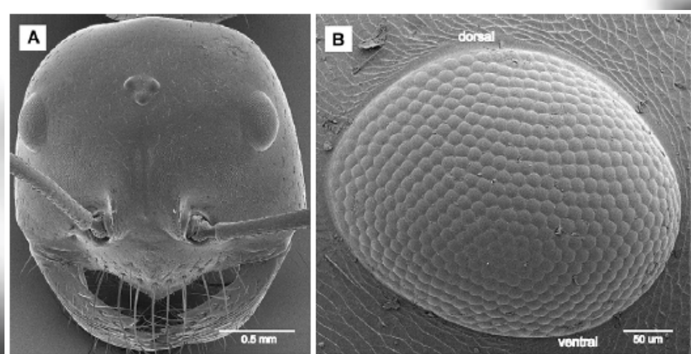
"Human"



"Ant"

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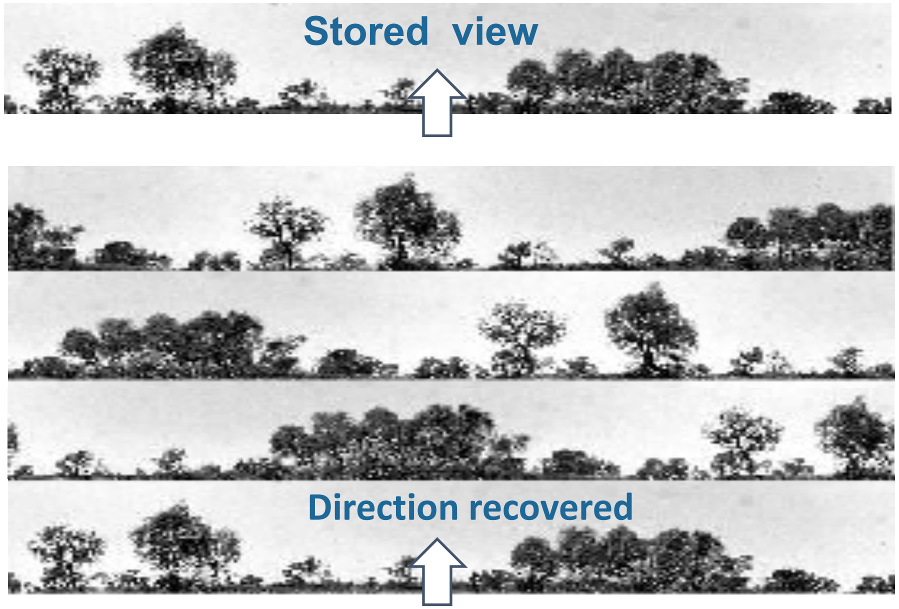
Visual navigation



Procedural

What do I do?

Low-res

No object recognition

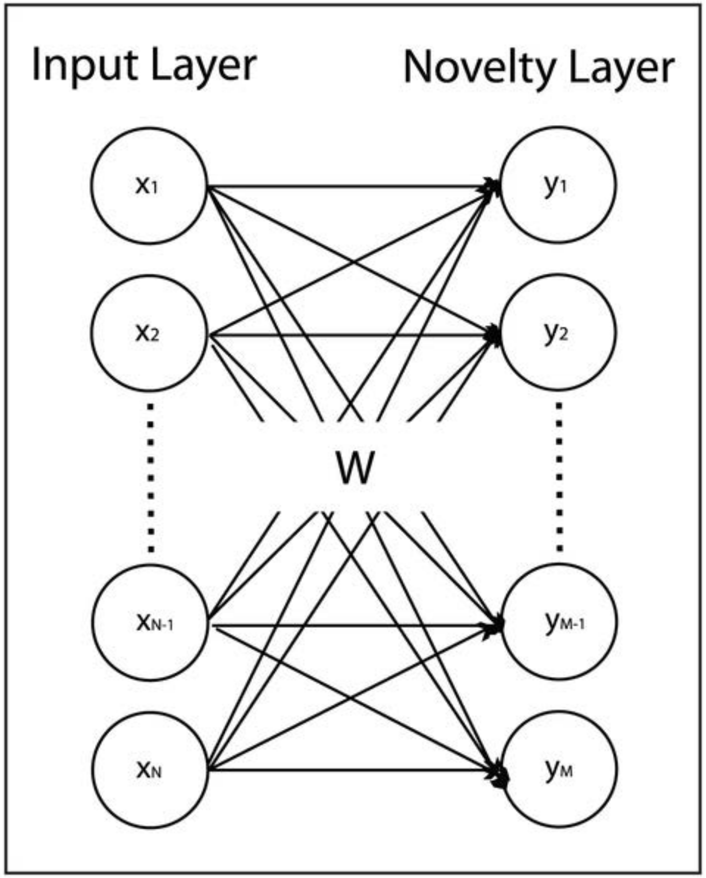
Have I seen this before?

Not where am I?

Perfect memory model

- Apply the view matching algorithm directly:
  - Store views regularly along a route
  - When repeating the route, calculate pixel distance with every view in every direction
  - Move in the direction of the globally best match

Infomax familiarity network model

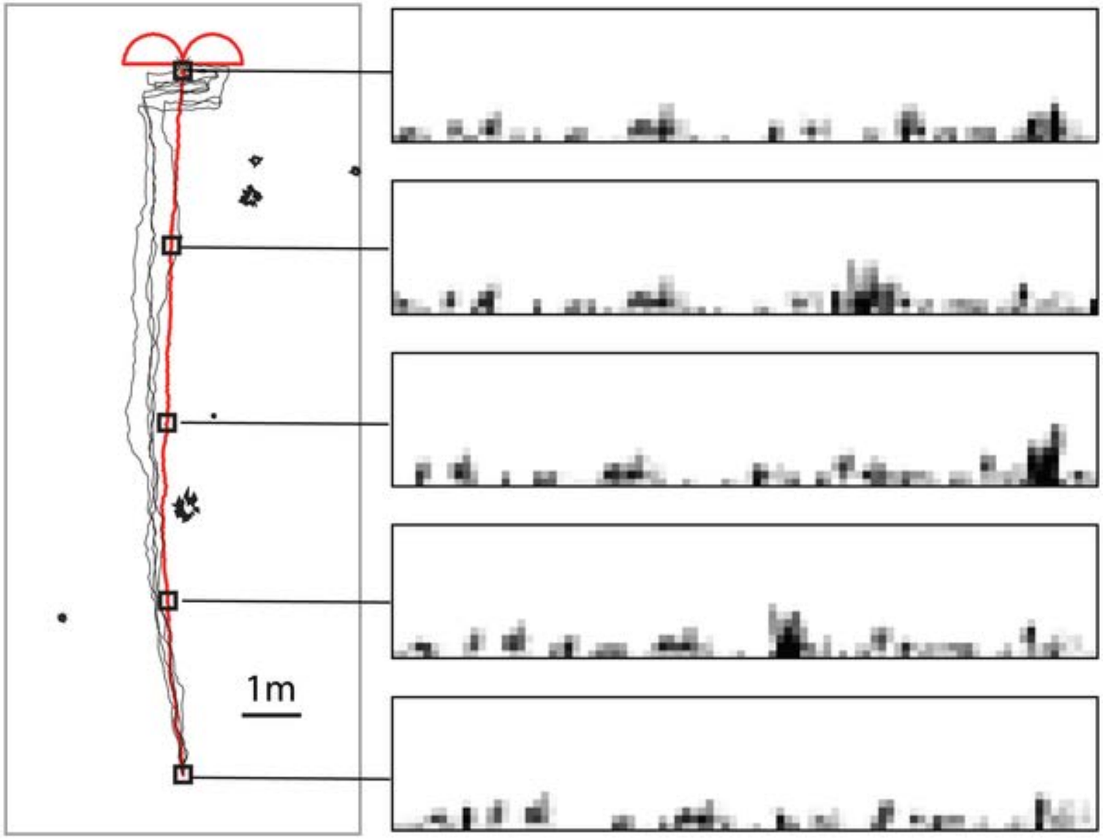


- Train a single layer ANN to predict view familiarity
- Test current view in all directions
- Move in direction of highest familiarity

PLOS COMPUTATIONAL BIOLOGY

Baddeley B, Graham P, Husbands P, Philippides A (2012) A Model of Ant Route Navigation Driven by Scene Familiarity. PLOS Computational Biology 8(1): e1002336. https://doi.org/10.1371/journal.pcbi.1002336
https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1002336

Navigation performance in sparse environment



PLOS COMPUTATIONAL BIOLOGY

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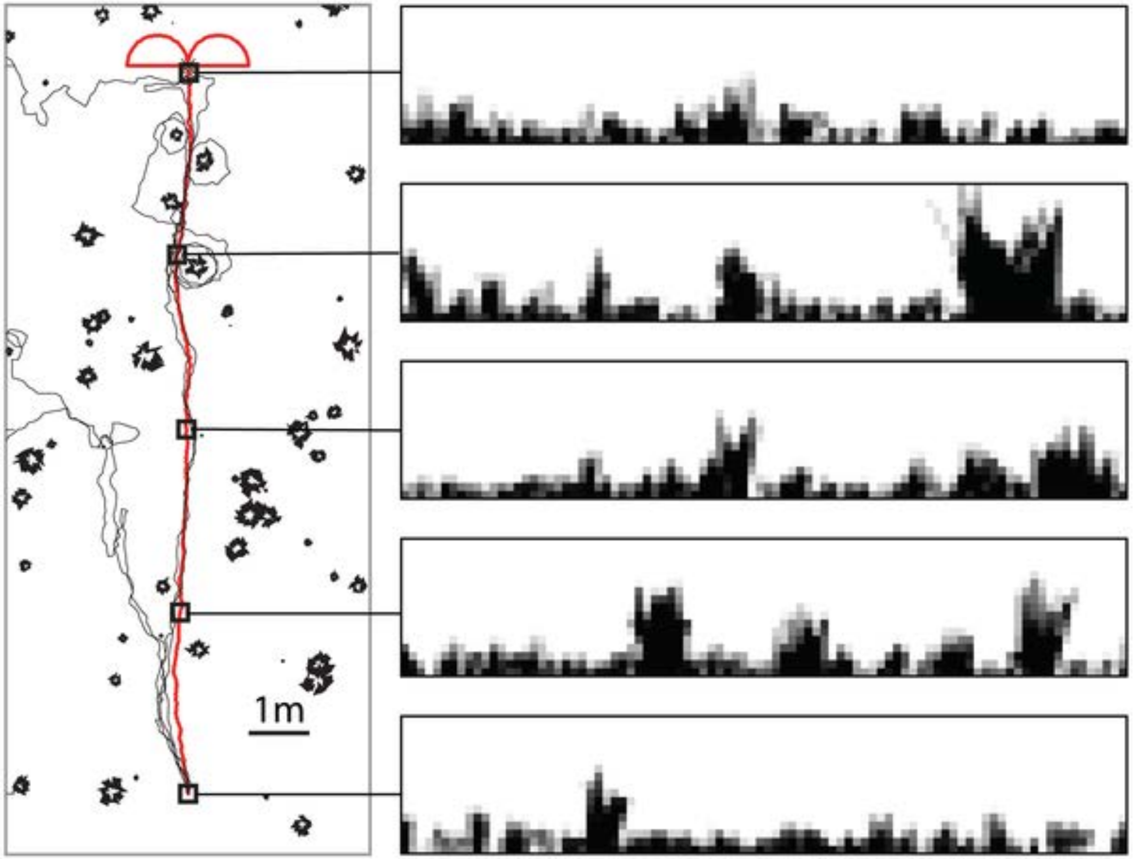
https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1002336

Navigation performance in cluttered environment



Baddeley B, Graham P, Husbands P, Philippides A (2012) A Model of Ant Route Navigation Driven by Scene Familiarity. PLOS Computational Biology 8(1): e1002336. https://doi.org/10.1371/journal.pcbi.1002336
https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1002336

(2012-1016)

GREEN BRAIN

WIFI

Courtesy: University of Sheffield

On Board

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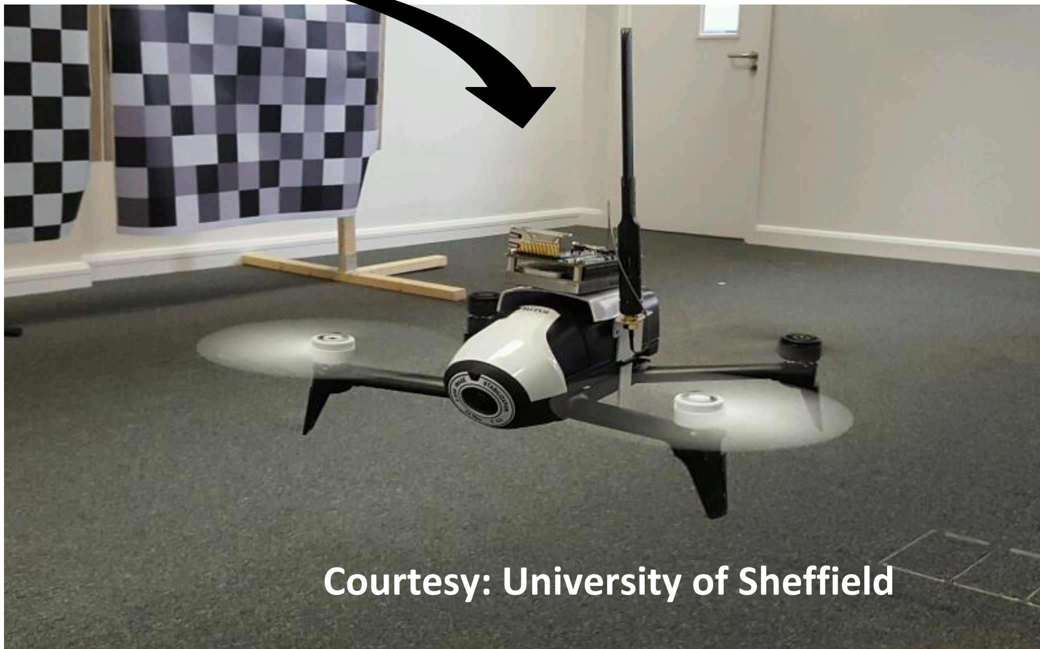
(2016-2021)



Acknowledgments

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PheroSys

BBSRC bioscience for the future

2008-2011

EPSRC Engineering and Physical Sciences Research Council

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2012-2016

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2017-2021

HFSP HUMAN FRONTIERS SCIENCE PROGRAM

odor objects

2015-2019

HBP Human Brain Project

2015-2021

Thank you!

More of this

Less of this