

# Odor-guided navigation in terrestrial animals

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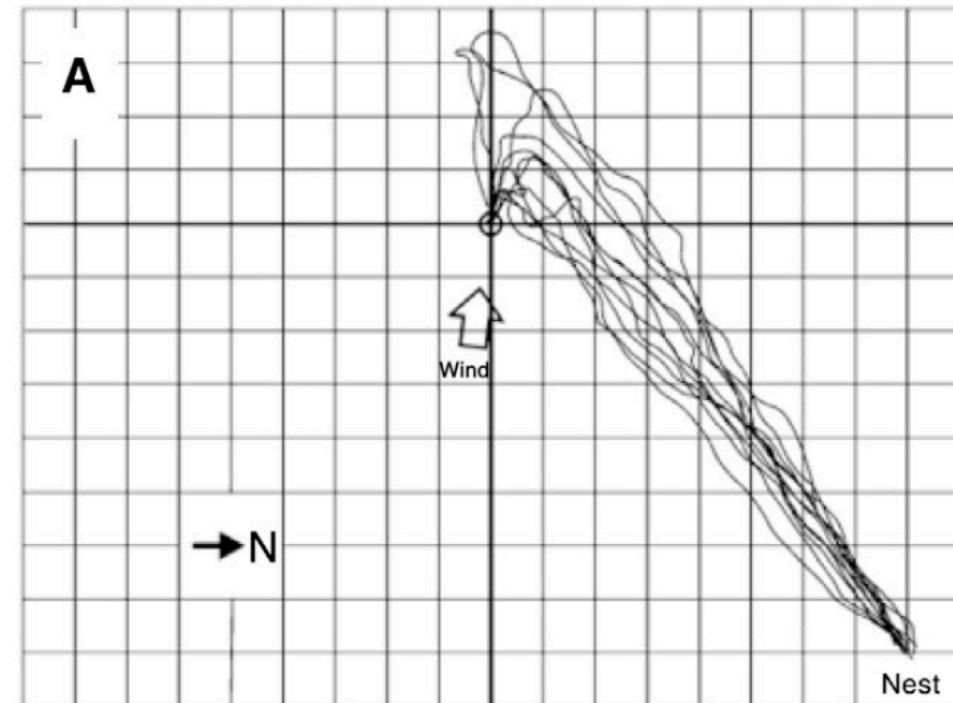
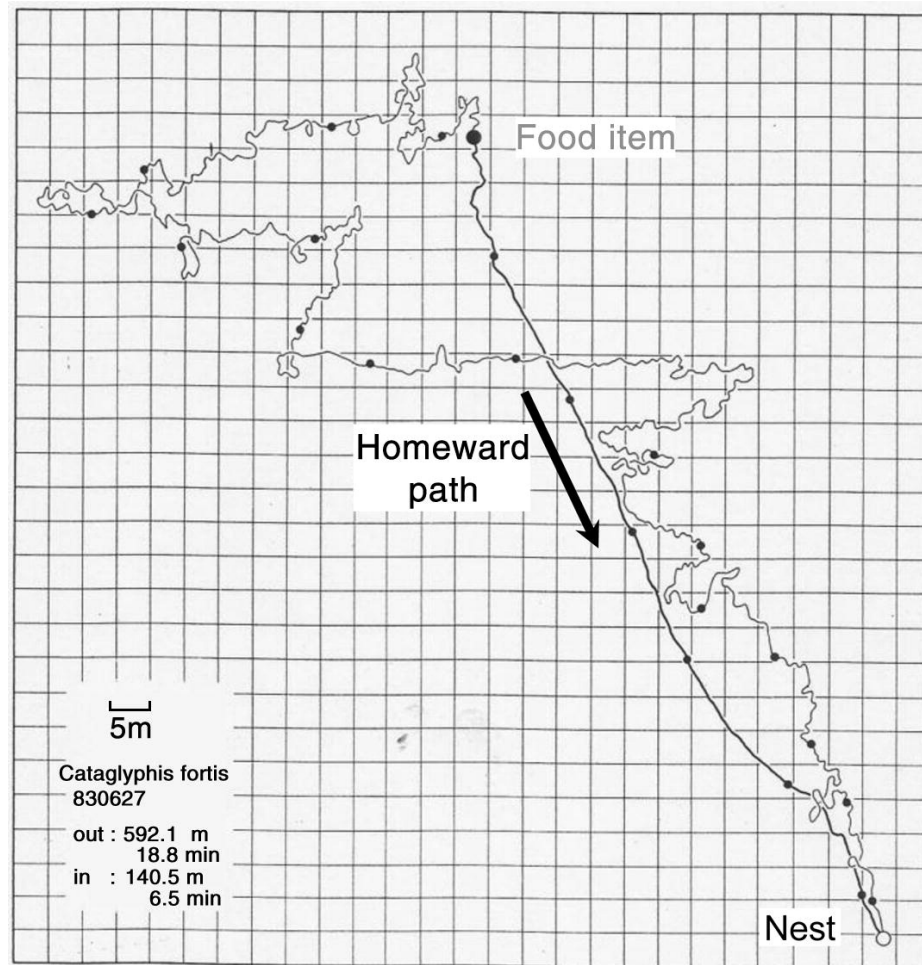
Venkatesh N. Murthy



Center for Brain Science  
and  
Department of Molecular & Cellular Biology

# Navigation vs. Foraging

The famous case of desert ants (*Cataglyphis*)

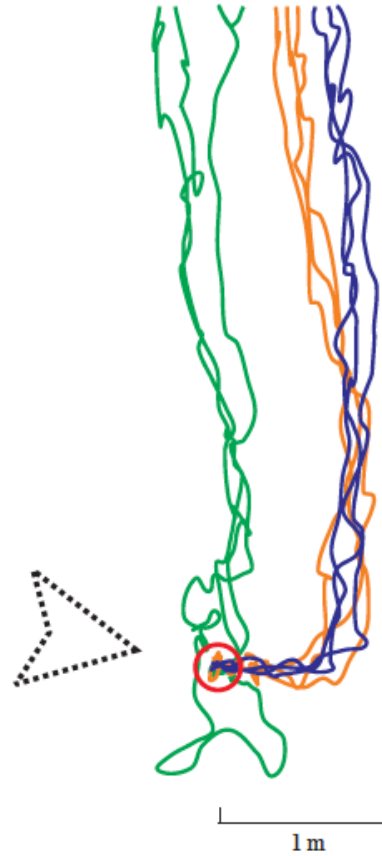
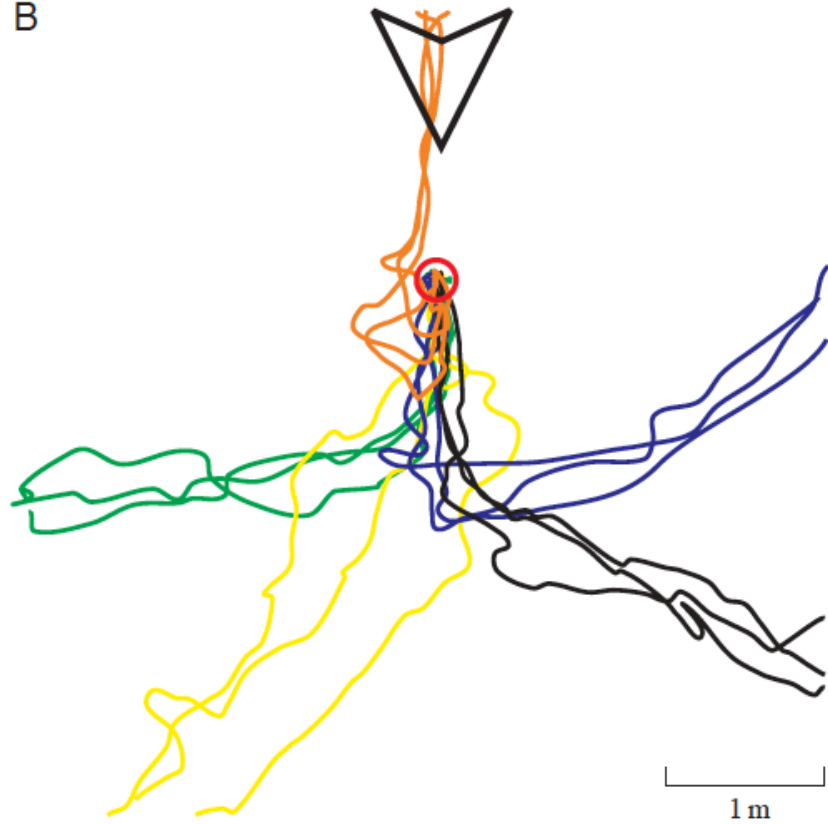


Behav. Ecol. Sociobiol. 62, 415–425.

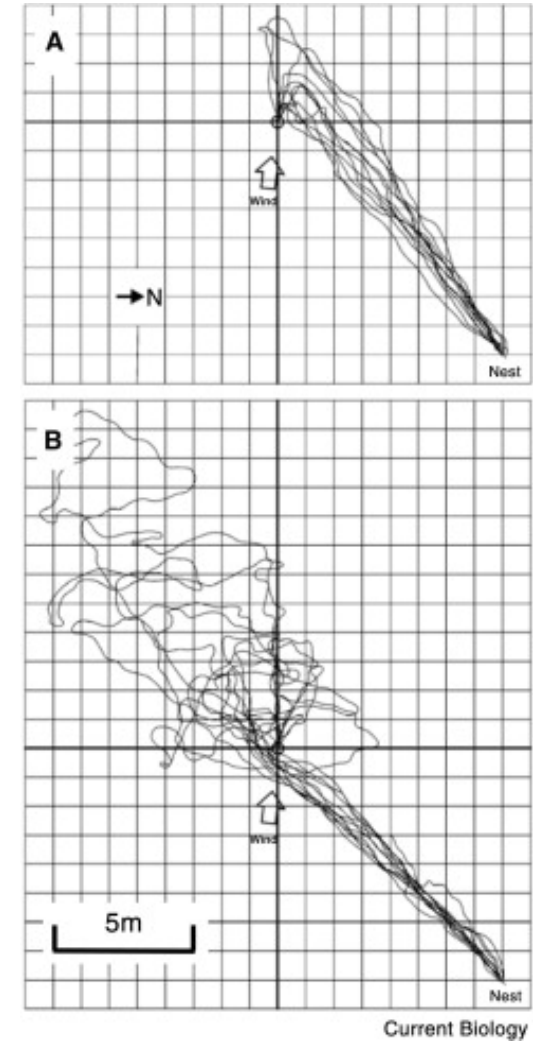
R. Wehner, S. Wehner. 1990. Insect navigation: use of maps or Ariadne's thread.  
Ethol. Ecol. Evol., 2: 27-48

# Even *Cataglyphis* use olfaction (+wind) to make food approach

B



The Journal of Experimental Biology 203, 857–868 (2000)



Behav. Ecol. Sociobiol., 62 (2008), pp. 415-425

# Navigation

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Landmark-based:

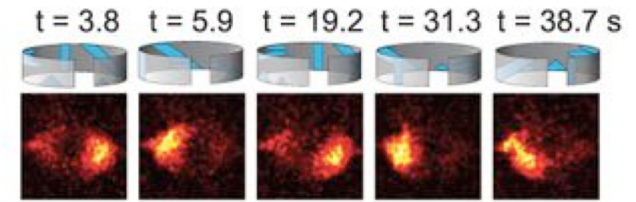
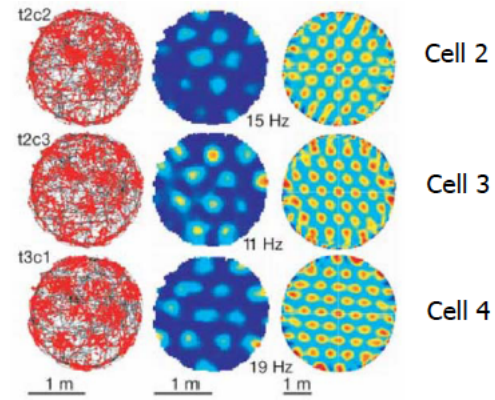
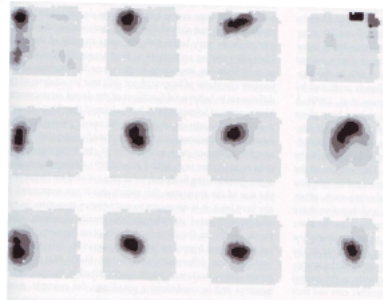
- (i) Beacons
- (ii) Route following
- (iii) Path integration

Map-based:

- (i) find your current location (with an internal representation?)
- (ii) use a “compass” to find direction for travel

# Brains and navigation

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# Foraging

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Using sensory cues:

1. Vision and audition:

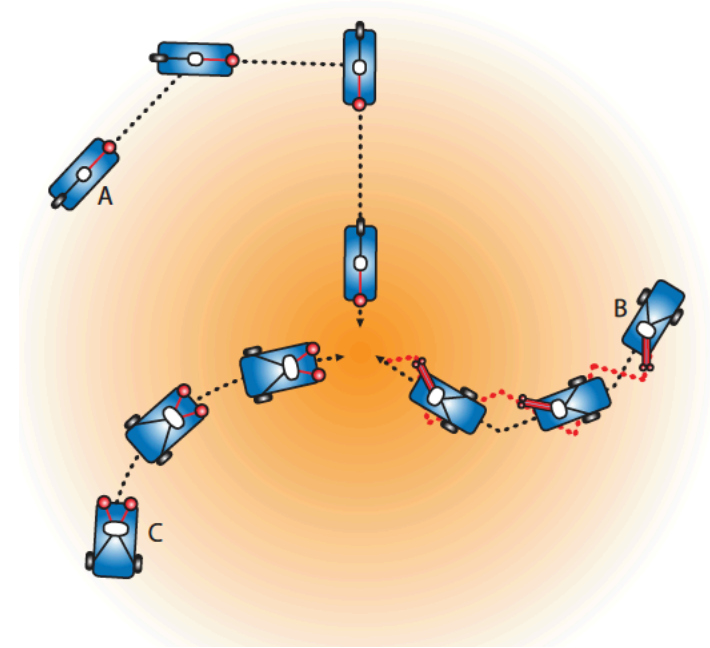
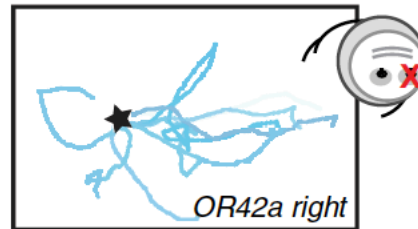
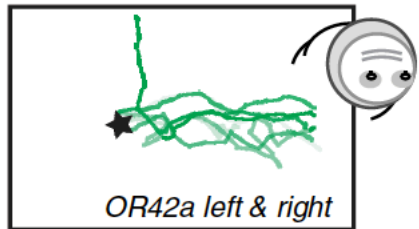
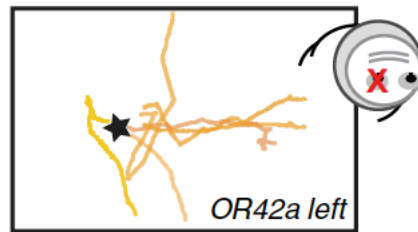
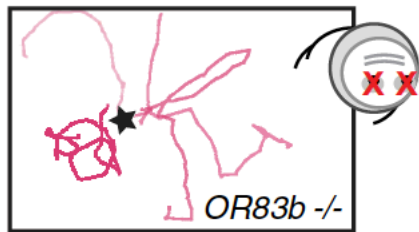
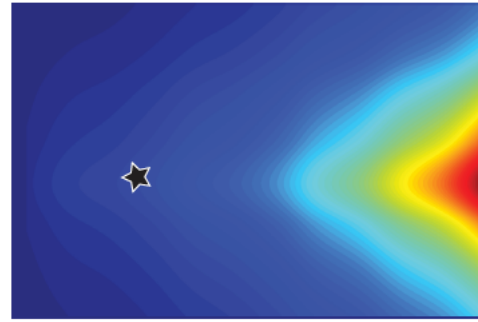
landmarks are localized by geometric considerations

2. Olfaction:

a bit more tricky

# Foraging with chemical senses

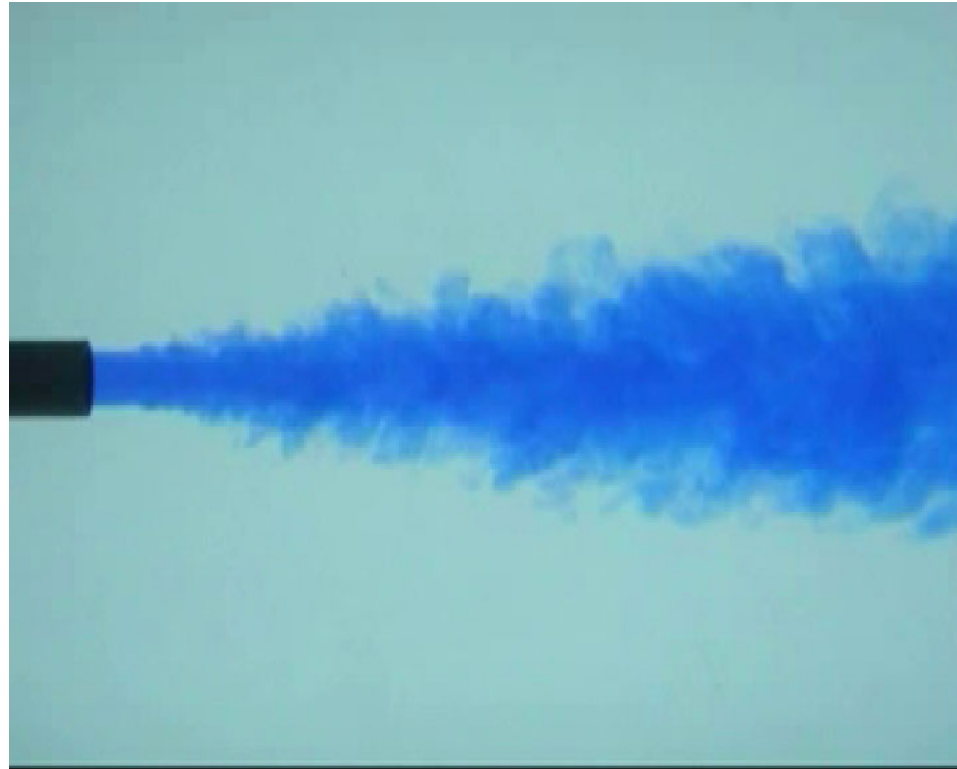
At short distances (define!), diffusion dominates



## Larger distances

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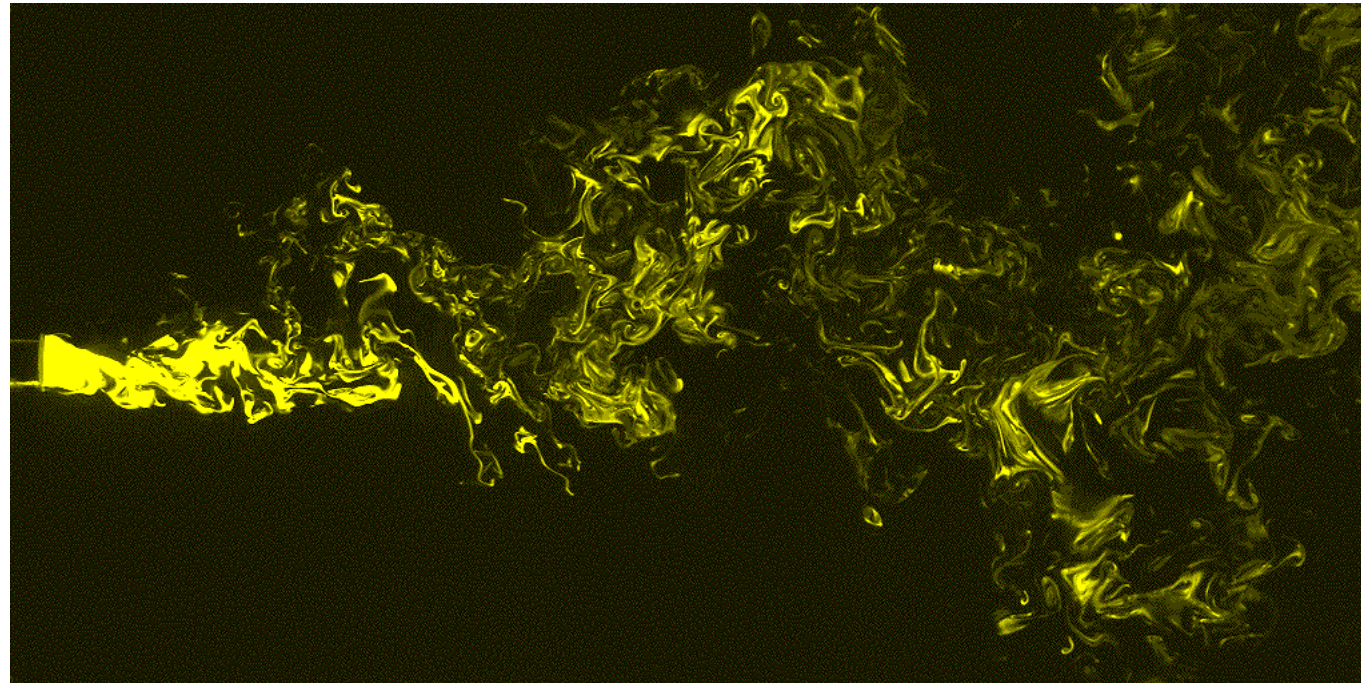
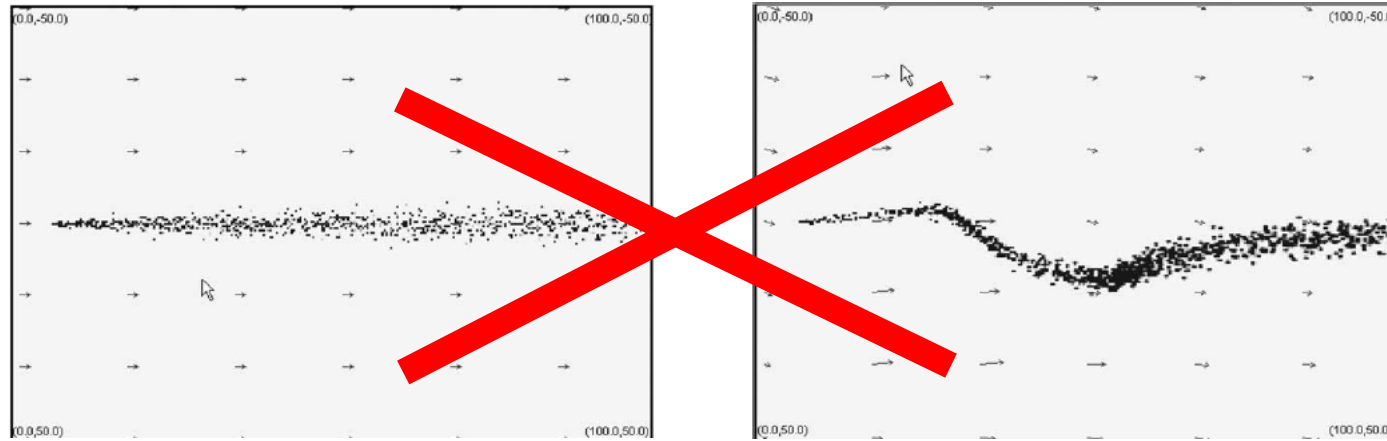
At larger distances, chemical gradients fluctuate





# Continuous vs. intermittent detection

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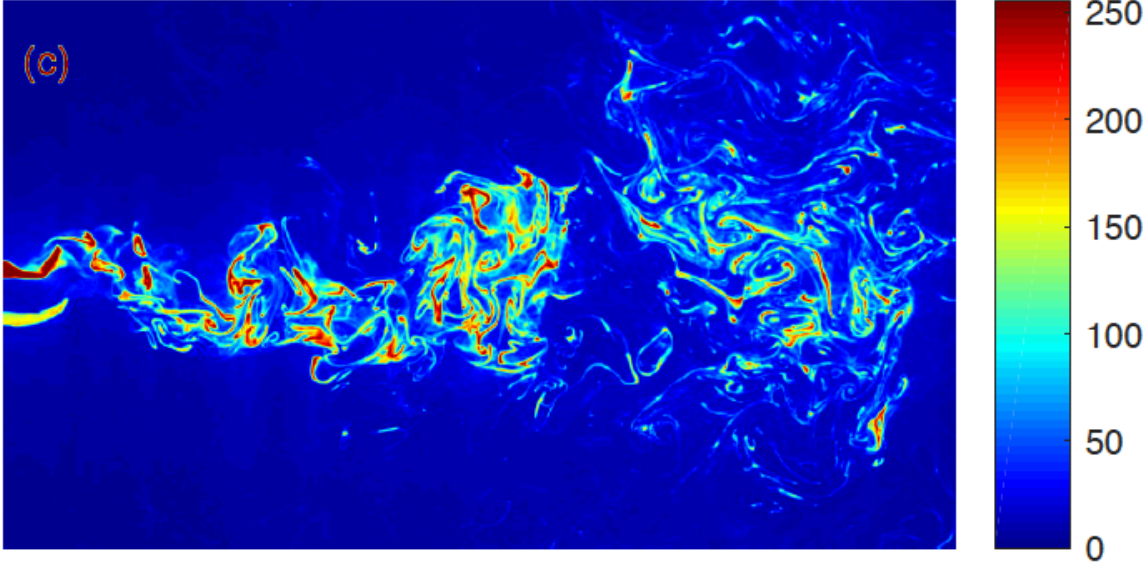


Courtesy M. Vergassola

# Local gradients may not be helpful

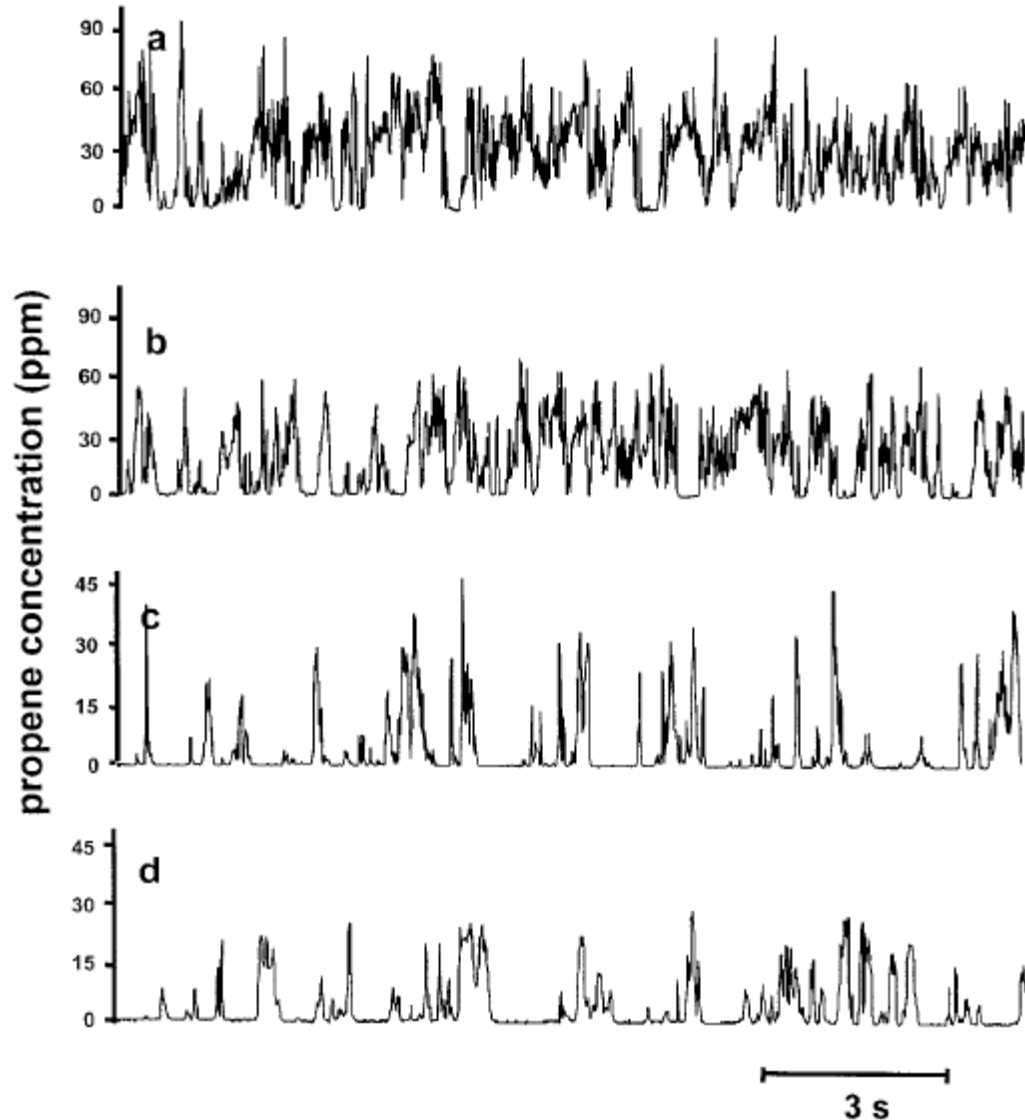
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Concentration



# Highly intermittent odor encounters

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*Environmental Fluid Mechanics* 2: 115–142, 2002.

## Scalar turbulence

Boris I. Shraiman\* & Eric D. Siggia†

NATURE | VOL 405 | 8 JUNE 2000 |

PHYSICAL REVIEW X 4, 041015 (2014)

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### Odor Landscapes in Turbulent Environments

Antonio Celani,<sup>1,2</sup> Emmanuel Villermaux,<sup>3</sup> and Massimo Vergassola<sup>1,4</sup>

# Strategies for tracking odors highly dependent on spatial scale

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Gradient descent (ascent)

Odor-guided anemotaxis

Infotaxis

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## Three examples from my group

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Navigating using air-borne odors (mice)

Tracking ground trails (mice)

Pheromone tracking (ants)

# Acknowledgment

Ryan Draft



Julien Grimaud



Siddharth Jayakumar



Vikrant Kapoor



Spencer Kim



Souvik Mandal



Nune Martiros



Alexander Mathis



Liz Shtrahman



Jenelle Wallace



Sonia Wang



Konrad Urban



Hao Wu



Joseph Zak



Matt McGill



## ***Support***

DFG, HFSP  
NARSAD  
NIH, NSF

## ***Collaborators***

Florin Albeanu, Matthias Bethge  
Catherine Dulac, David Gire  
Alexei Koulakov, Jeff Macklis  
Mackenzie Mathis, Agnese Seminara  
Massimo Vergassola

## Three examples from my group

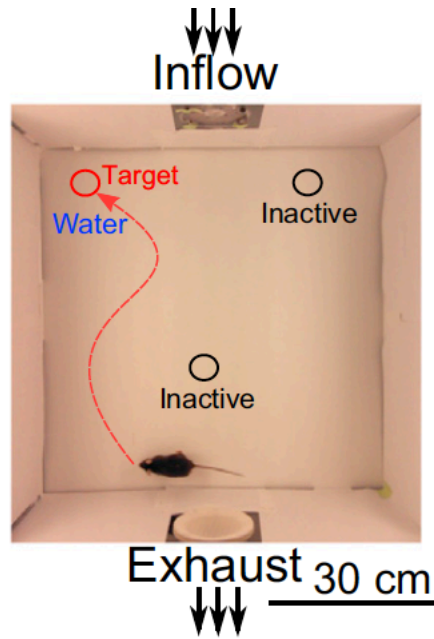
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Navigating using air-borne odors (mice)

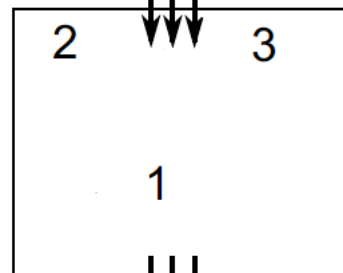
Tracking ground trails (mice)

Pheromone tracking (ants)

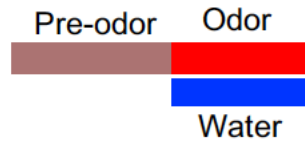
# Locating source through airborne odor cues



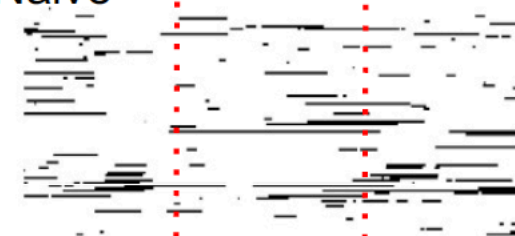
Source locations



Task timing



Naive



Trained



David Gire

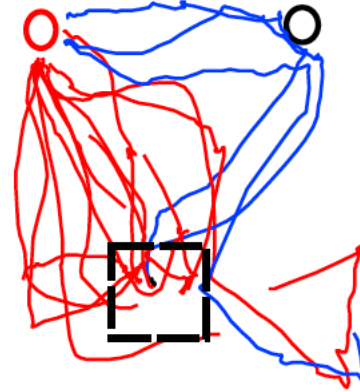
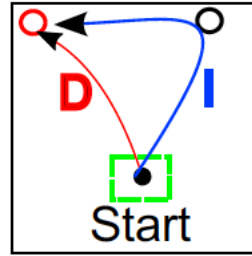


Agnese Seminara

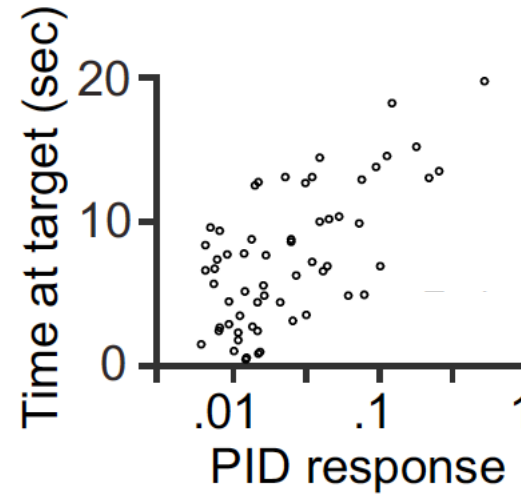
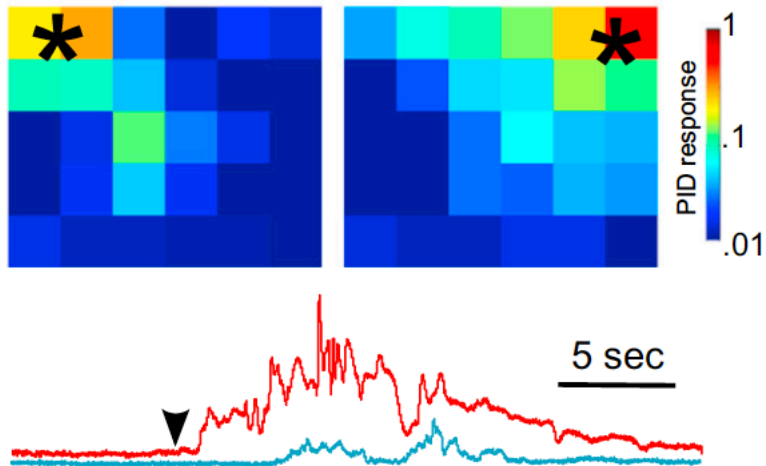




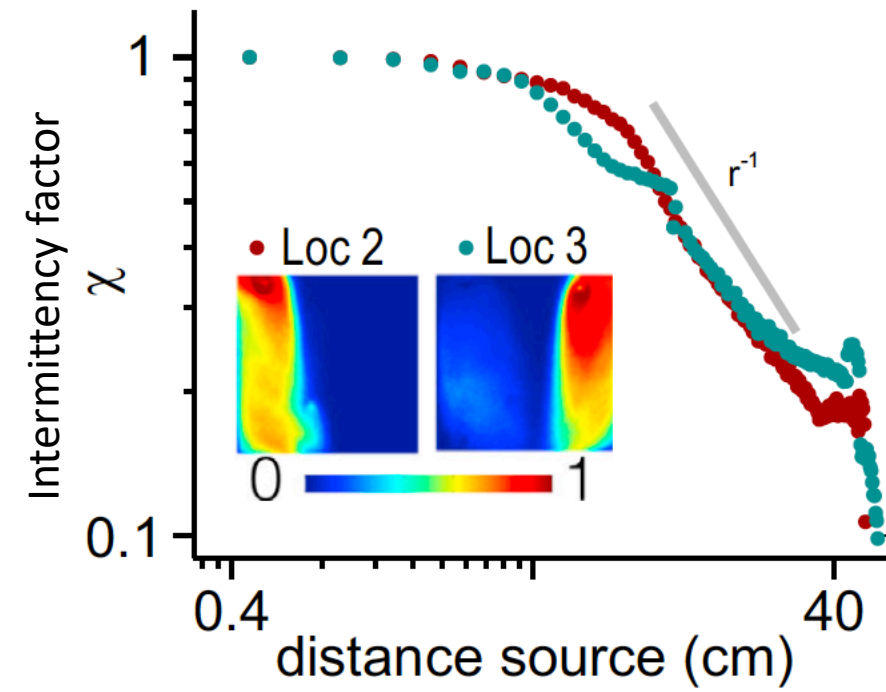
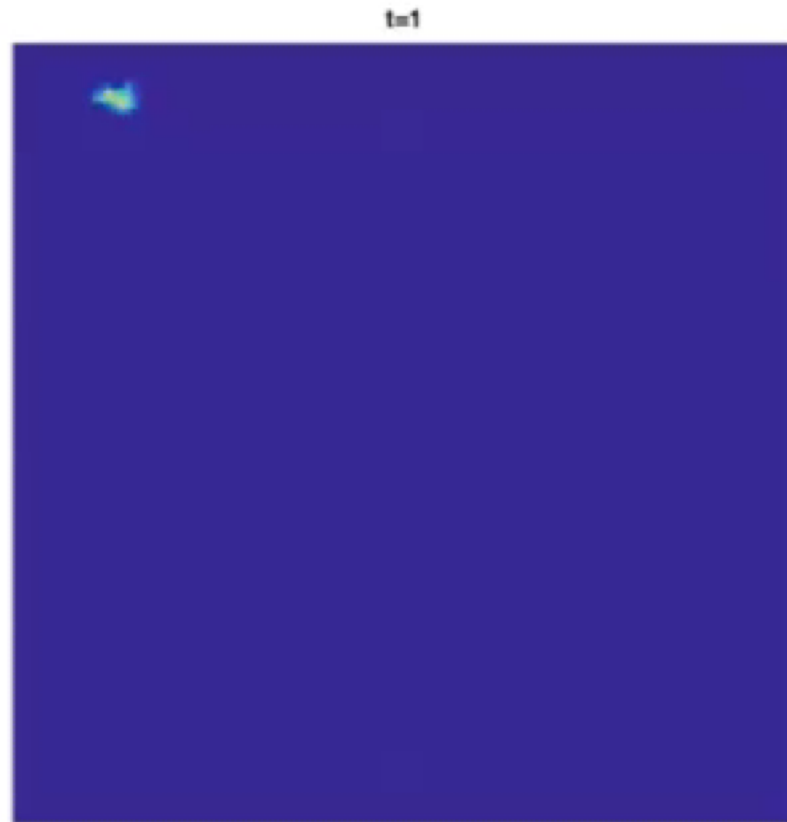
# Mice can navigate to odor source



Average odor concentrations  
in the arena

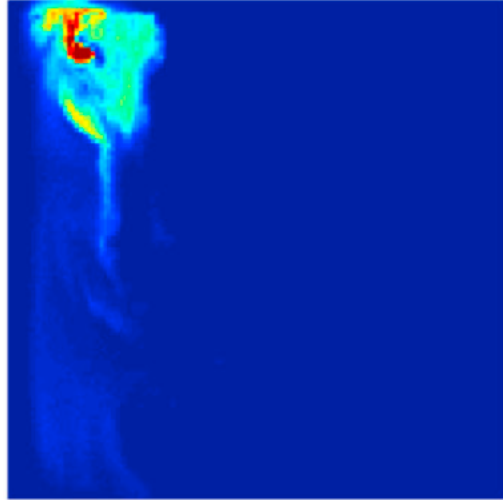


# Computational fluid dynamics simulations

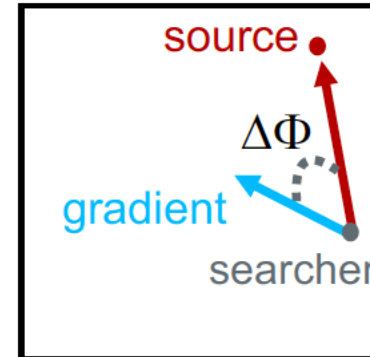
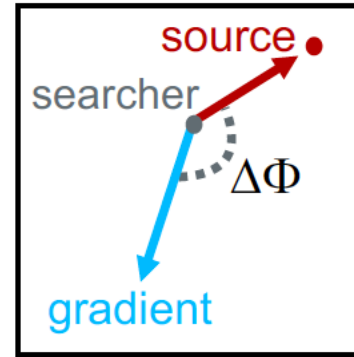


# Gradient-based search

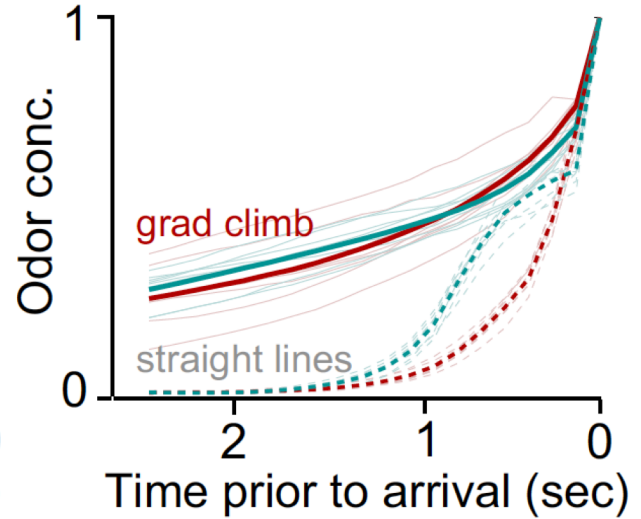
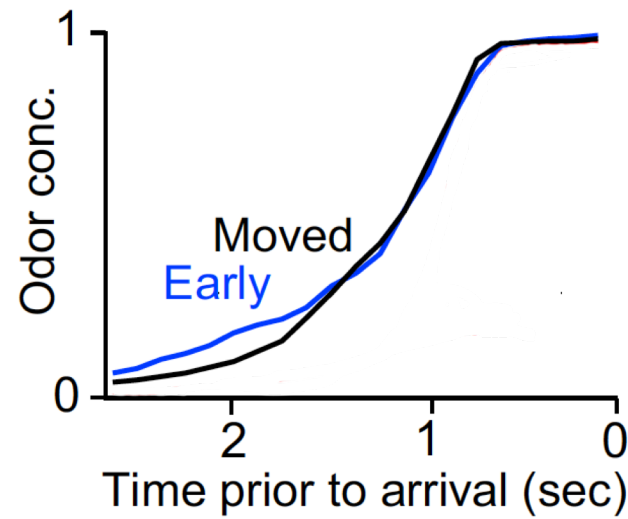
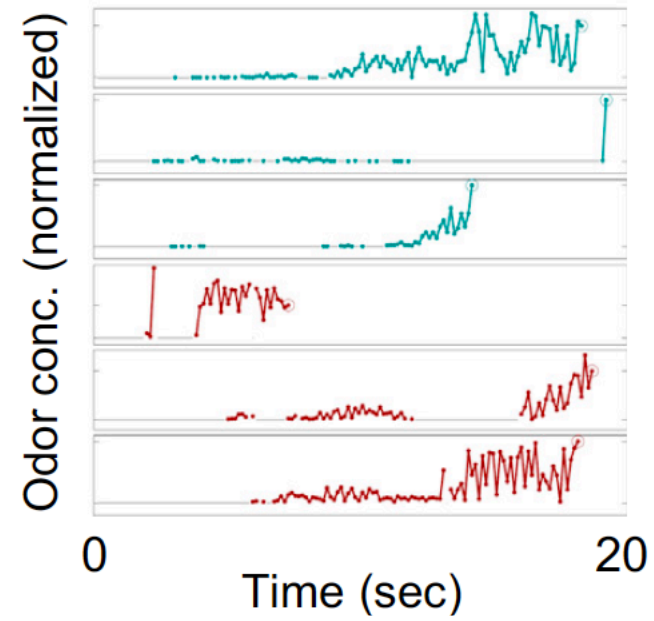
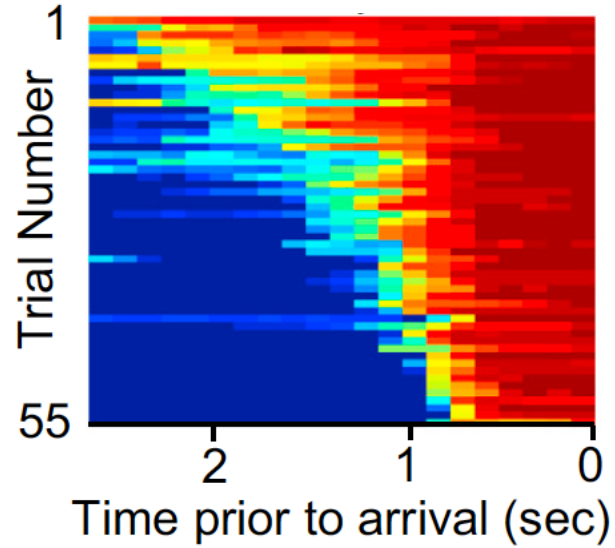
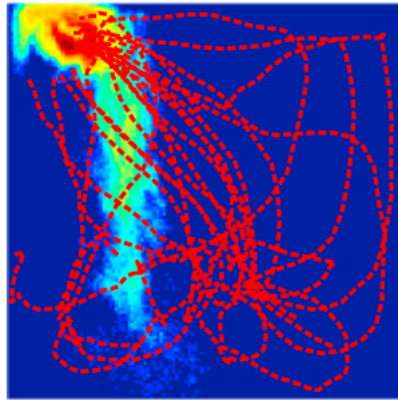
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$$X_{t+1} = X_t + \alpha \frac{\nabla c}{|\nabla c|}$$

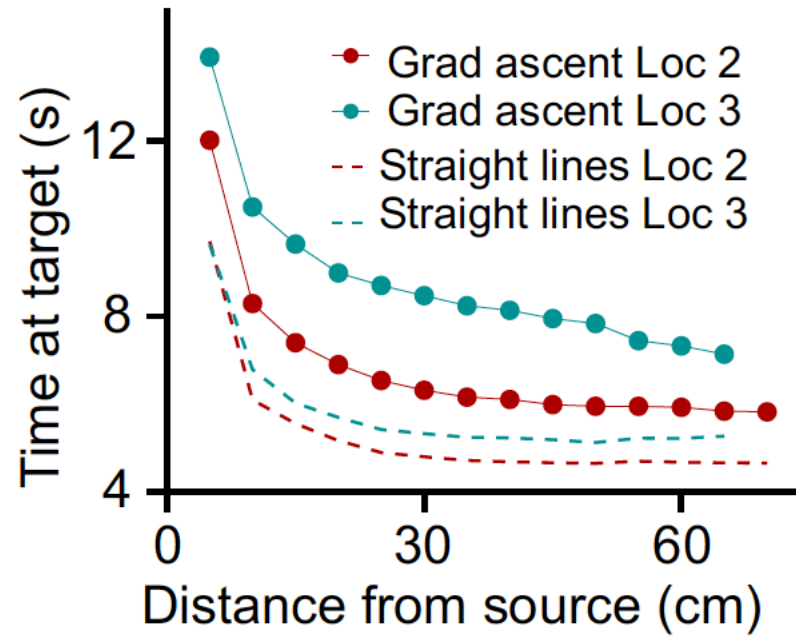


# Comparing mouse and “gradient ascent searcher” trajectories



# Gradient ascent works at distances $\sim 0.5\text{m}$

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## Three examples from my group

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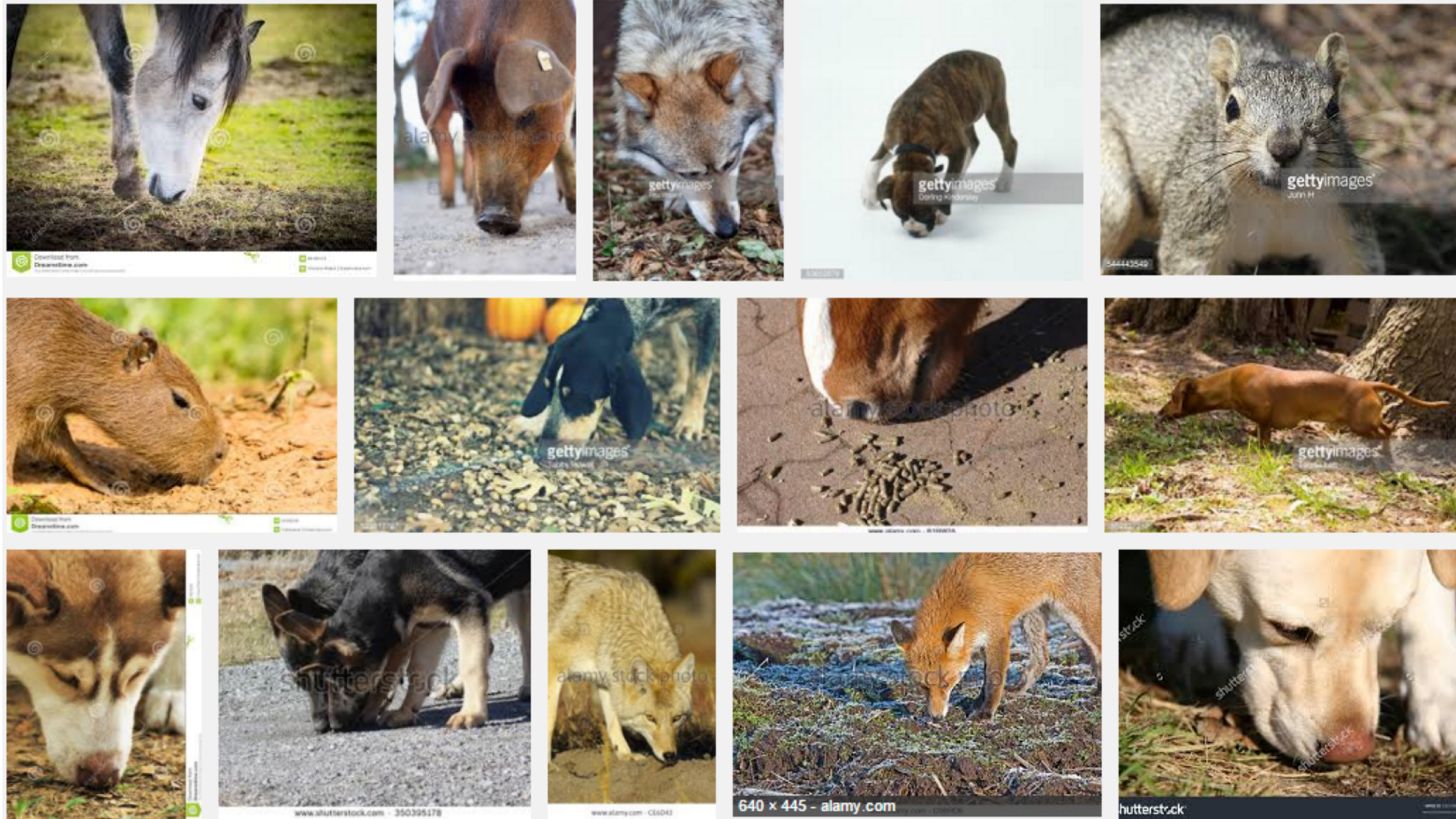
Navigating using air-borne odors (mice)

Tracking ground trails (mice)

Pheromone tracking (ants)

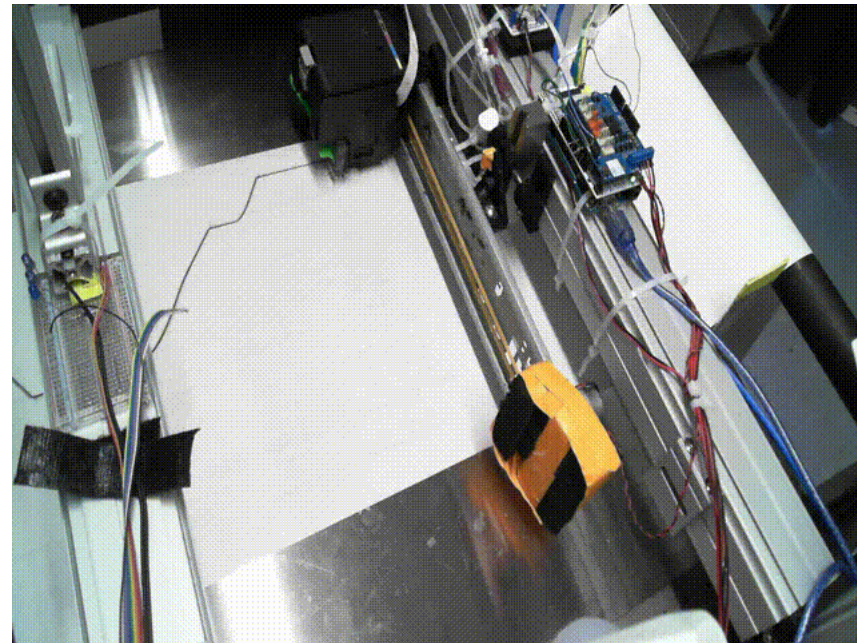
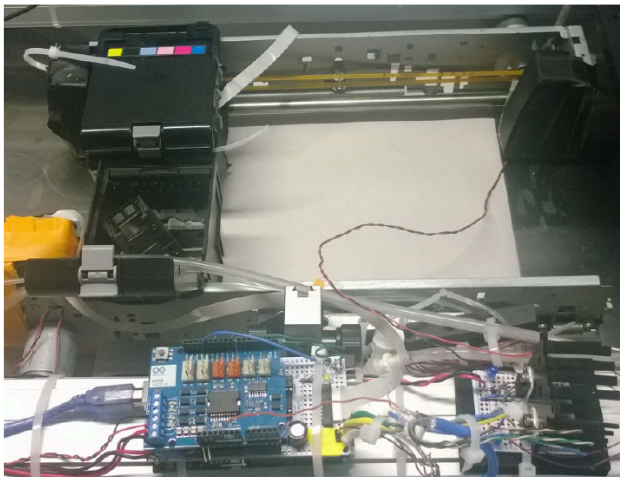
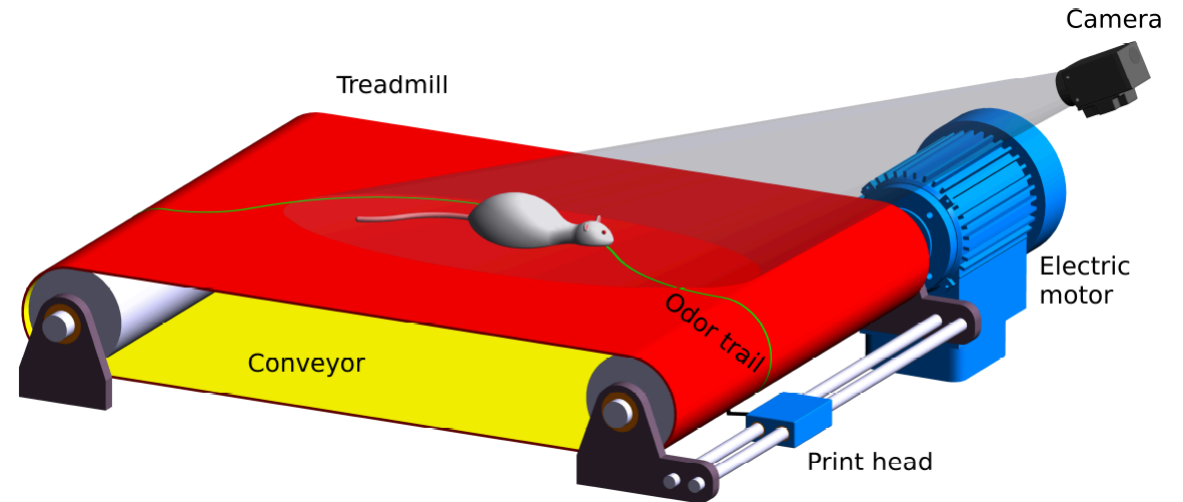
# Sampling the chemical world on surfaces

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*Google search on "close to ground sniffing"*

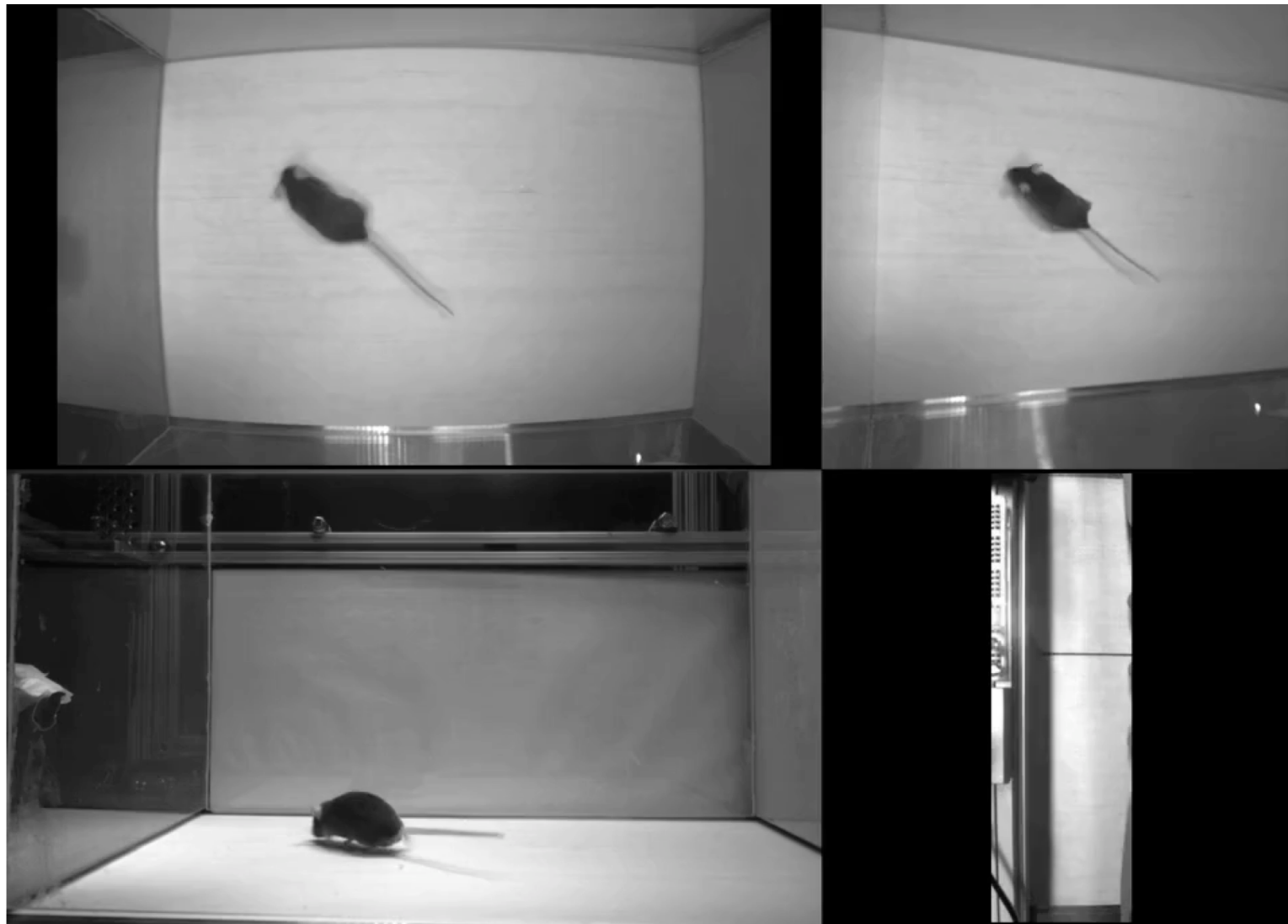
# Mice on a paper treadmill with continuously printed odor trail



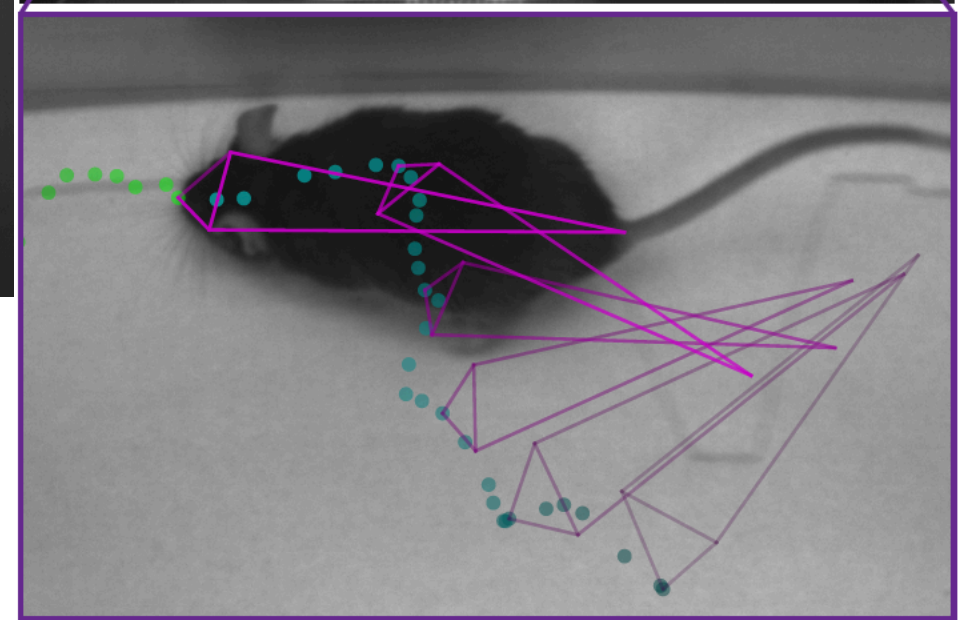
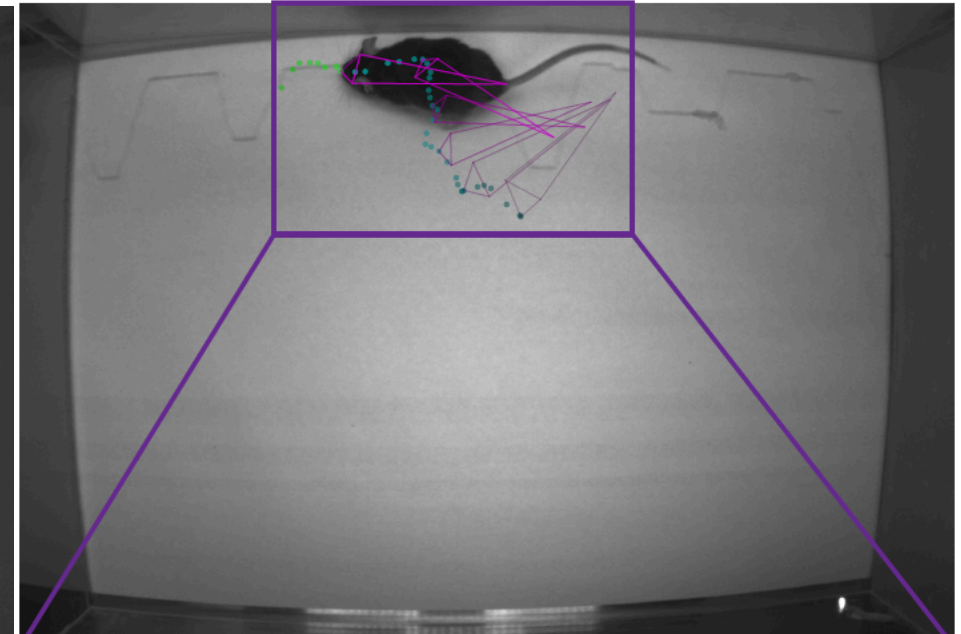
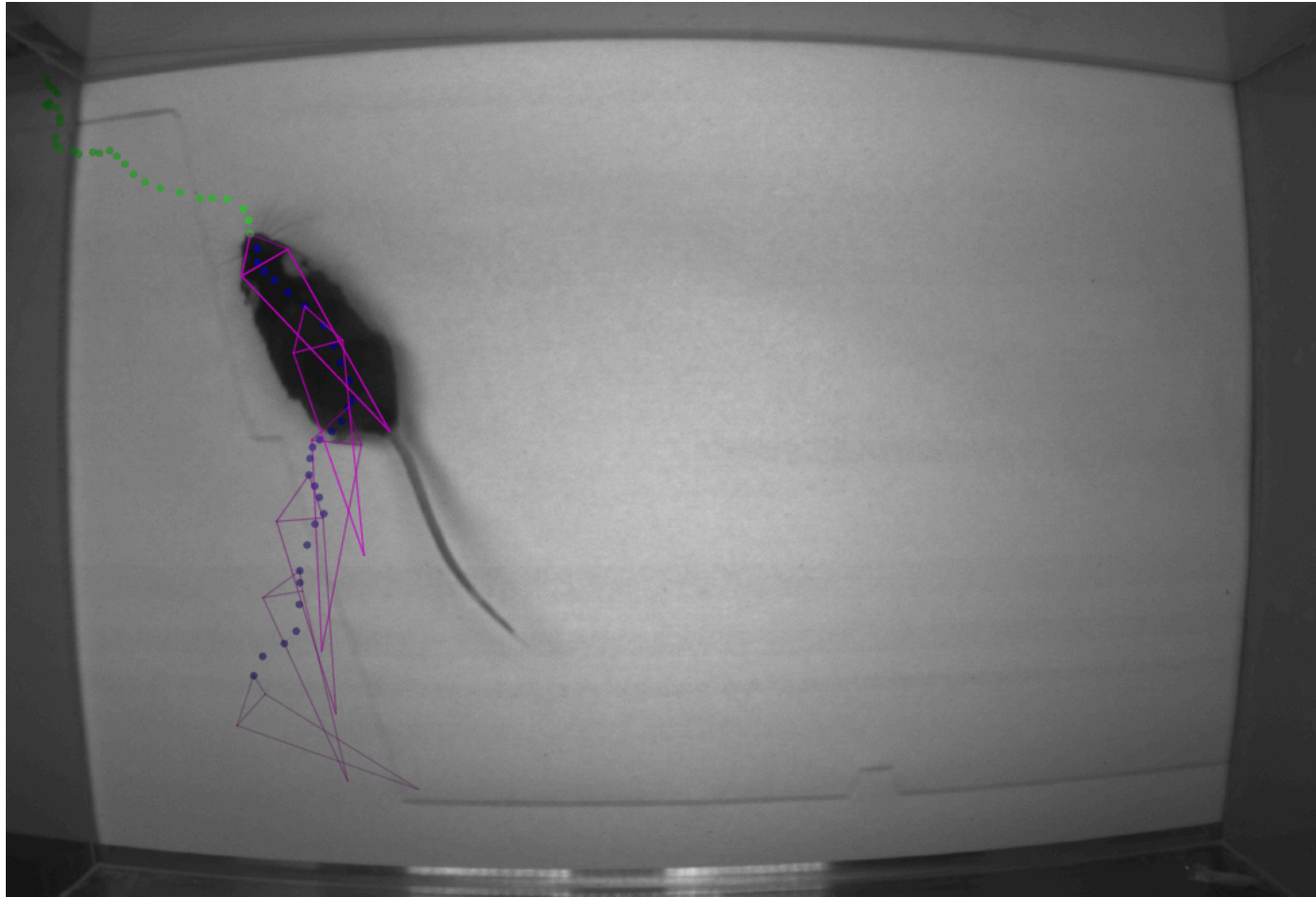


# Videography of mice tracking trails

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# Automatic posture/part detection



<https://arxiv.org/abs/1804.03142>

nature  
neuroscience

TECHNICAL REPORT

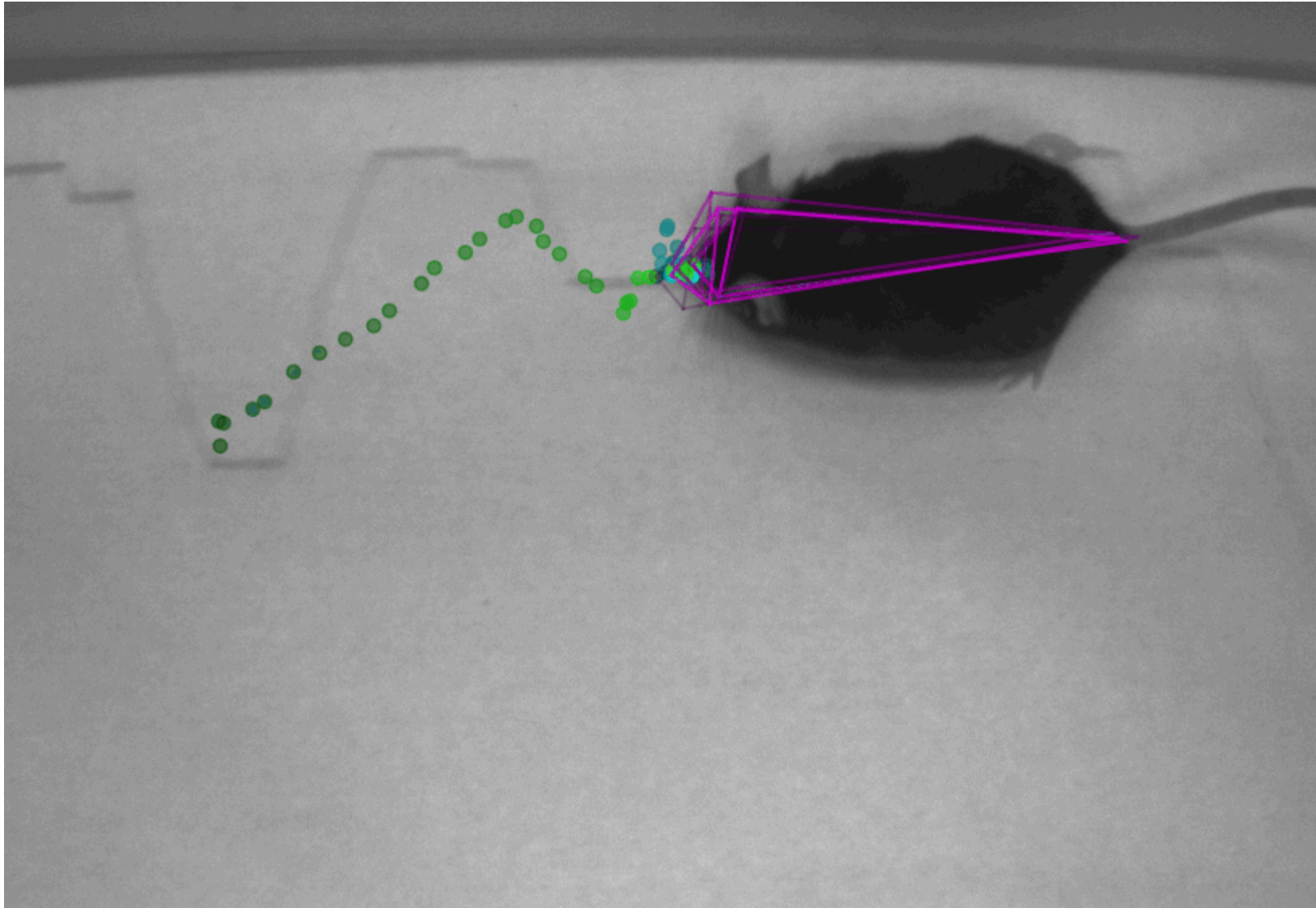
<https://doi.org/10.1038/s41593-018-0209-y>

## DeepLabCut: markerless pose estimation of user-defined body parts with deep learning

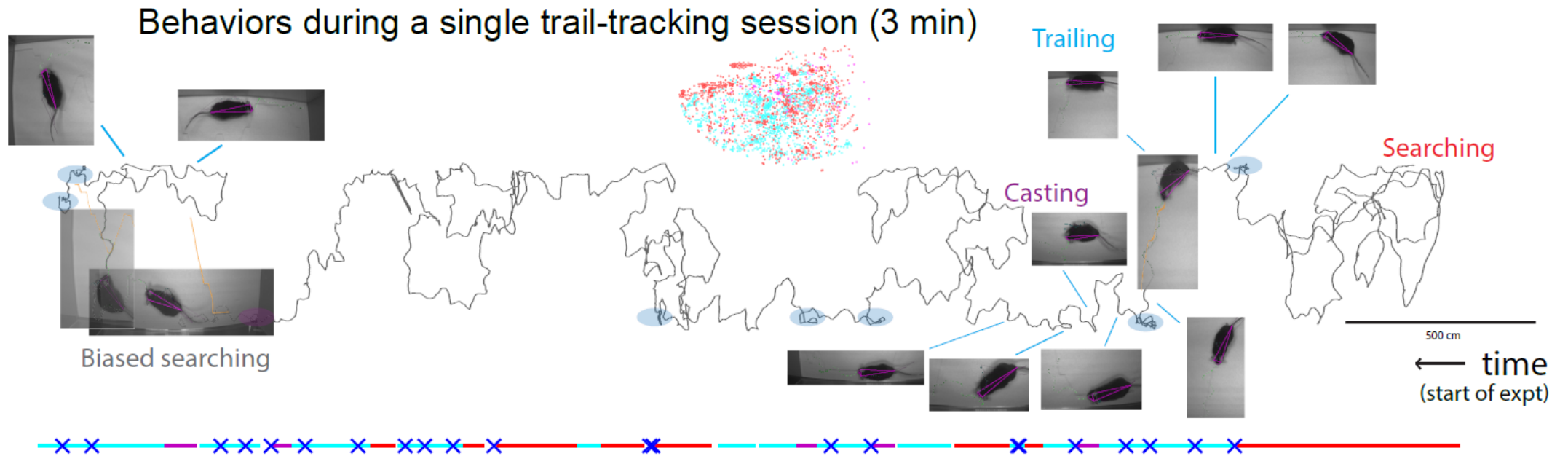
Alexander Mathis<sup>1,2</sup>, Pranav Mamidanna<sup>1</sup>, Kevin M. Cury<sup>3</sup>, Taiga Abe<sup>3</sup>, Venkatesh N. Murthy<sup>2</sup>, Mackenzie Weygandt Mathis<sup>1,4,8\*</sup> and Matthias Bethge<sup>1,5,6,7,8</sup>

## Following mice as they track odor trails

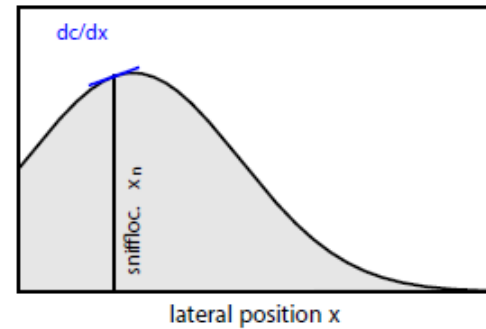
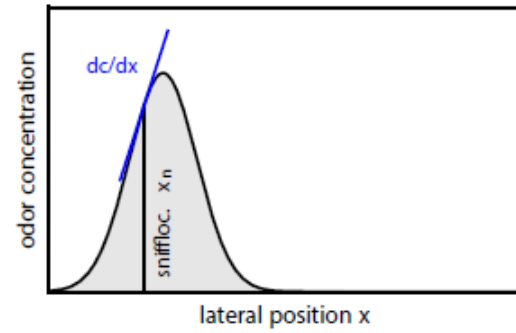
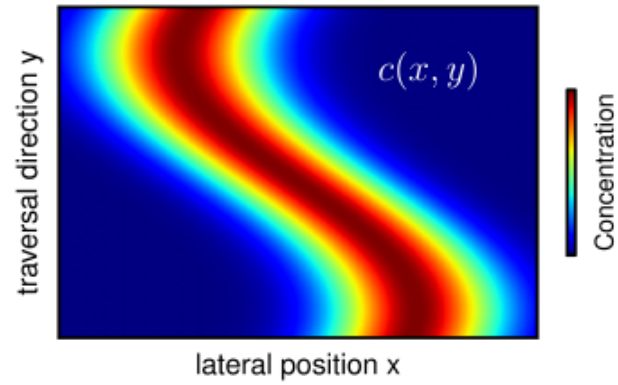
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# Dissecting behavior



# Getting at algorithms for tracking



## Three examples from my group

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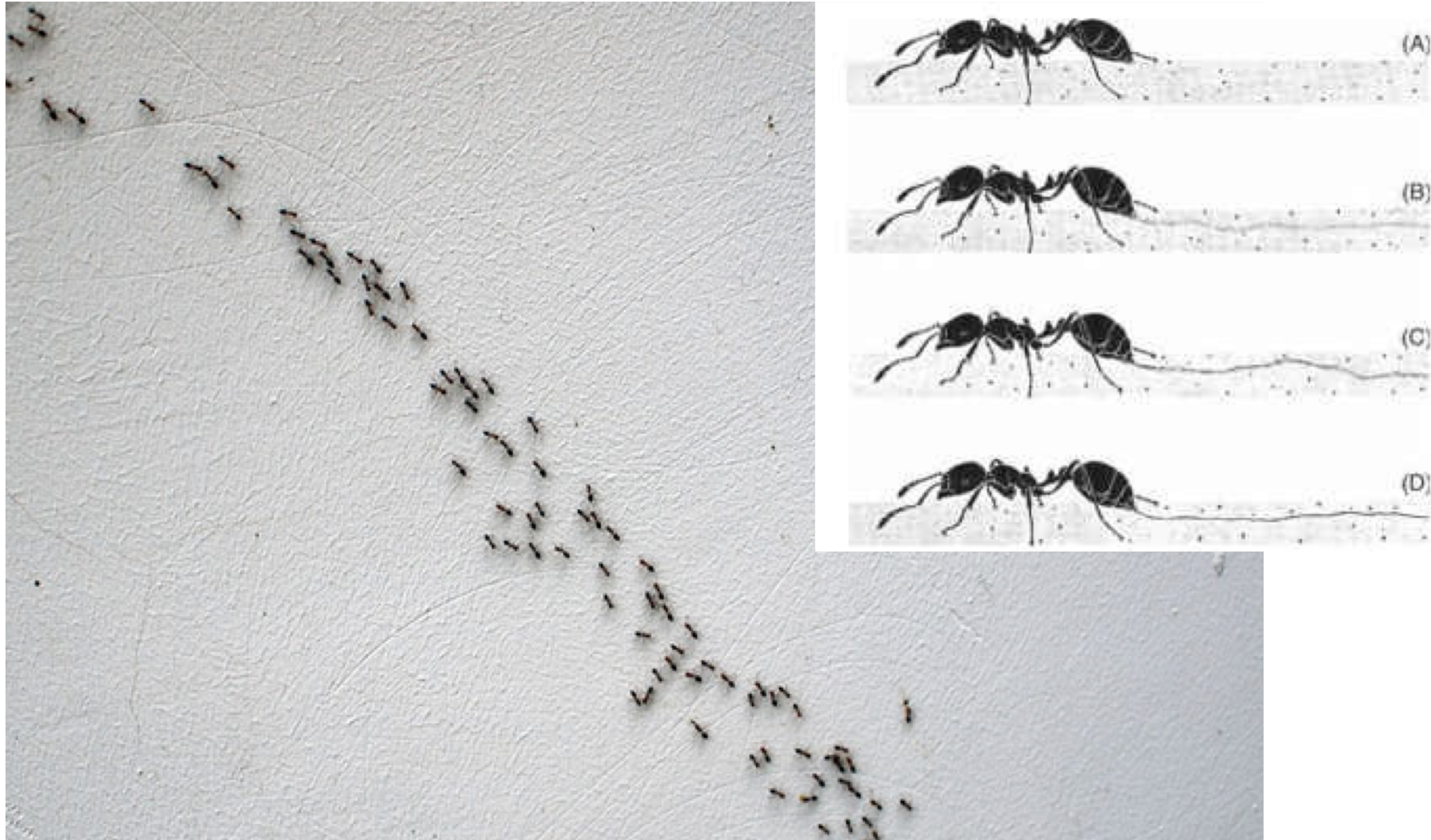
Navigating using air-borne odors (mice)

Tracking ground trails (mice)

Pheromone tracking (ants)

# Ants track pheromone trails

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## *Camponotus Pennsylvanicus*, the black carpenter ant

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6-12 mm

Up to 15,000 per colony

Single queen

Dormant/torpid in winter

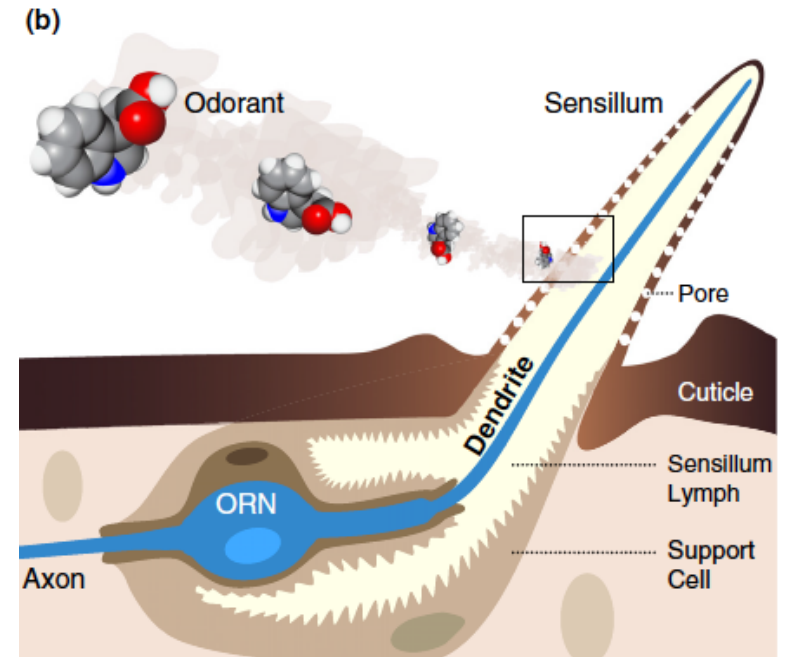
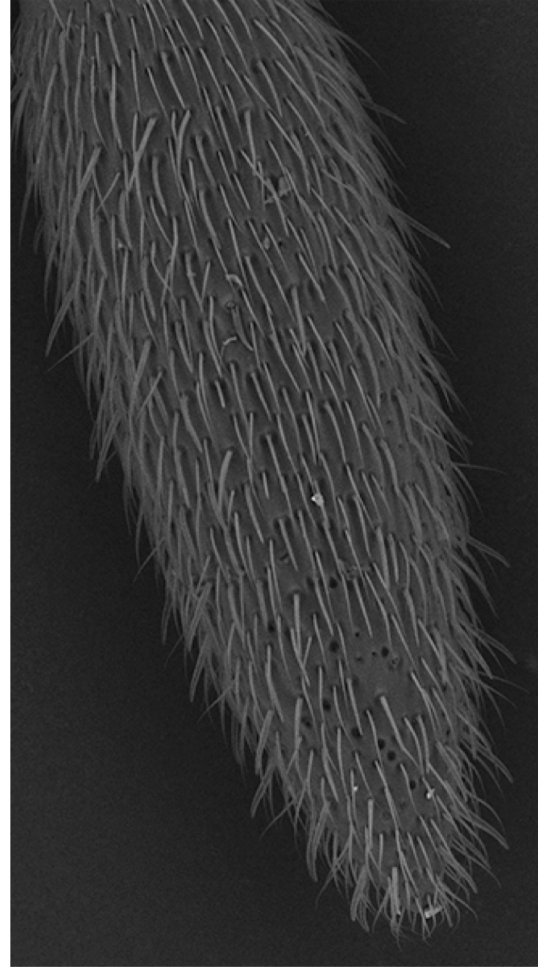
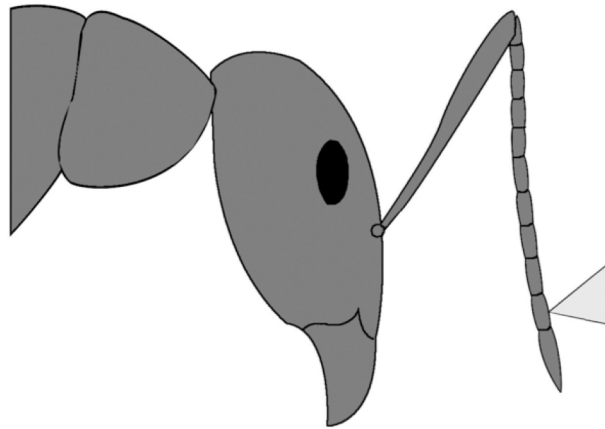
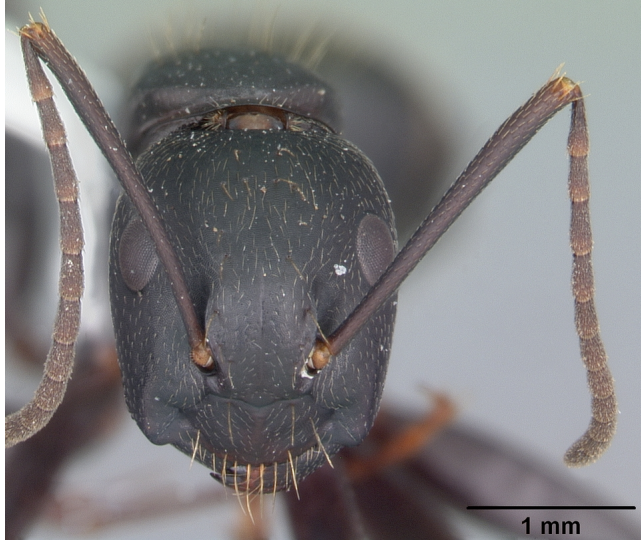
Nocturnal/Crepuscular



[http://www.antwiki.org/wiki/Camponotus\\_pennsylvanicus](http://www.antwiki.org/wiki/Camponotus_pennsylvanicus)

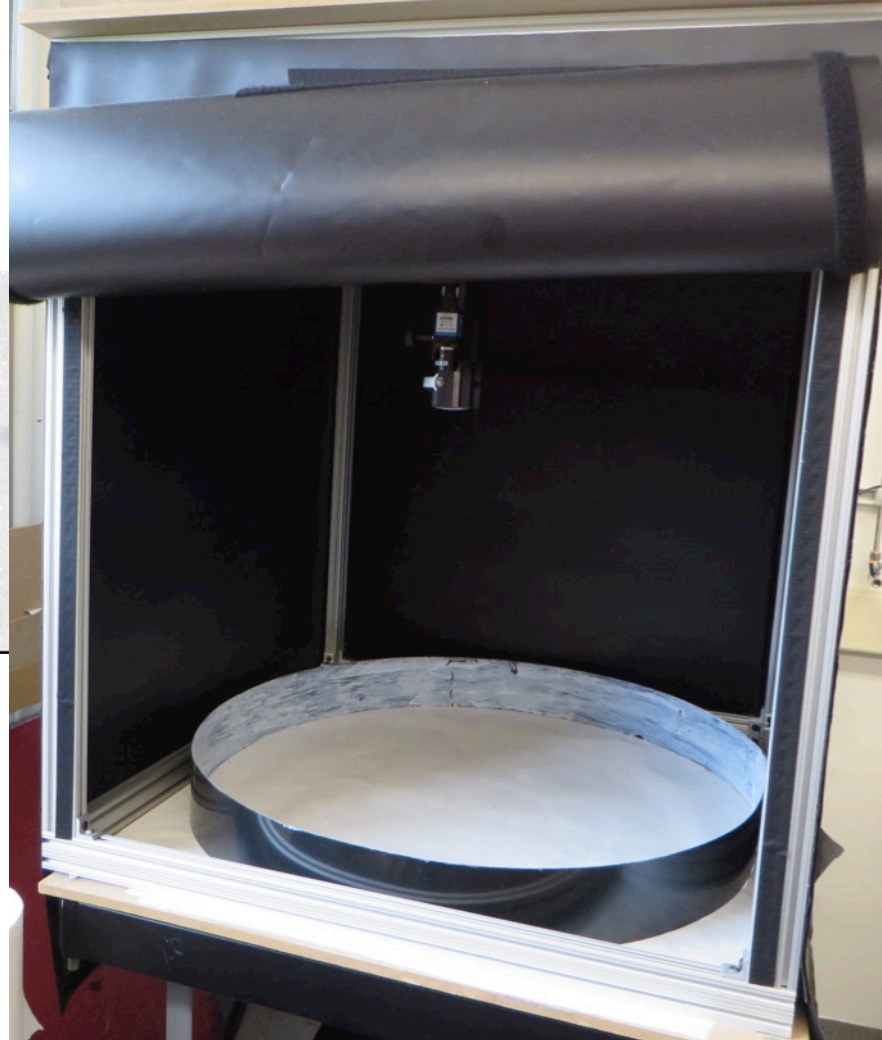
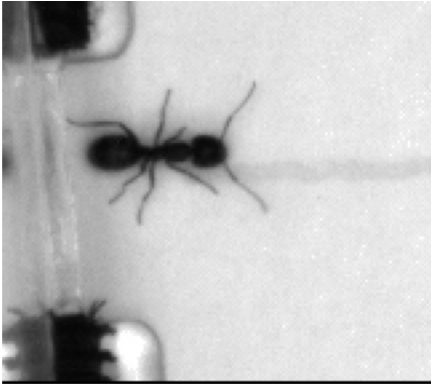


# Ant antennae



## Getting ants to track (visualized) pheromone trails

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IR light  
Minimal air currents  
White paper background  
6" trail (hindgut extract), hand-drawn  
11" x 8" field of view  
30 fps, 1280x960, 0.22 mm/px

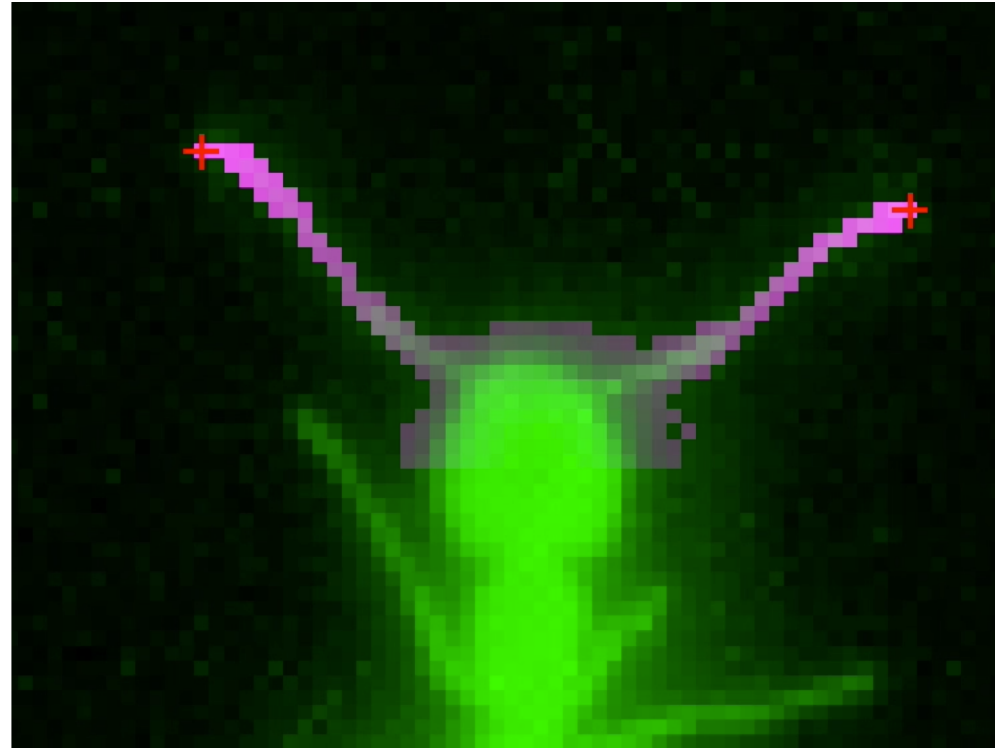
Looking more closely and slowly...

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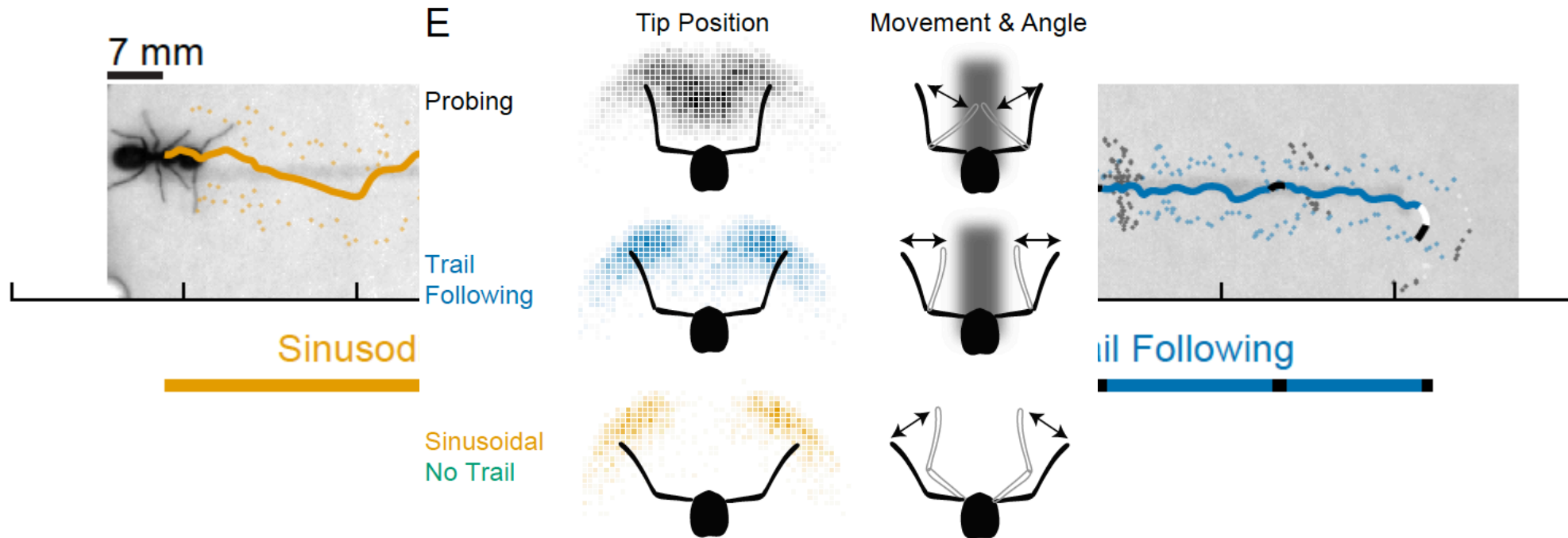
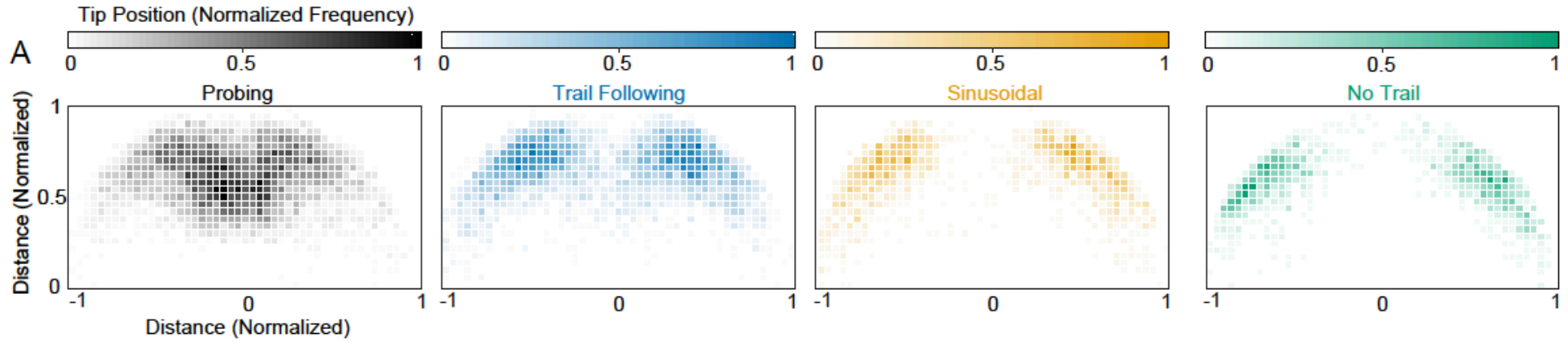


# Active sampling with the antennae

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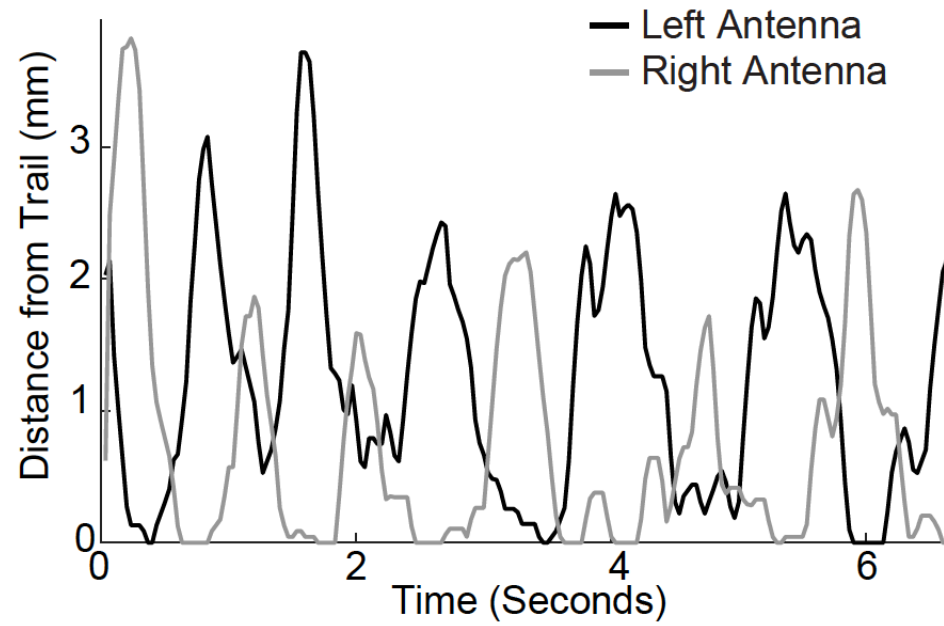
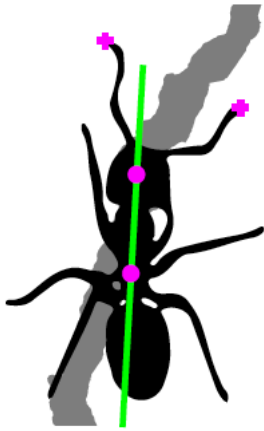


# Antennal dynamics vary with behavioral “modules”

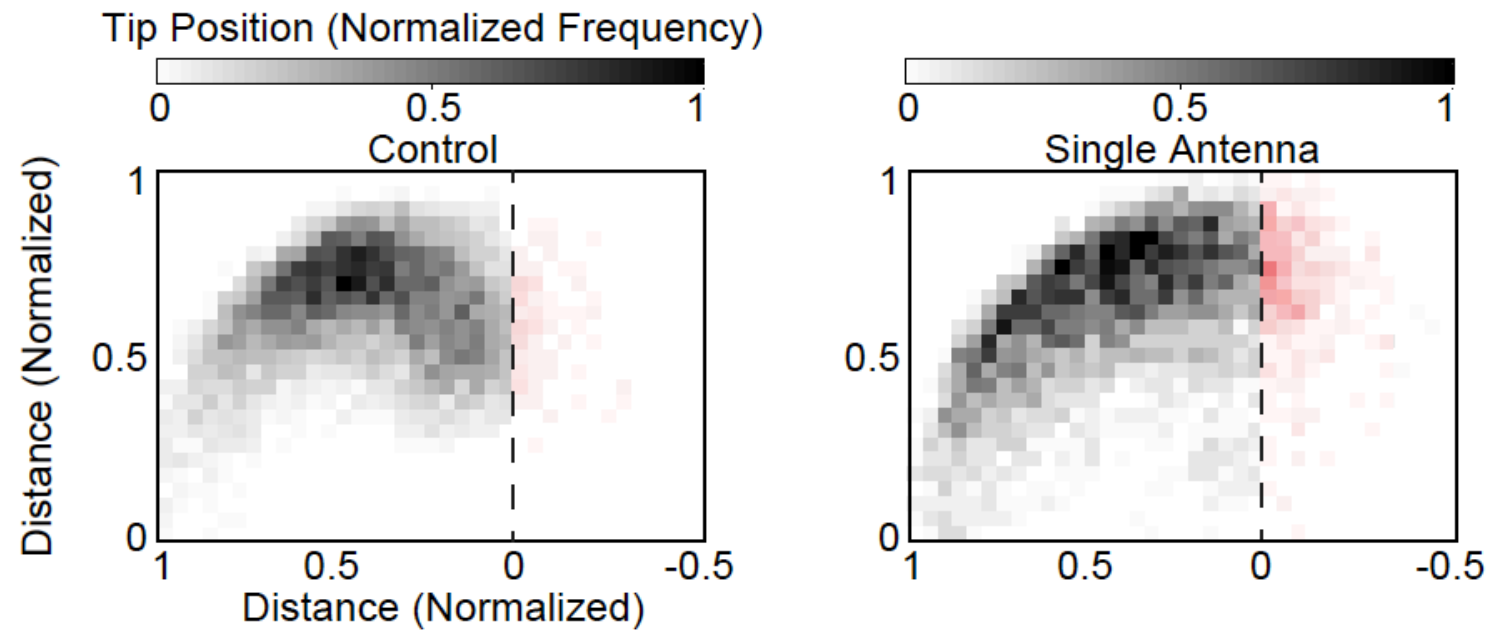
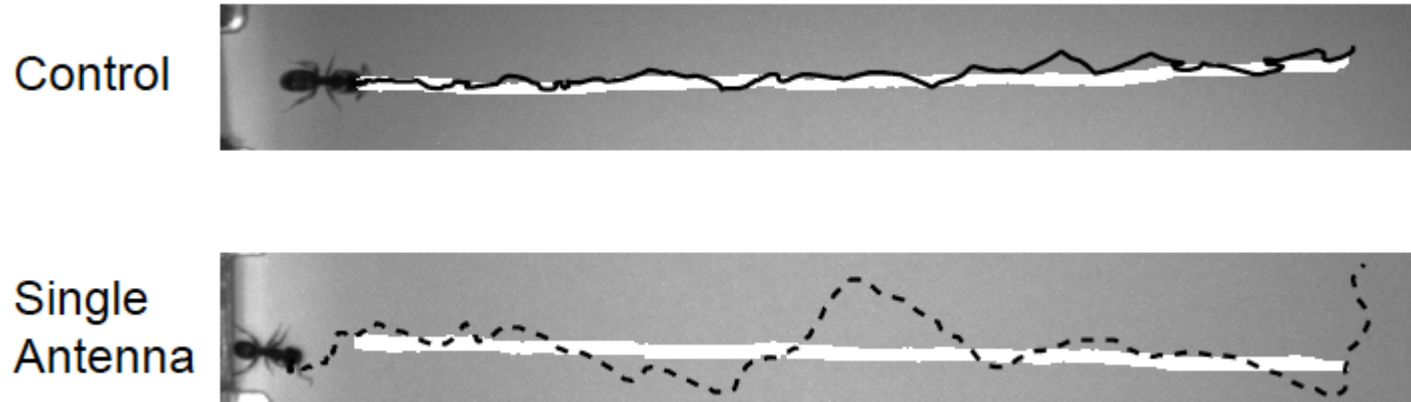


# Asymmetric (alternating) contact with trail

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# Scent trail tracking with single antenna



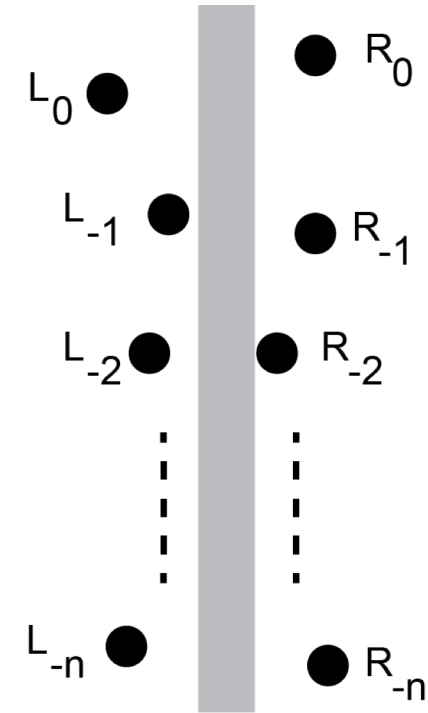
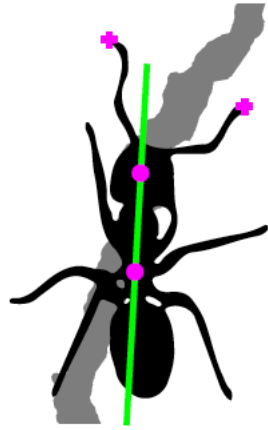
# What's the big deal about tracking scent trails?

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# Deciding where to go based on current + past knowledge

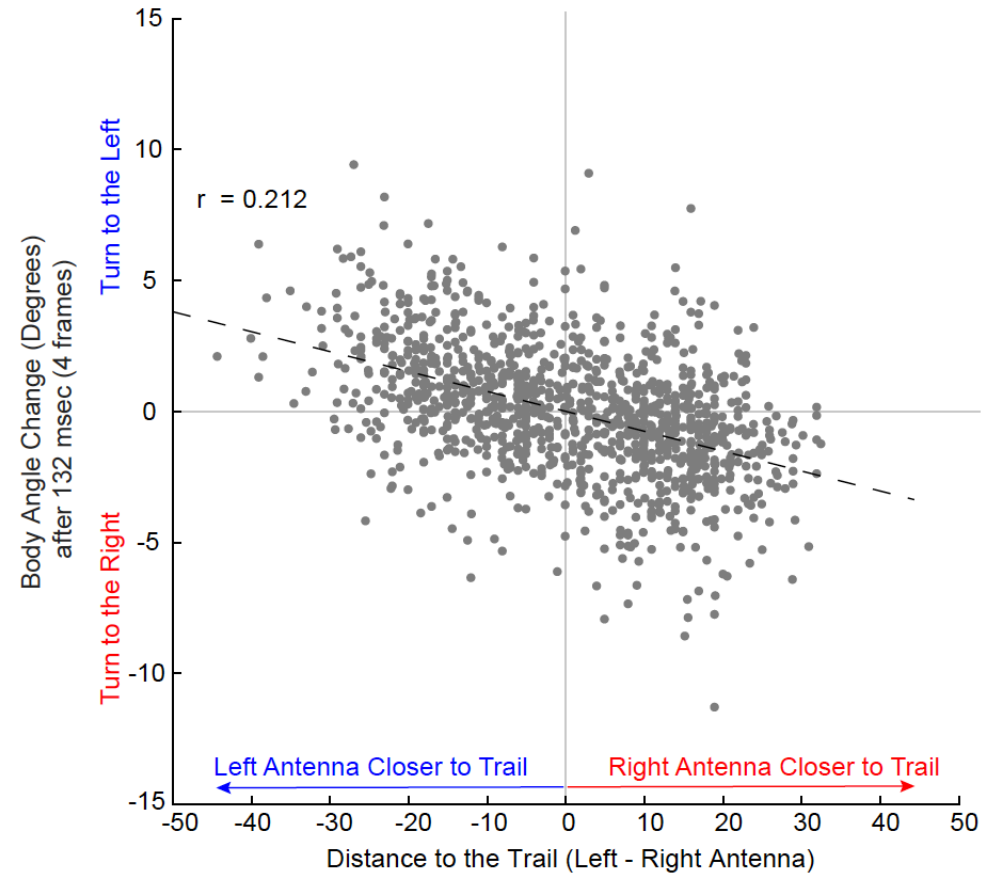
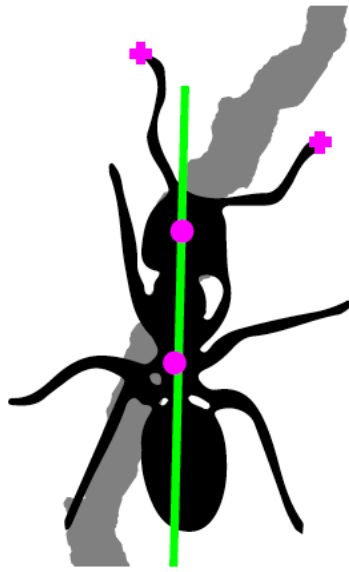


Given:

$$L = [x_L y_L c_L]$$

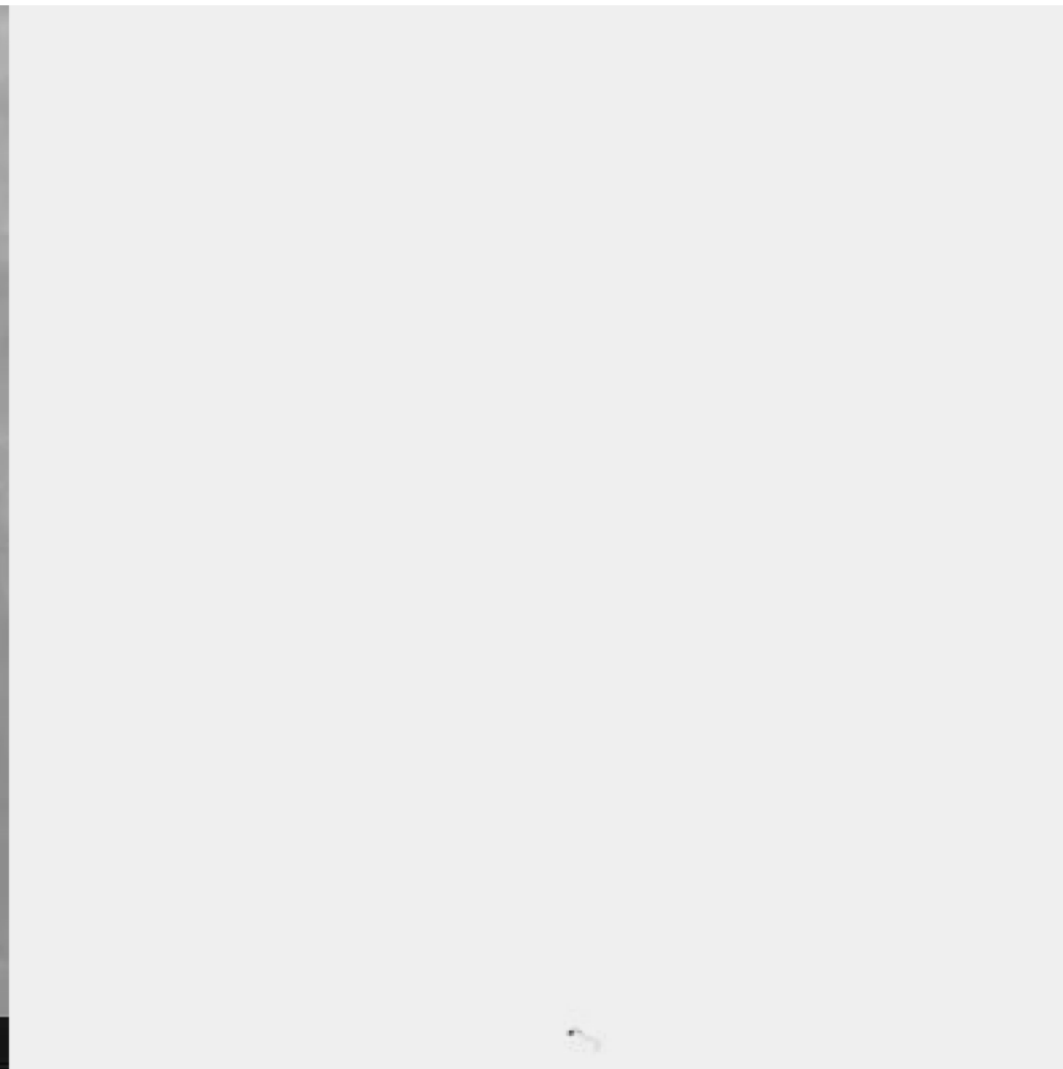
$$R = [x_R y_R c_R]$$

# A simple (linear) predictive model for turning



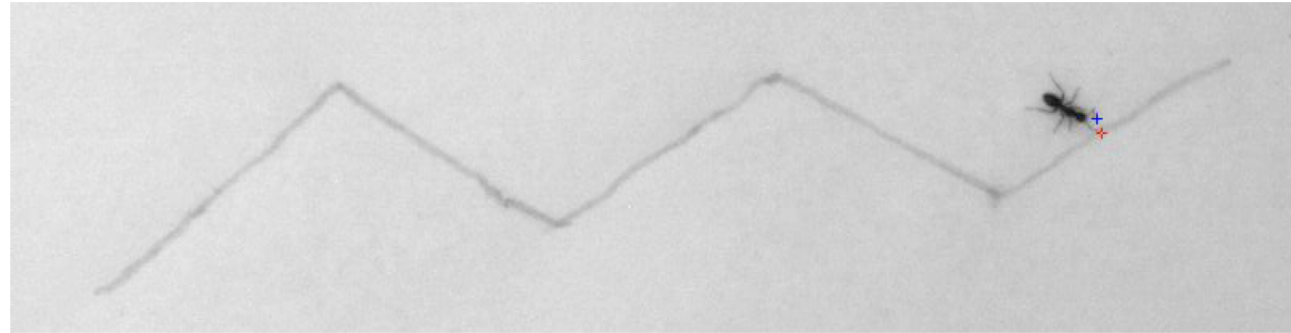
# Following ants in a large arena

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# Using tricky trails to get at the strategies & algorithms

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## Three examples from my group

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Navigating using air-borne odors (mice)

Tracking ground trails (mice)

Pheromone tracking (ants)

End

