Insect Olfactory Landmark Navigation

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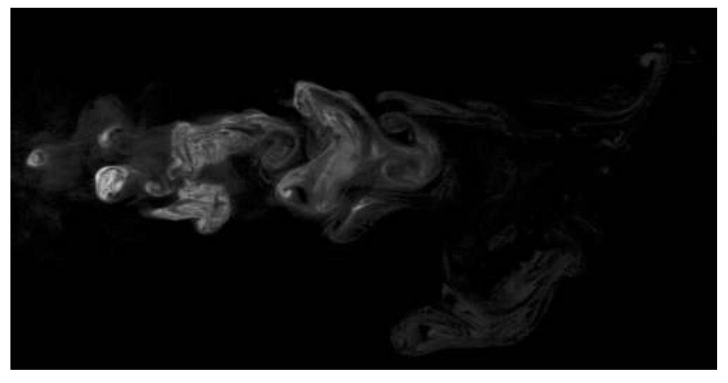
Introduction and Motivation

- The desert ant species, *Cataglyphis fortis*, was recently found by Steck et al. to be able to use olfactory landmarks to navigate within a narrow linear channel.
- The first part of this project was a field study aiming to see if this behaviour could be observed in a related ant species *Cataglyphis velox* when navigating in a more open environment.
- The second part of this project focussed on trying to establish how much location information is available to ants from their sensation of the plumes emitted from olfactory landmarks by attempting to model the olfactory signals experienced by the ants.

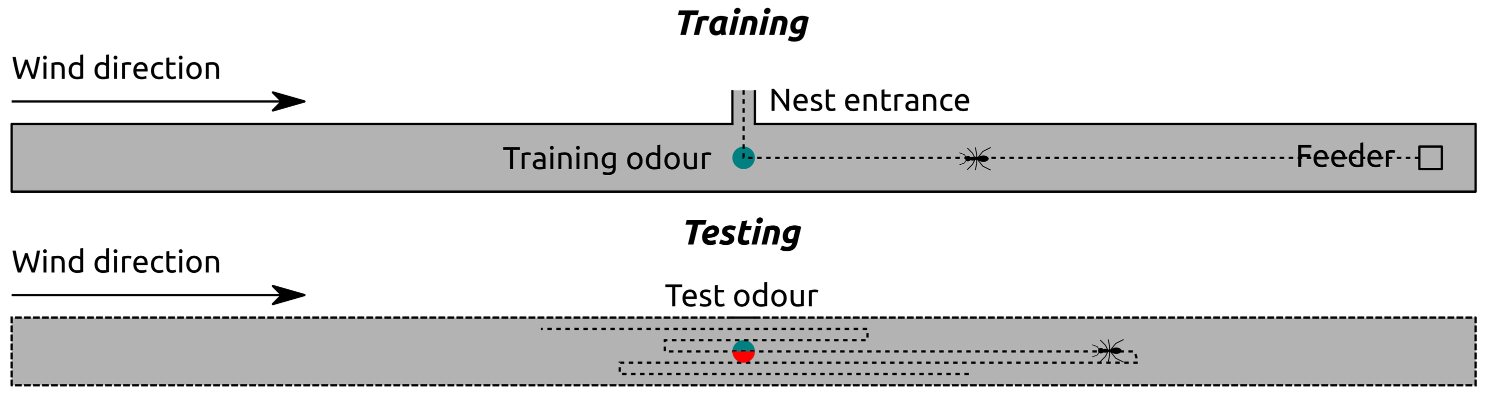
Insect olfactory navigation



Example of a cross section through a turbulent plume - intermittency and complex dynamics of such plumes make olfactory navigation a challenging task.

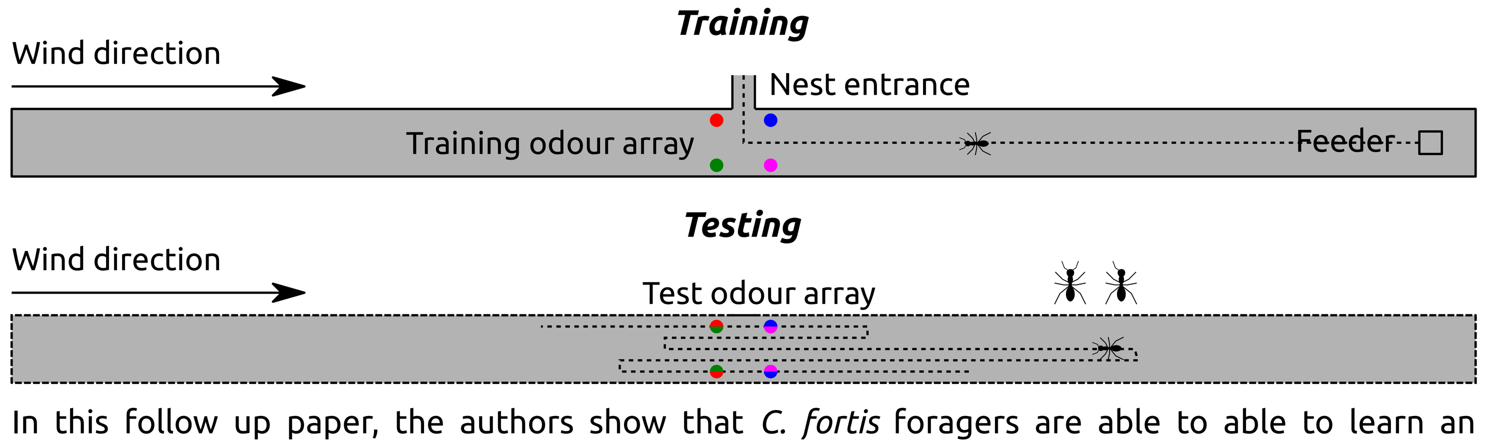
Insects often need to follow an odour plume to its source - for example a male moth searching for a sex-pheromone releasing female. In this case the odour source and target are colocated. A more complex task is to use one or more odour sources as 'olfactory landmarks' to navigate to an arbitrary point not necessarily coincident with the odour source(s). Such behaviour was recently observed for the first time in a species of desert-dwelling ants, *Cataglyphis fortis* by Kathrin Steck and colleagues. Below their main results are summarised.

Smells like home: desert ants, *Cataglyphis fortis*, use olfactory landmarks to pinpoint the nest. (Steck et al. 2009 [1])



In this paper the authors demonstrate first that there are odour blends present in structures in the natural environment of *C. fortis* that are place specific, detectable by the ants and stable over the a time window of a day. In an accompanying behavioural experiment they show that *C. fortis* foragers trained to associate an artificial odour landmark with the location of their nest entrance, when later introduced in to a separate test environment will focus their search at the location of the training odour but not at non-trained odours.

Can desert ants smell the scenery in stereo? (Steck et al. 2010 [2])



In this follow up paper, the authors show that *C. fortis* foragers are able to able to learn an association between multiple odour sources in a fixed array arrangement and the location of their nest entrance within that array. When introduced to a separate test environment, the ants search most densely at the location corresponding to their nest entrance when the specific arrangement of odours they were trained with is present. When the odours are swapped around the ants search is less focussed and the ants performance also drops when trained and tested with one antenna removed versus intact ants suggesting they benefit from bilateral olfactory input when navigating.

Fieldwork: Can Cataglyphis ants use olfactory landmarks to navigate in two dimensions?

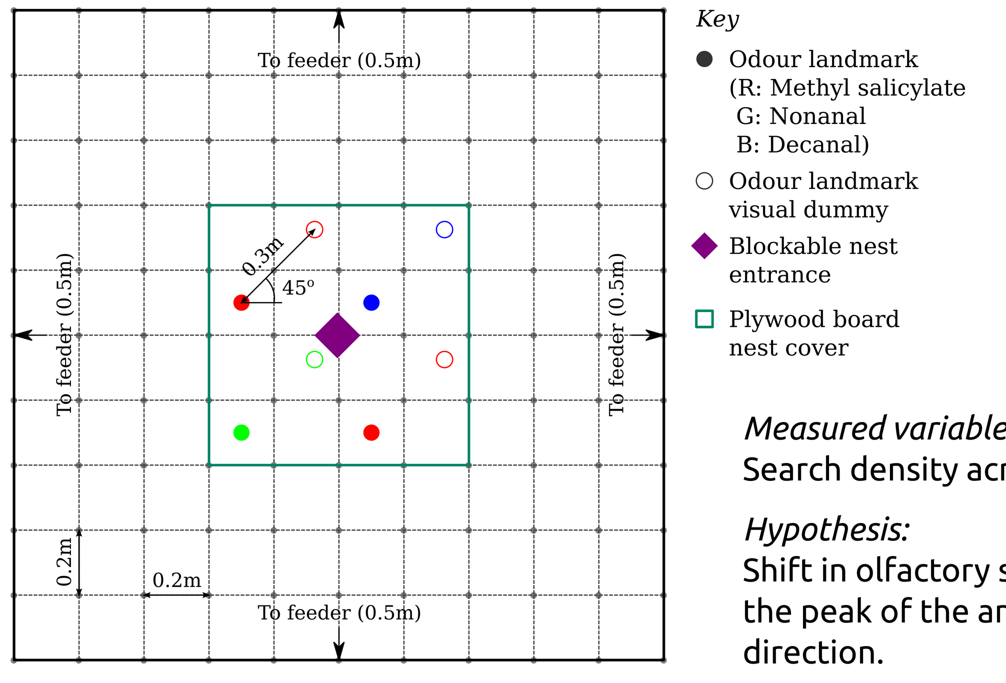
Field site habitat near Seville

Inconspicous nest entrance

Cataglyphis velox forager

Field study conducted outside Seville, Spain with European desert ant species *Cataglyphis velox*. The aim was to see if the work of Steck et al. on olfactory landmark navigation with *Cataglyphis fortis* could be extended to a less restrictive open environment .

Experimental setup



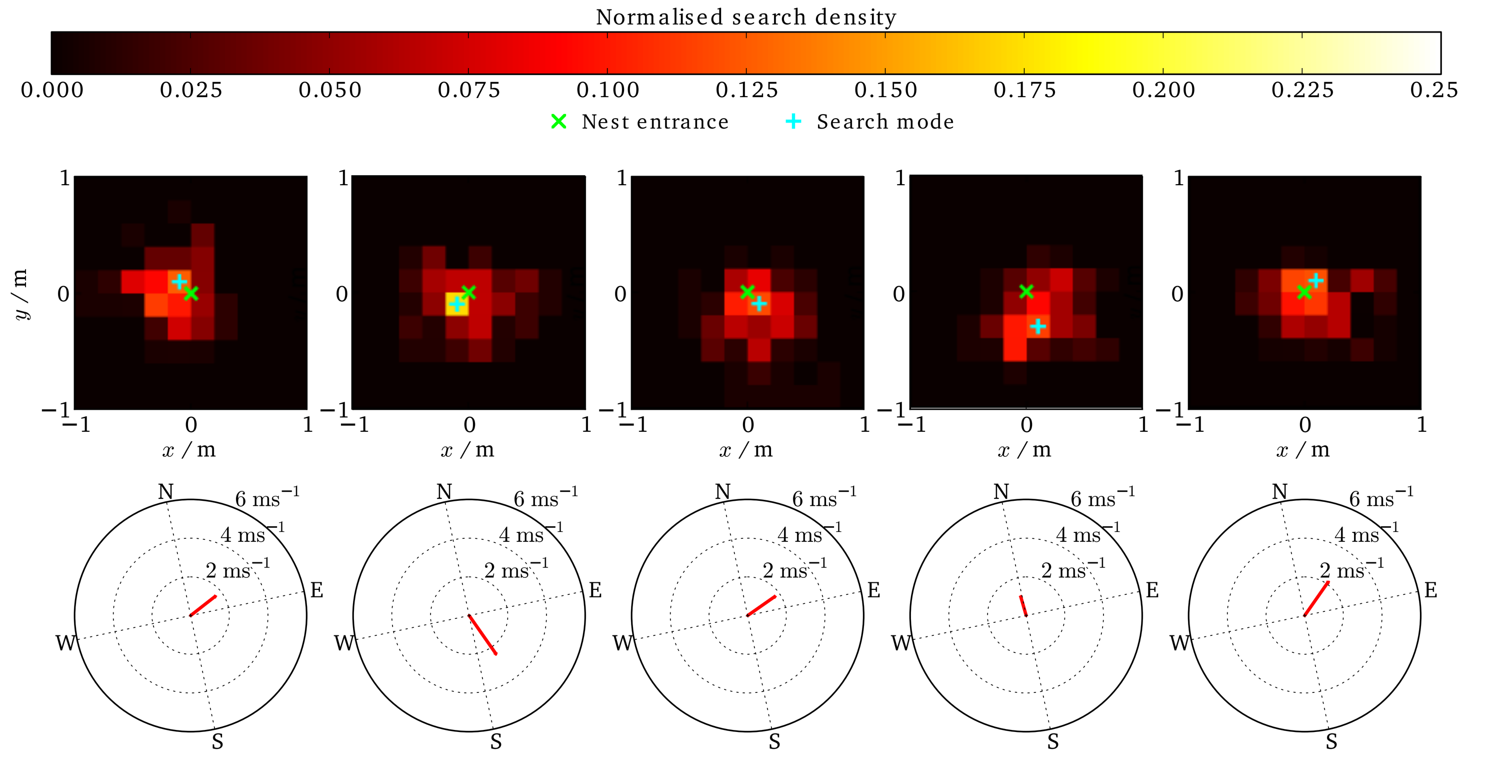
CONTROL *condition*:
Olfactory landmark at same positions as training.

SHIFT *condition*:
Olfactory landmarks swapped with dummy pegs, offsetting olfactory scenery while keeping visual and other cues constant.

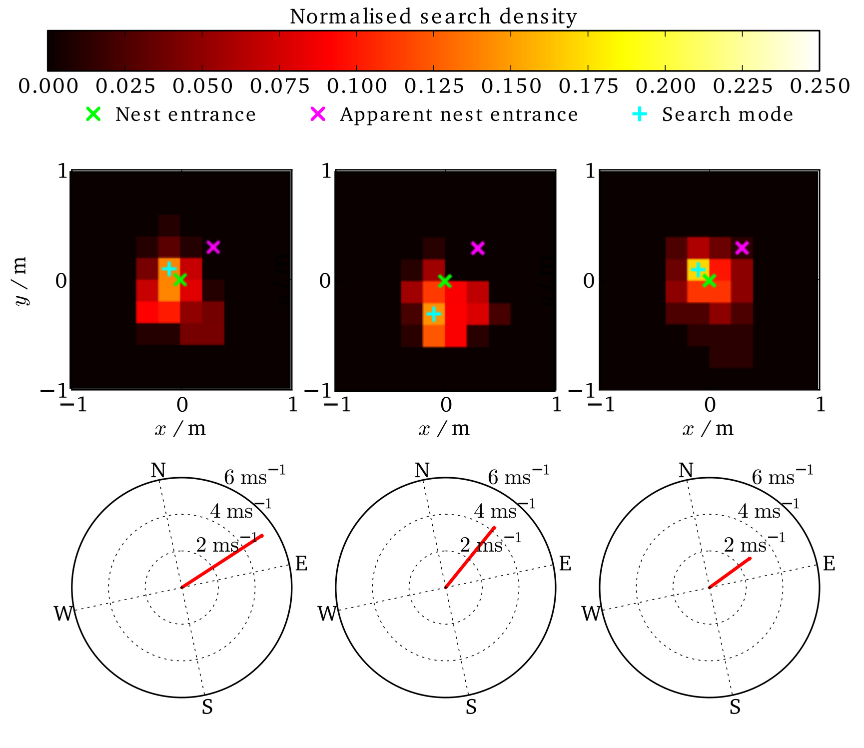
Measured variable:
Search density across 20 cm recording grid.

Hypothesis:
Shift in olfactory scenery should lead to a shift in the peak of the ants search density in the same direction.

CONTROL condition results



SHIFT condition results



No significant shift was found in peaks of SHIFT condition ants' search densities versus CONTROL, however conclusions were limited by small sample sizes and likely weak effect.

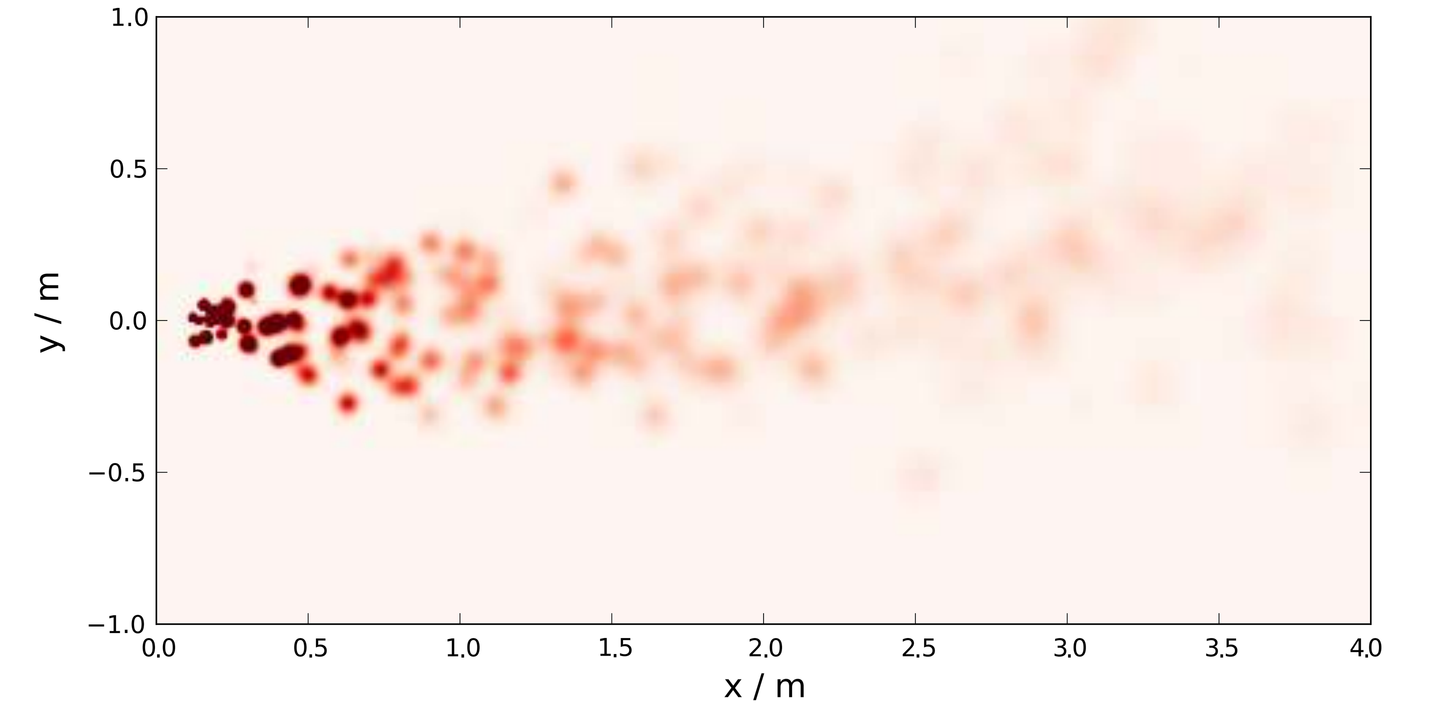
The continued presence of other strong cues including landmarks in the visual surroundings, tactile information from the surfaces around the nest and natural olfactory markings laid down by the ants around the nest possibly had a dominanting effect that overwhelmed any difference due to the shift in artifical olfactory landmarks.

Problems were also encountered on site with variable weather conditions and poor forager motivation.

Modelling: What and how much information is available from olfactory landmarks?

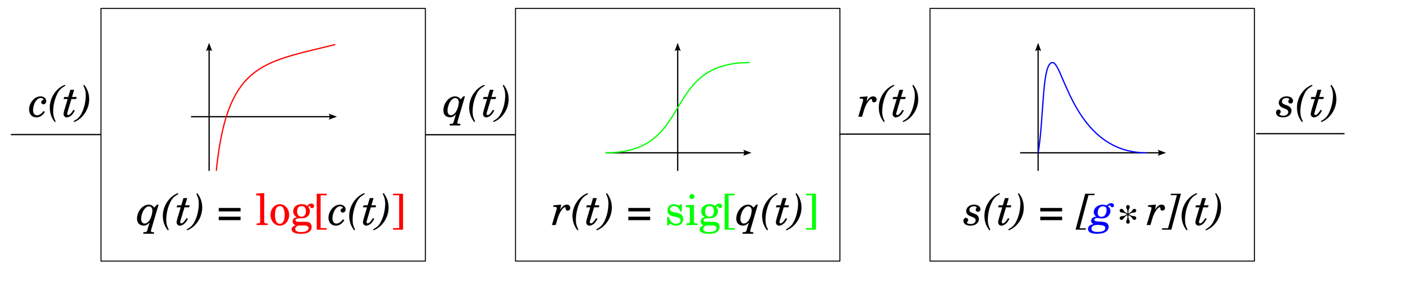
Turbulent plume model (Farrell et al. 2002 [3])

A part mechanistic, part phenomenological model was used to simulate the time-course of the concentration and wind velocity fields within a turbulent odour plume. The model simulates the transport of discrete 'puffs' of odour by a time-varying wind field, a stochastically driven dispersion process and isotropic diffusion based 'spreading'.

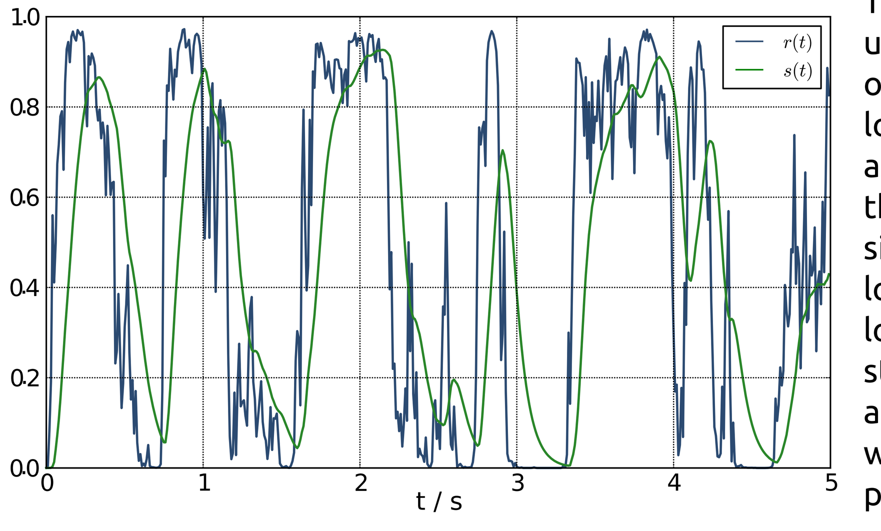


Sensor model

A simple phenomenological model was used to simulate the processing performed by initial stages of the ant's olfactory sensory system. The concentration response was determined by a Hill equation function (based on results of odour coding in honeybee antennal lobe [4]) and time response modelled as a LTI damped second order system, this attenuating the high frequency components of the signal (based on study of cockroach olfactory sensory neurons [5]).



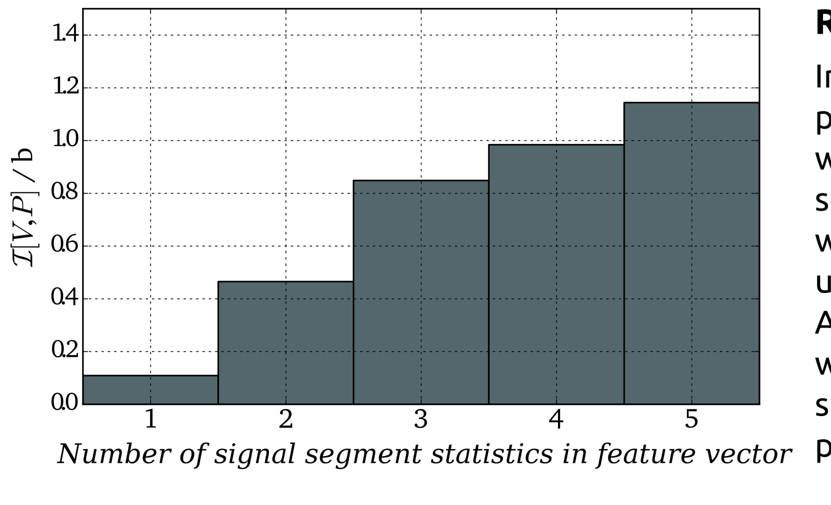
Modelled olfactory sensory signal



The sensor and plume models were used to produce data sets of modelled olfactory signal at different plume locations. An important factor in assessing the information available to the ants was the duration of the odour signal segments used to help infer their location. Although there are simple location dependecies in the signal statistics over long intervals (minutes) ants navigate much faster than this would allow. Therefore the analysis was performed with short (~1s) segments.

Information theory analysis

The mutual information $\mathrm{I}[\boldsymbol{s},\boldsymbol{p}]$ indicates by how much receiving a segment of odour signal $\boldsymbol{s}$ reduces uncertainty about the position $\boldsymbol{p}$ that signal was received at. The signal segment $\boldsymbol{s}$ lies in a very high dimensional space making it hard to estimate joint density $\mathrm{p}(\boldsymbol{s},\boldsymbol{p})$. Therefore it was attempted to extract feature vectors $\boldsymbol{v}$ from $\boldsymbol{s}$ which maintain as much information about $\boldsymbol{p}$ as possible and estimate $\mathrm{p}(\boldsymbol{v},\boldsymbol{p})$ and from this $\mathrm{I}[\boldsymbol{v},\boldsymbol{p}]$. This acts as a lower bound on $\mathrm{I}[\boldsymbol{s},\boldsymbol{p}]$.



Results

In isolation, statistics of odour signal provided minimal positional information when signal segments of duration one second and below were used, however when combined they could provide more useful uncertainty reductions.

A more realistic turbulent plume model would be needed to assess if fine scale structure contains further useable positional information.

References

[1] K. Steck, B. S. Hansson, and M. Knaden. Smells like home: desert ants, *Cataglyphis fortis*, use olfactory landmarks to pinpoint the nest. *Front. Zool*, 6(5), 2009.
[2] K. Steck, M. Knaden, and B. S. Hansson. Do desert ants smell the scenery in stereo? *Animal Behaviour*, 79(4):939-945, 2010.
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[4] S. Sachse and C. G. Galizia. The coding of odour-intensity in the honeybee antennal lobe: local computation optimizes odour representation. *European Journal of Neuroscience*, 18(8):2119-2132, 2003.
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