A computational Approach to Behavior

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AAAI Symposium on
``Computational Principles of Natural and Artificial Intelligence''
Stanford University

California gull vs. alkali fly

(Larus californicus vs *Ephydra hians)*

Mono Lake, CA

37°58’50.6”N, 119°06'33.4"W

brain+
body

development,
regulation

genes

perception
learning

decision,
control

behavior

natl. selection
gene expression

environment

HW+
SW

construction

design

perception
learning

decision,
control

behavior

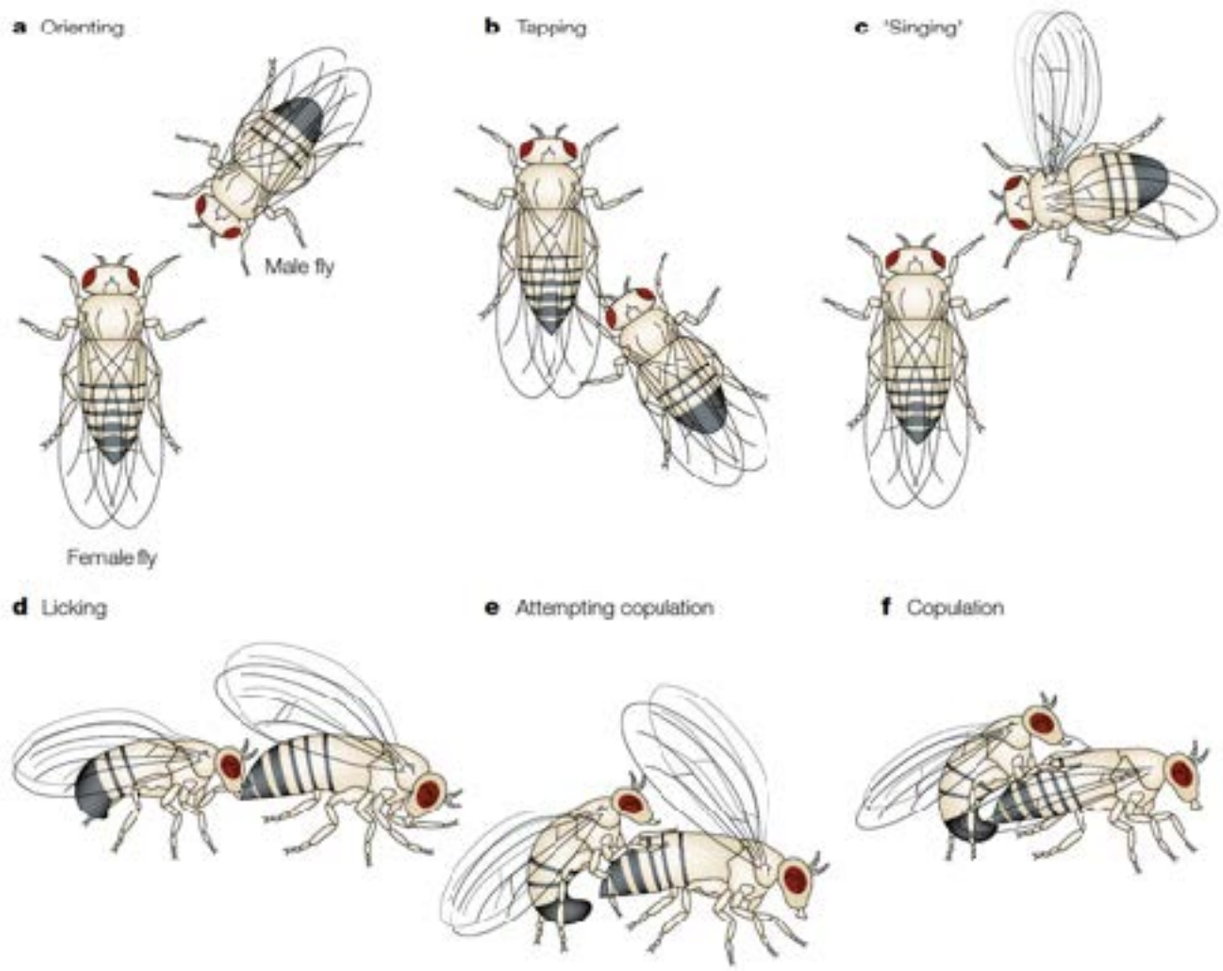
analysis of
performance

environment

What is `behavior’?

Zidane in a dish

Courtship in *Drosophila*



Marla B. Sokolowski
Nature Reviews Genetics 2, 879-892 (2001)

A Lunging

Side

Top

B Wingthreat

C Tussling

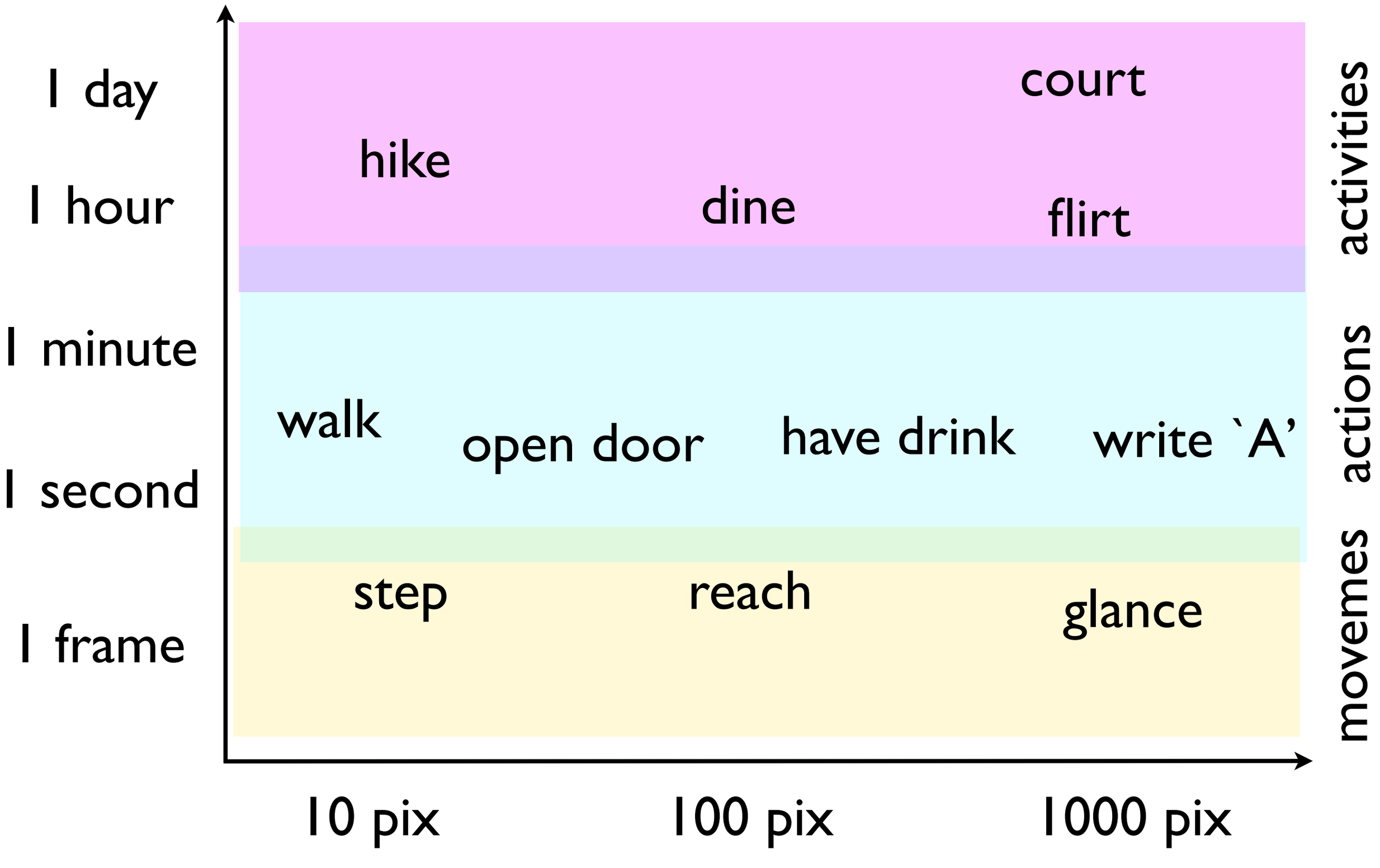
D Copulation

E Chasing

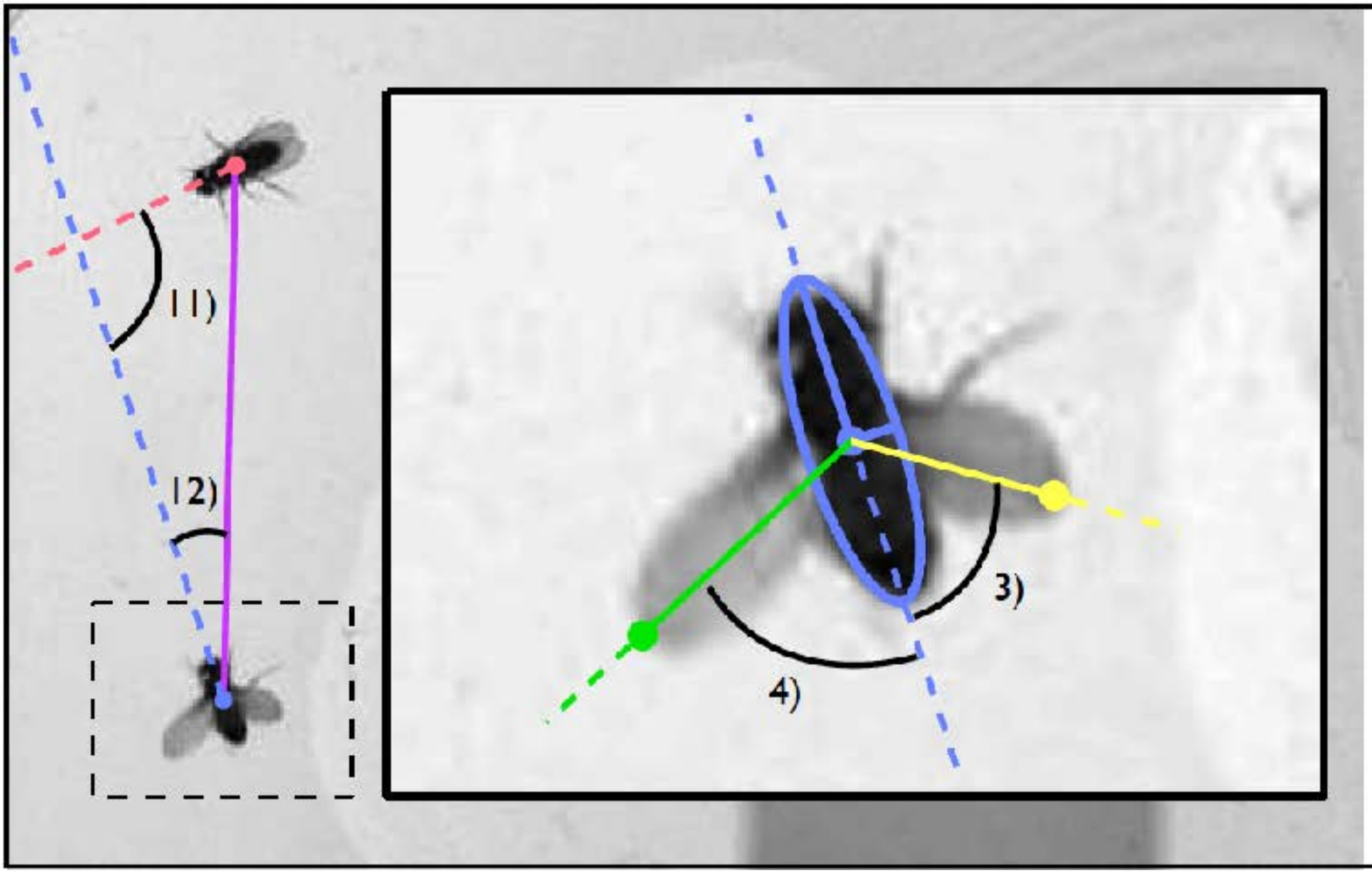
Time = [SS.CS]

F Wing extension & circling

Phenomenology: many scales



Parametrization



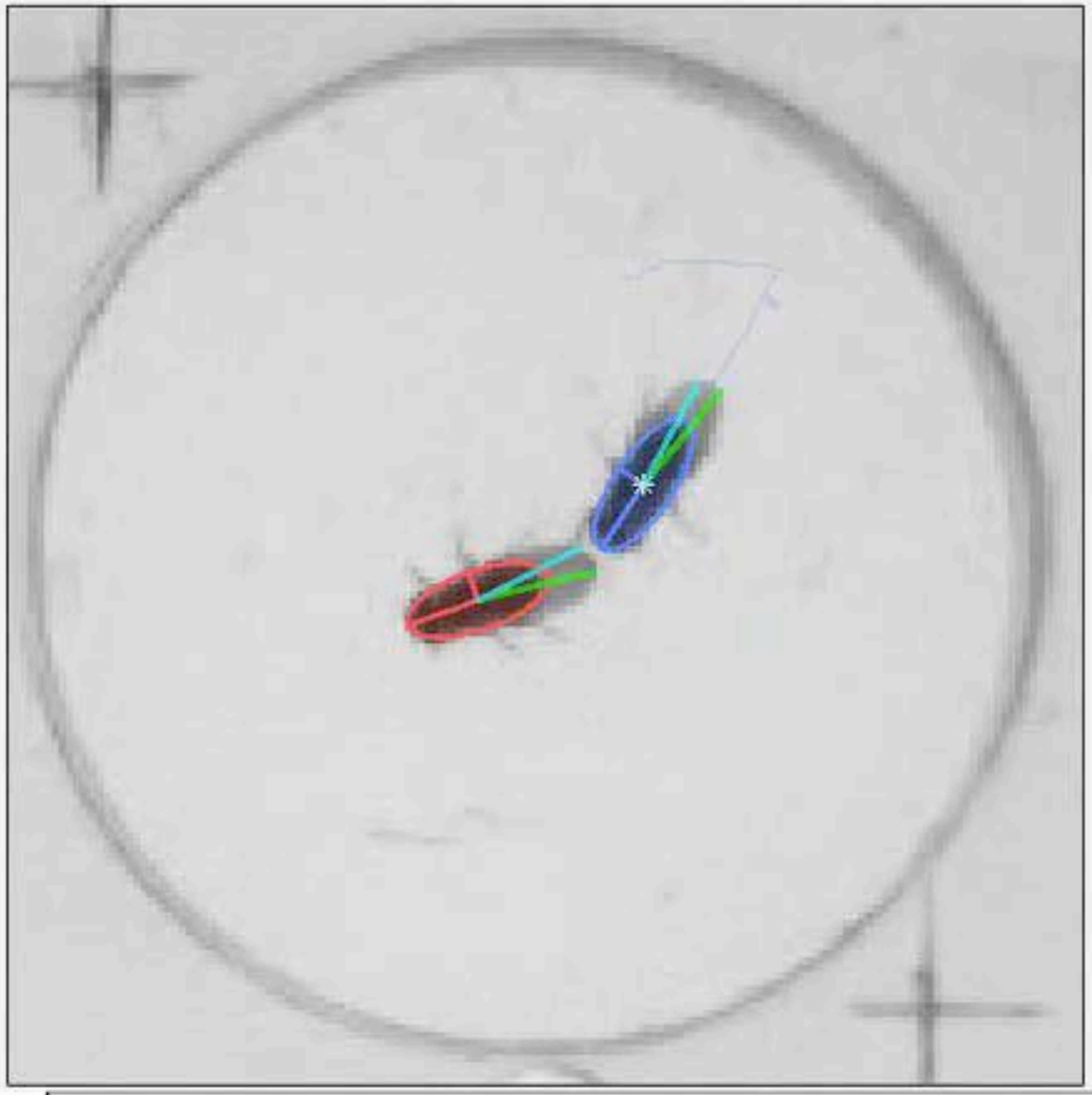
Individual features

1) velocity
2) angular velocity
3) min wing angle
4) max wing angle
5) mean wing length
6) body axes ratio
7) fg body ratio
8) image contrast

Relative features

9) distance between
10) leg distance
11) angle between
12) facing angle

/Users/eyrun/Caltech/TestMovies/Aggression/movie6.mp4



play | 2741 / 54000 | framerate: 30

GT:

Pred.:

axis_ratio | apply threshold

Display settings

- [x] show image
- [x] show tracks
- [x] ellipse
- [x] trail
- [x] wings
- [ ] legs

Active fly id: 1

Identity correction

Potential id swaps: sort by frame

< 0 > / 197 | play clip | swap

save changes

Behavior annotation

Action: lunge

Bout type: prediction

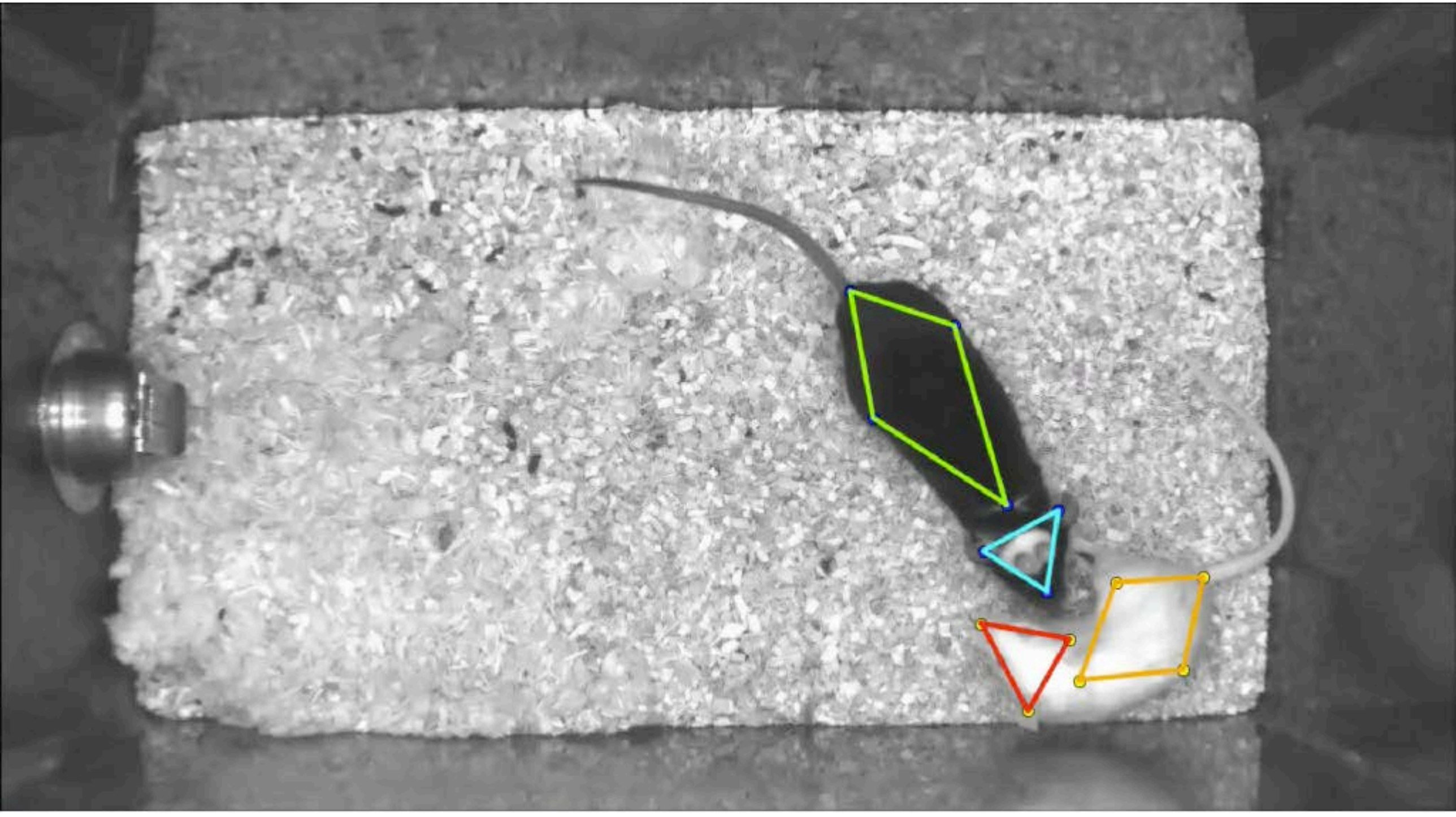
< 0 > / 189 | play clip

ADD NEW | DELETE | MOVE | COPY

Certainty: maybe | probably | definitely

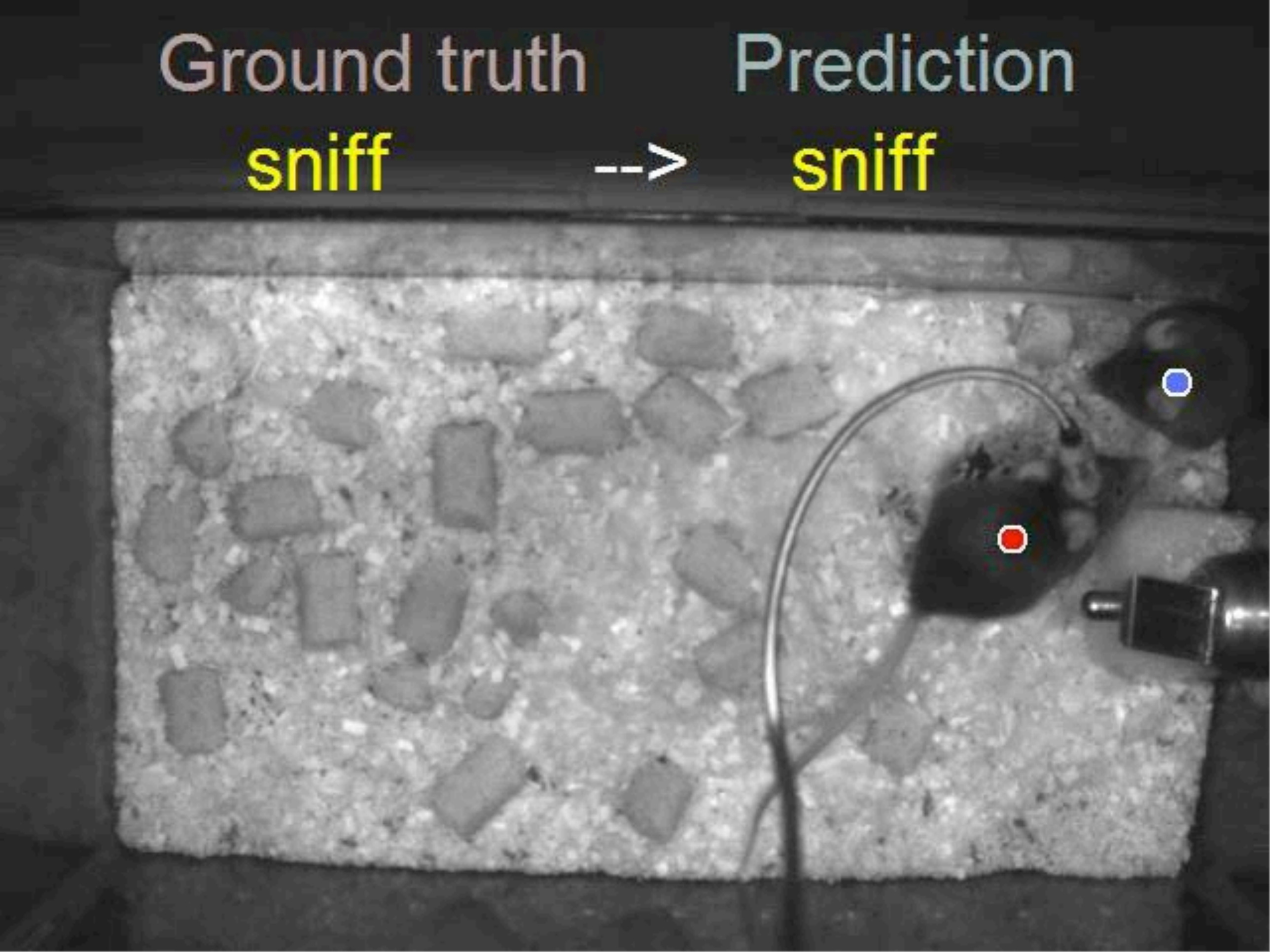
save changes

[Eyjolfsdottir, 2014]

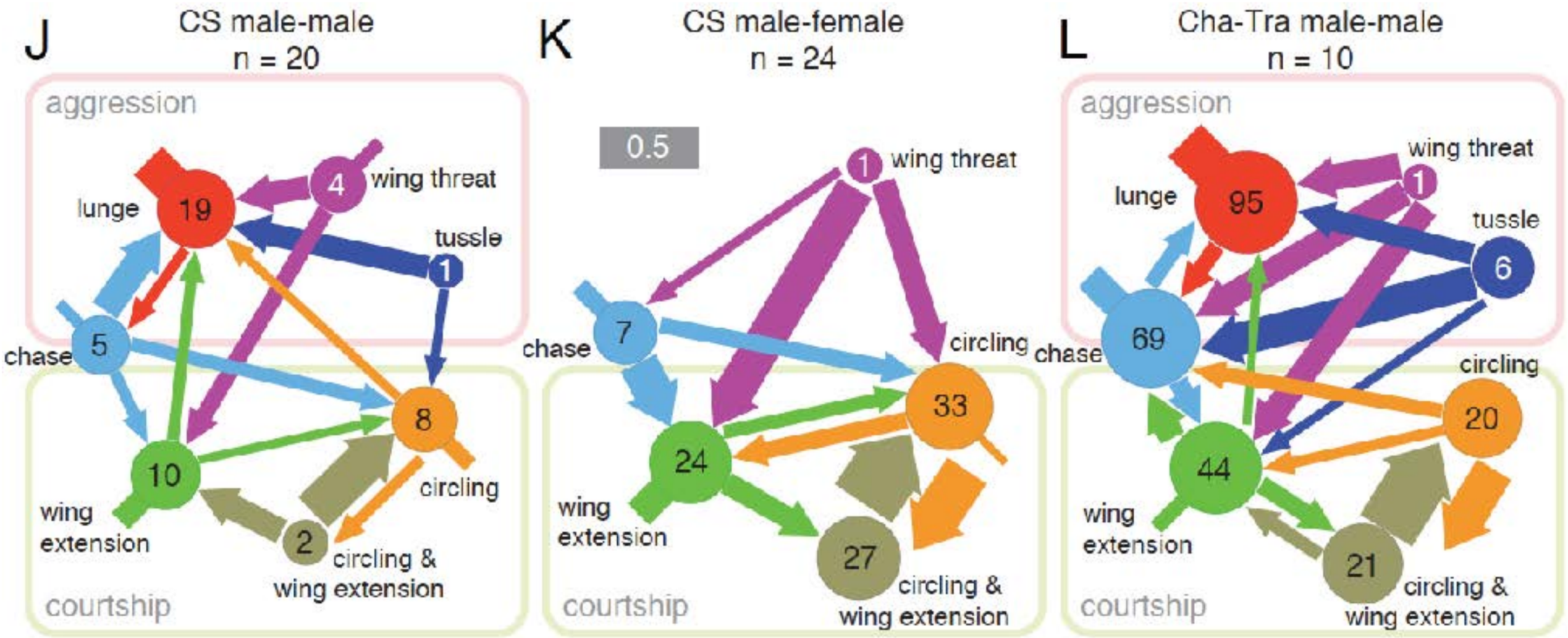


Ground truth Prediction

sniff --> sniff



Ethograms



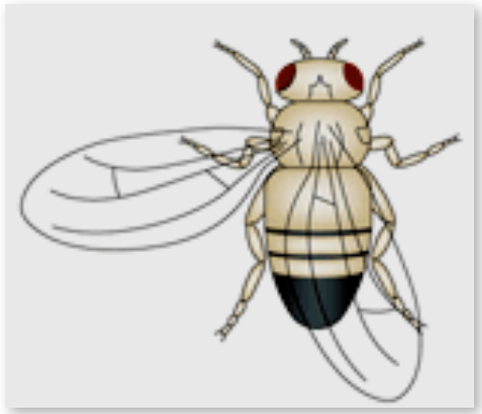
[Dankert et al., Nature Methods, April 2009]

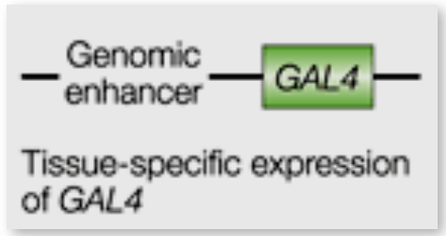
by hand it would have taken (20+24+10)*1/3 * 3 * 7 = 400h

Levels of enlightenment

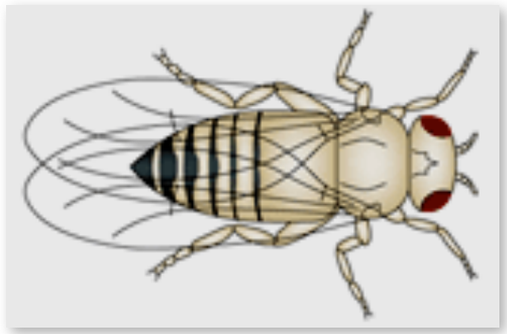
- Description
- Phenomena
- Mechanisms

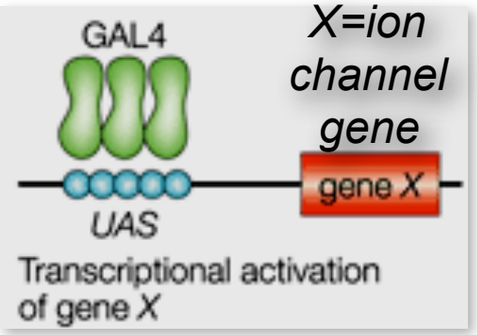
FINDING AGGRESSION NEURONS IN THE FLY

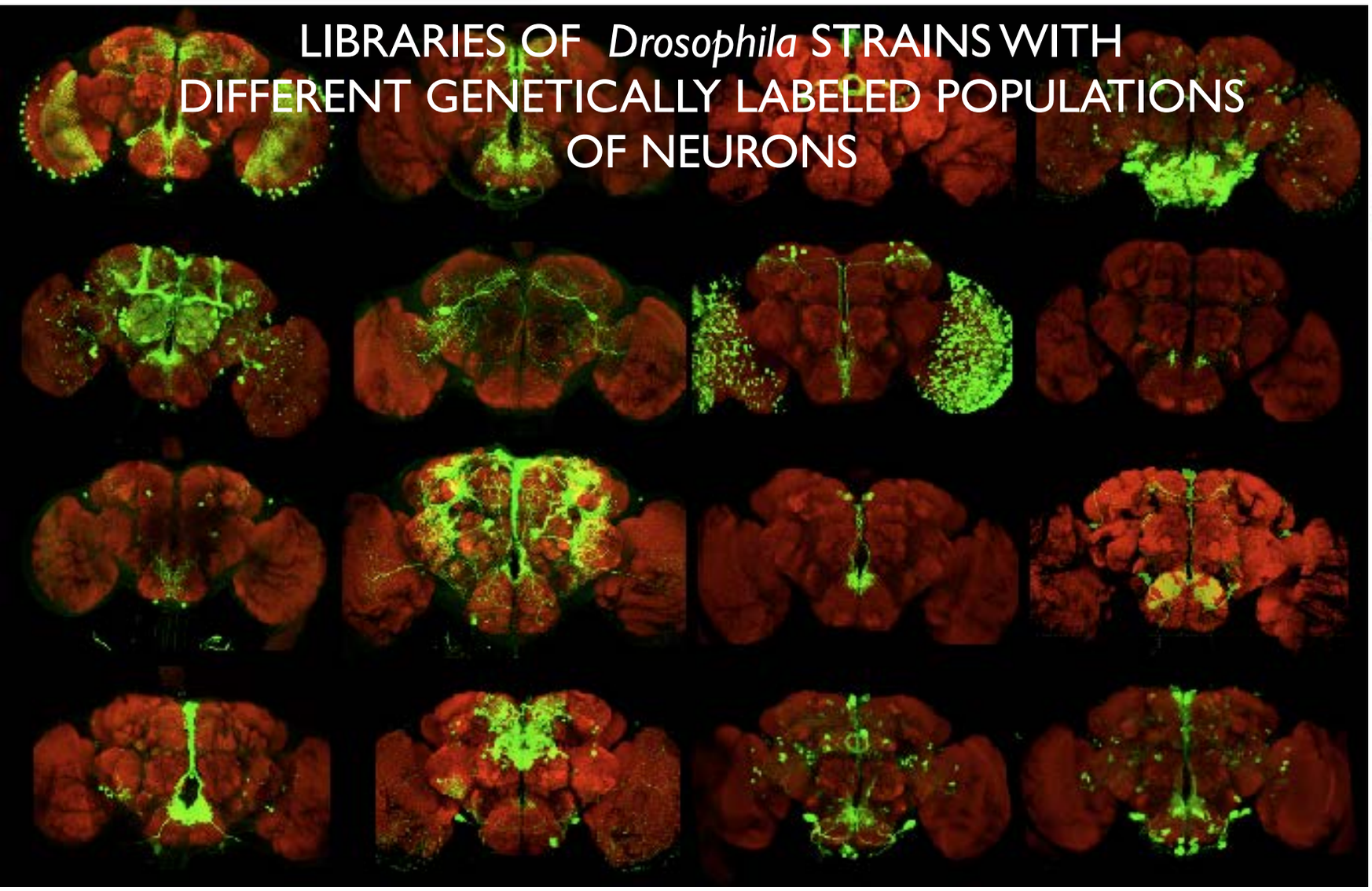




X

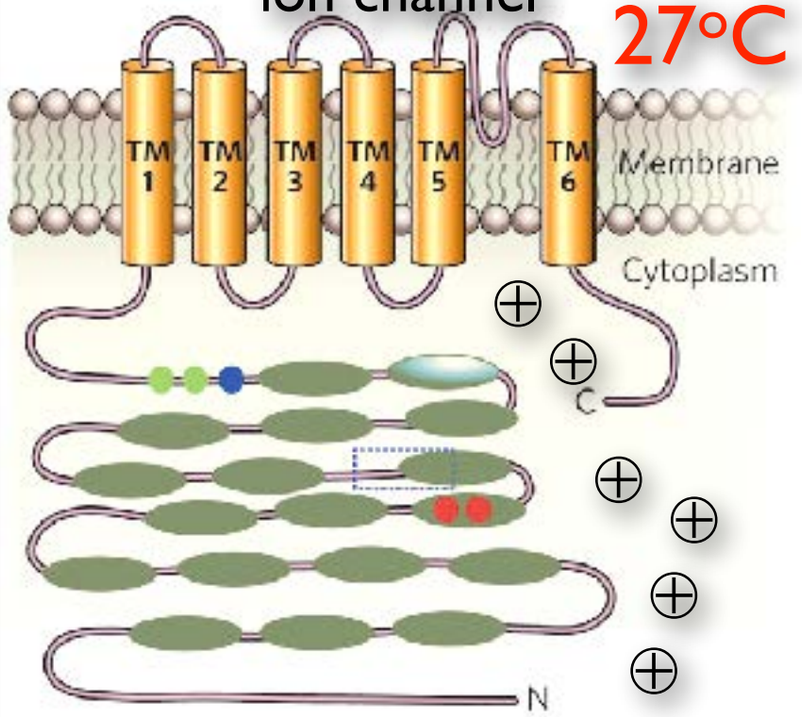






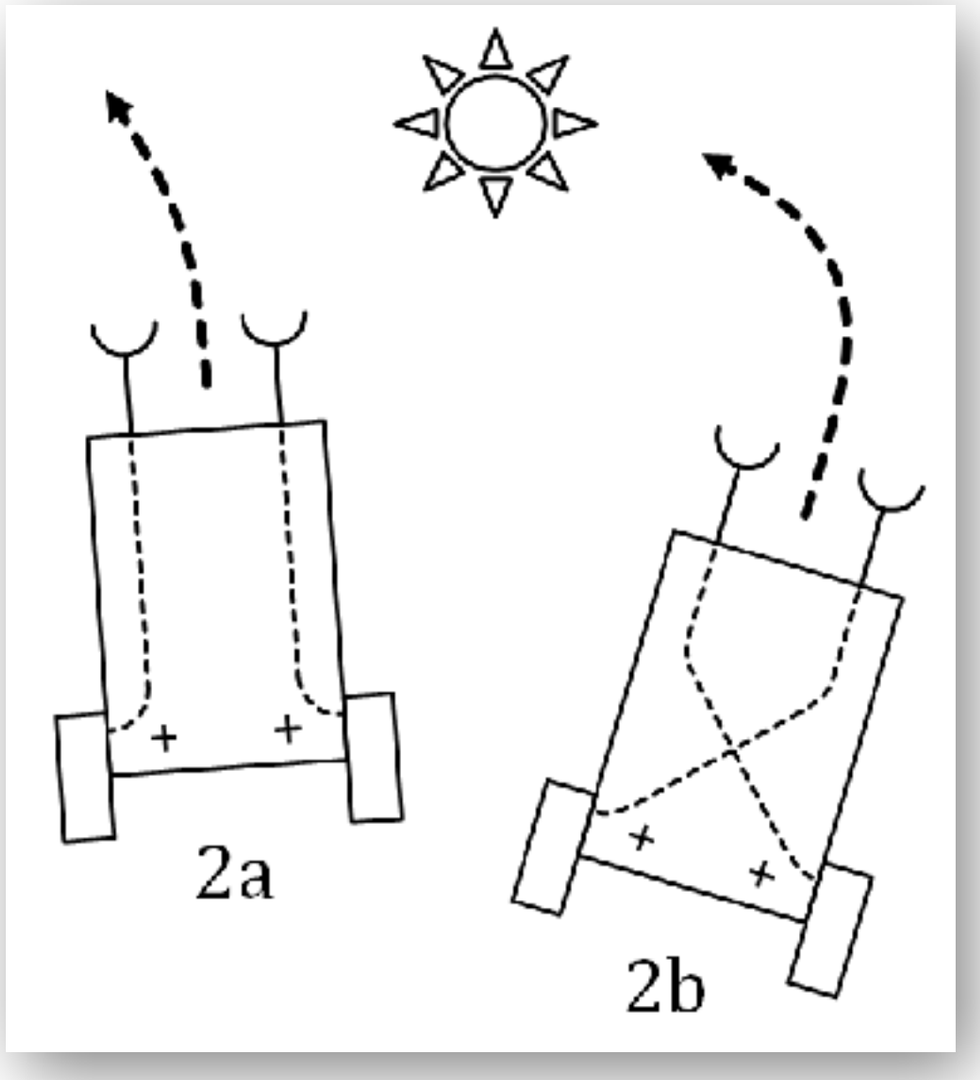
warmth-sensitive ion channel

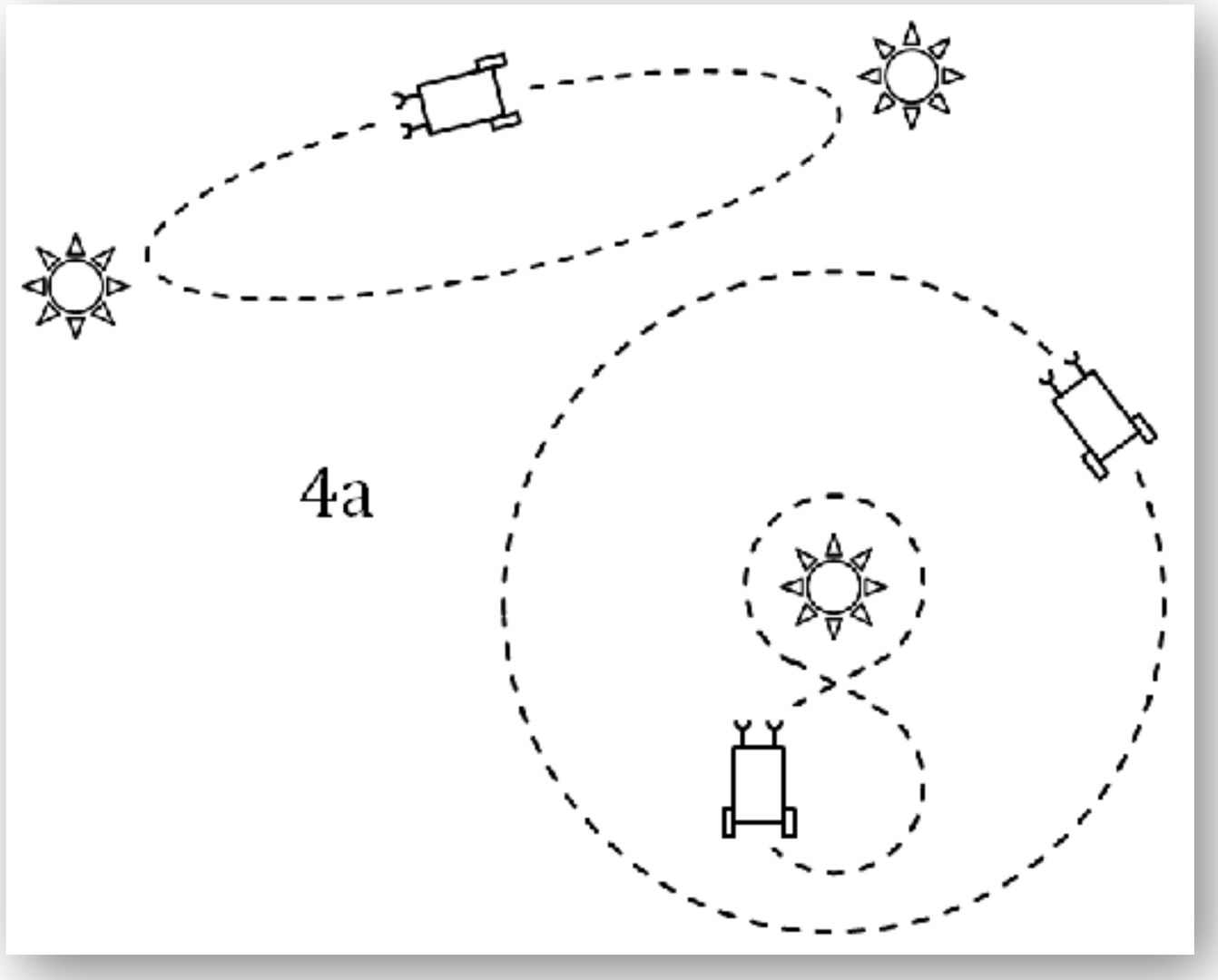
27°C



hyperaggressive?

Analysis by synthesis





[Braitenberg, 1984]

Action

Perception

PLANNING

REPRESENTATIONAL

group-level goals and plans

SOCIAL NETWORK

interaction, cooperation, competition

SOCIAL INTERACTION

INDIVIDUAL

individual goals and plans

PREFRONTAL CORTEX

plans, goals, behavior, relationships ...

COGNITION

motor programs

MOTOR CORTEX, BASAL GANGLIA etc.

pose, movemes, actions, activities, objects, scenes

RECOGNITION

MOTOR

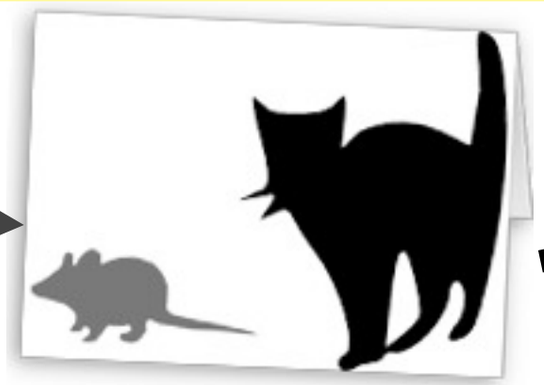
SENSORY

sensor-based control

SPINAL CORD

images, trajectories

IMAGING.TRACKING



World

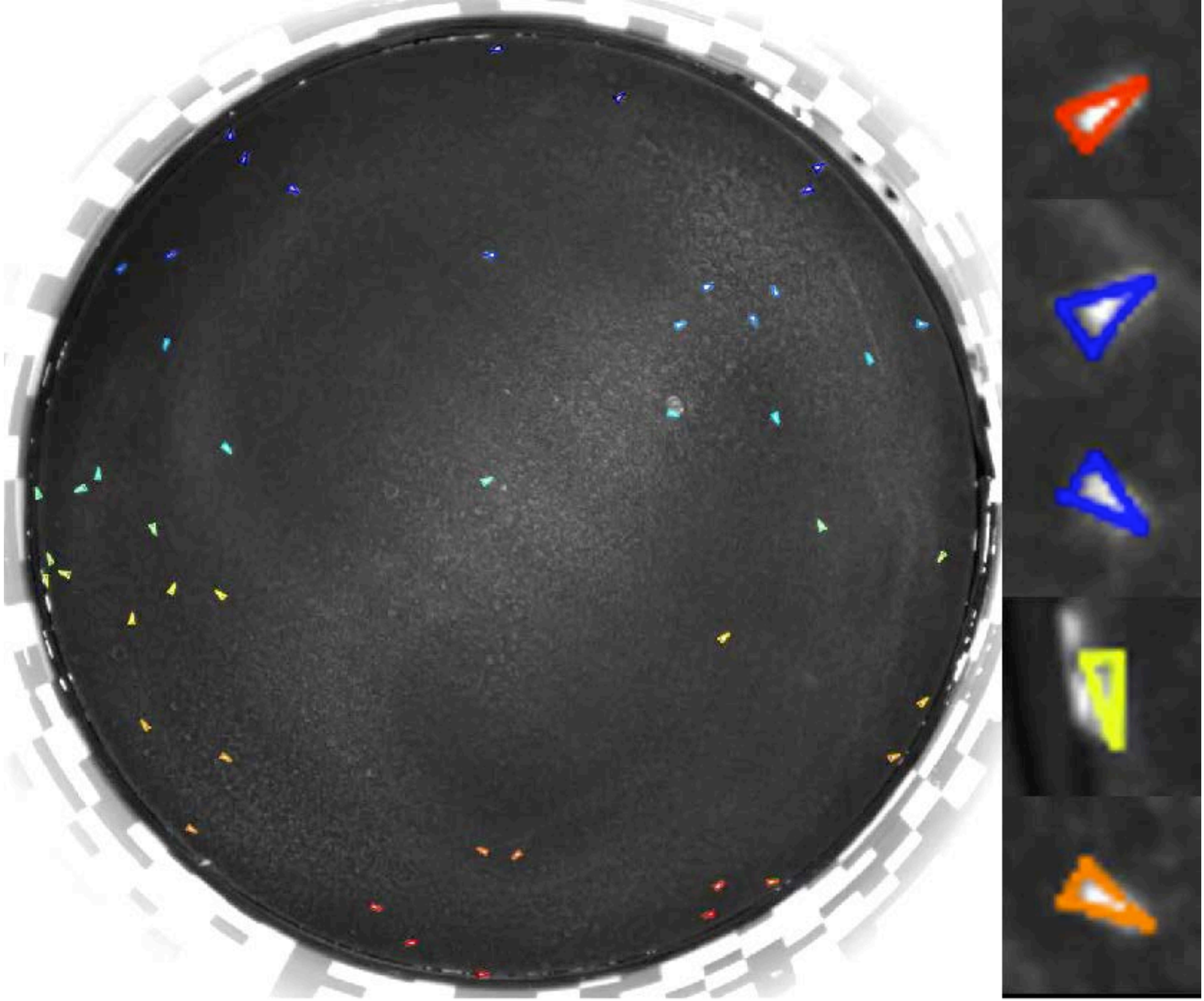
Levels of analysis

- Description

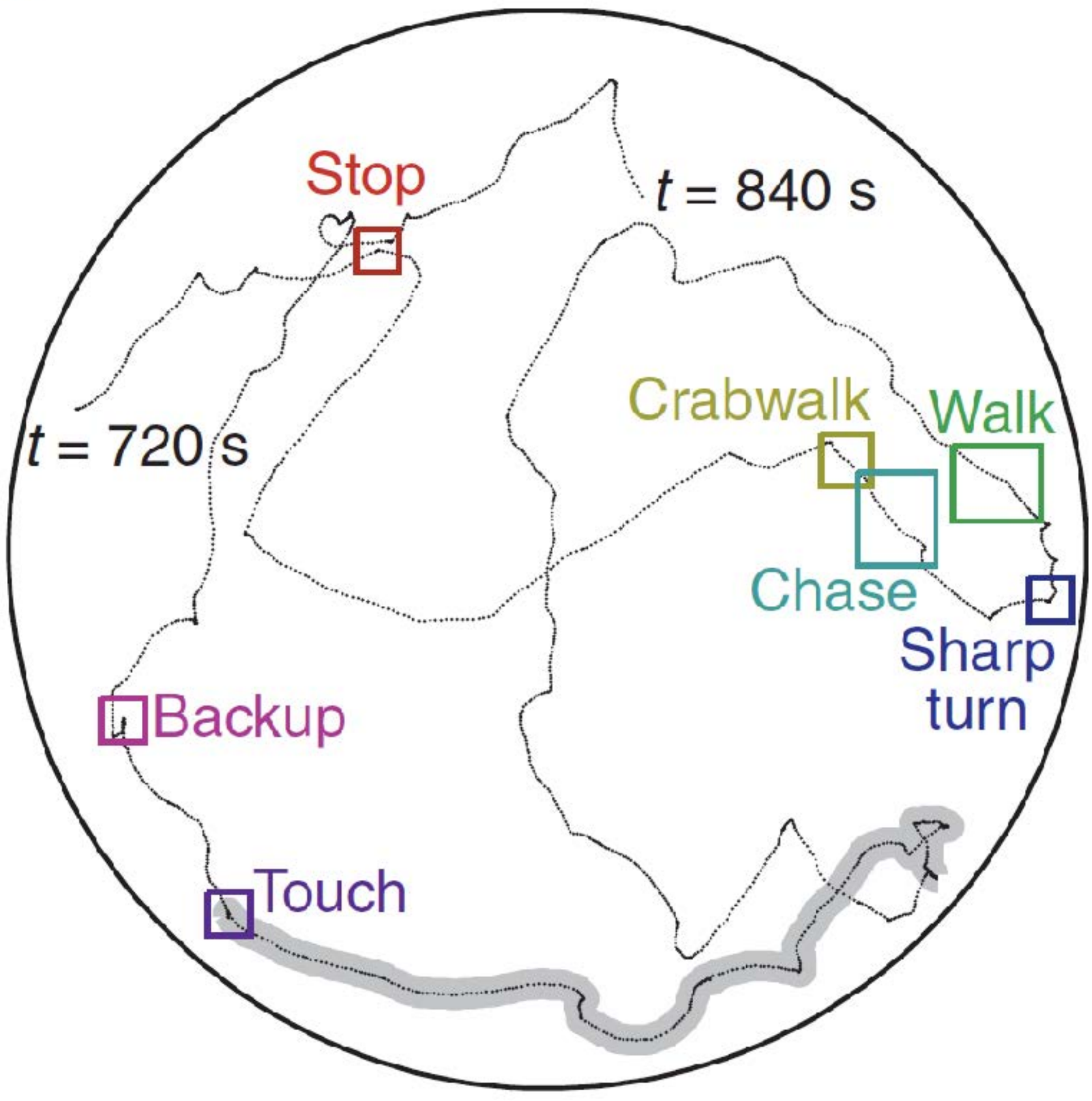
- Phenomena
- Grammar

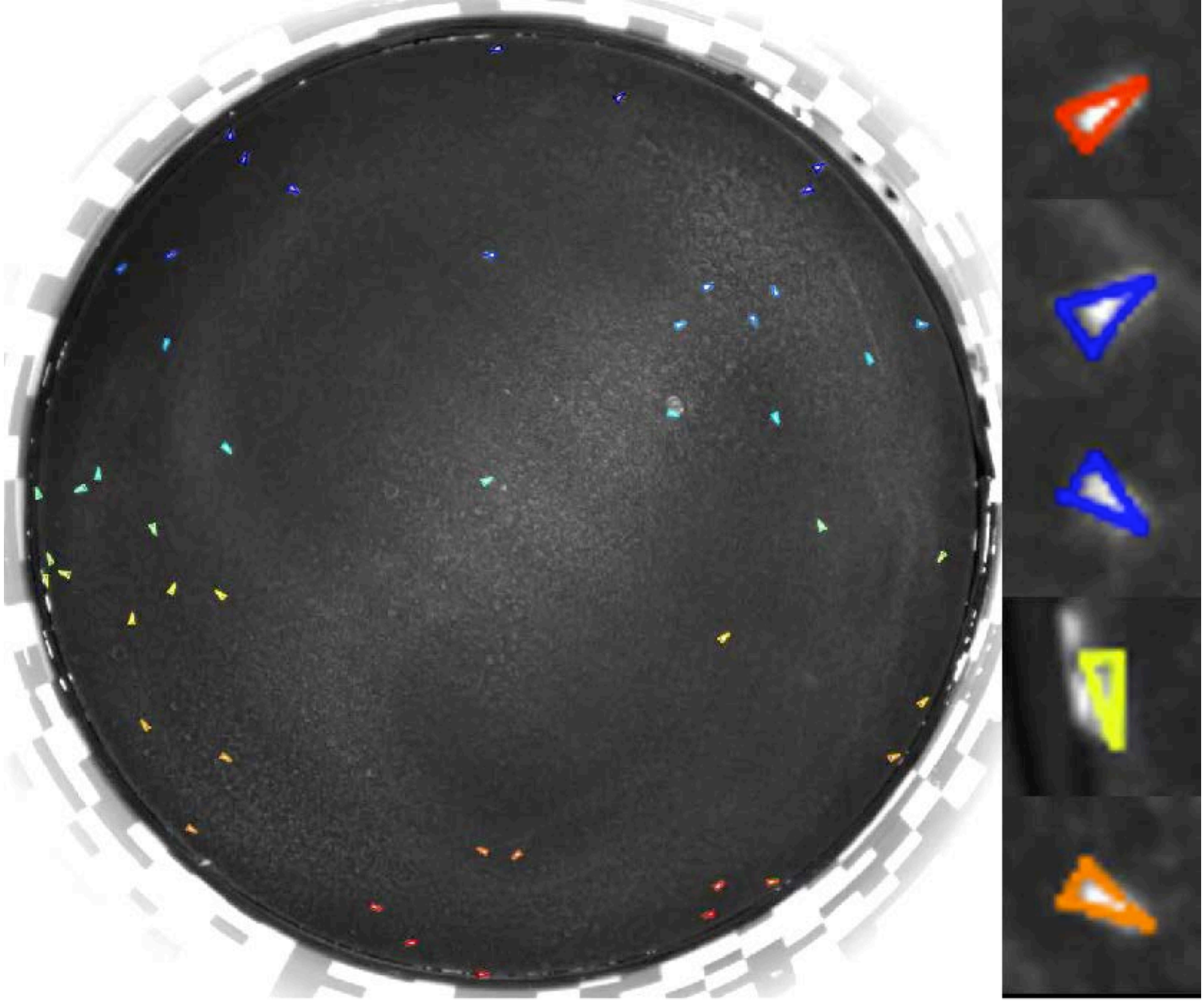
- Purpose
- Mechanisms
- Performance
- Ontogeny
- Phylogeny

From phenomena to mechanisms: a simple example



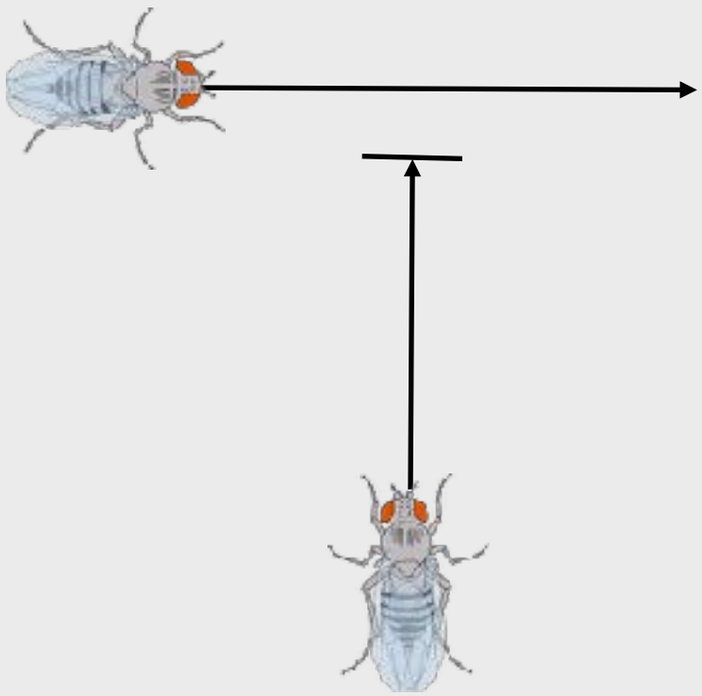
[Branson et al. Nature Methods, Jun. ’09]


Stop
t = 840 s
t = 720 s
Crabwalk
Walk
Chase
Sharp
turn
Backup
Touch

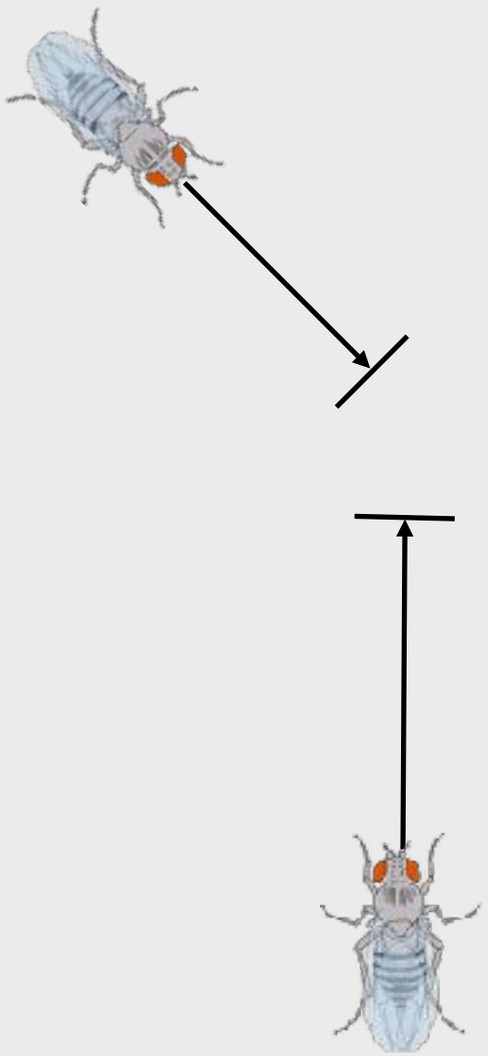


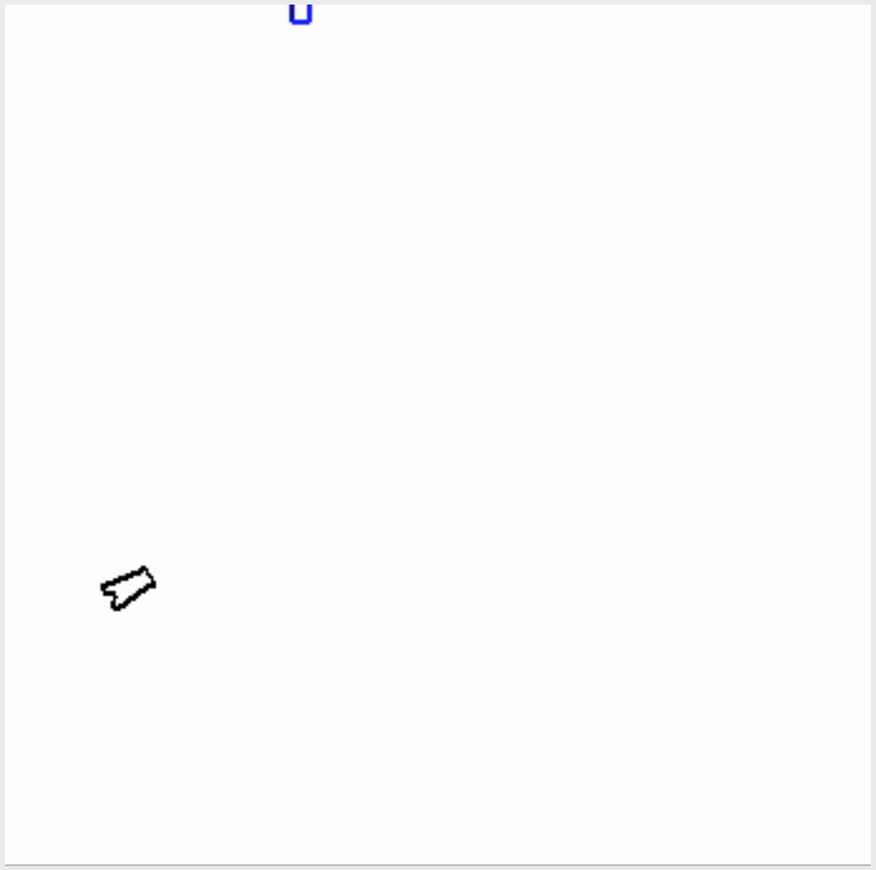
[Branson et al. Nature Methods, Jun. ’09]

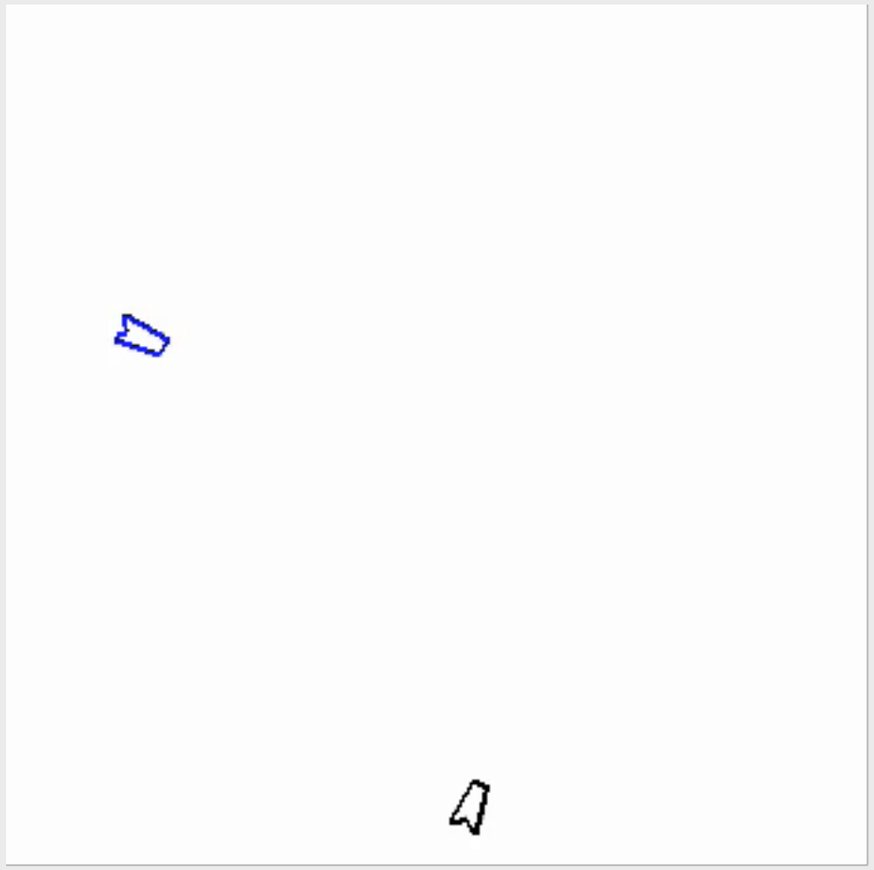
‘T-Stops’

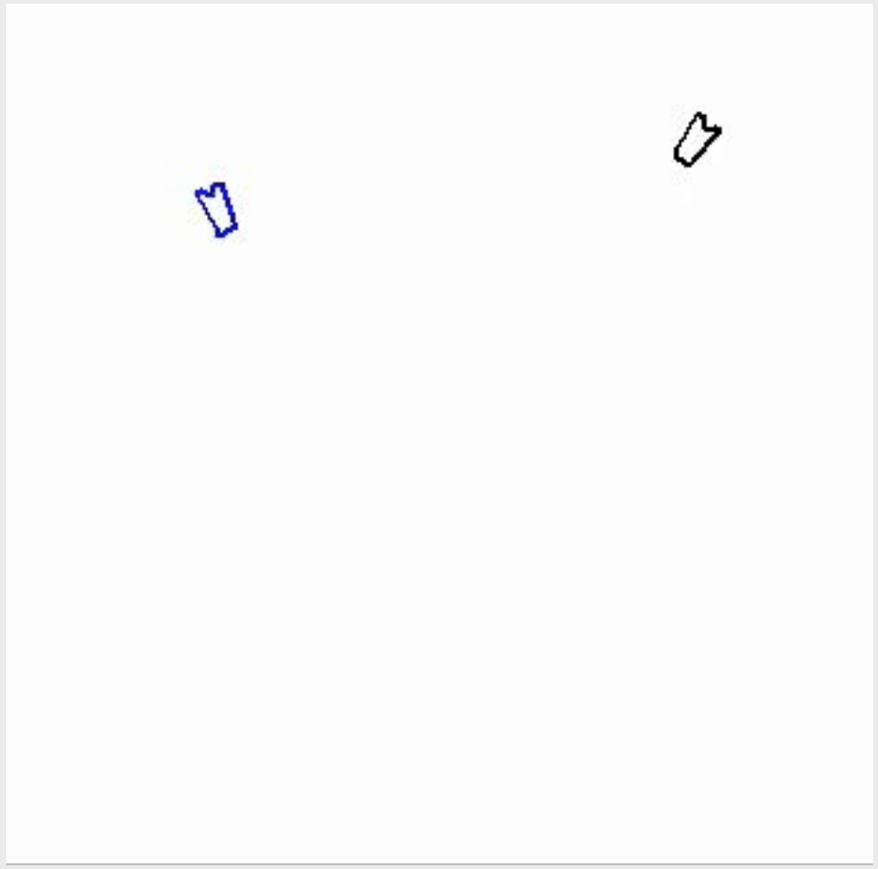


‘X-Stops’









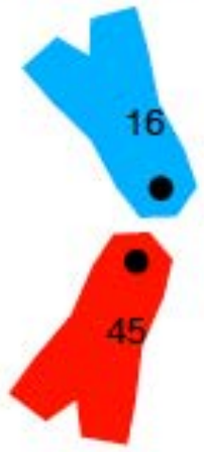
An engineers' solution

Wang et al. 2003.

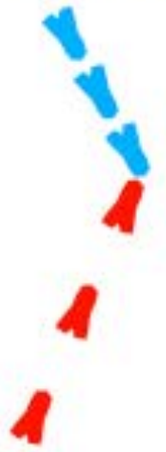
Try implementing it with 10^5 neurons

http://www.news.wisc.edu/newsphotos/images/fruit_fly_research03_6801.JPG

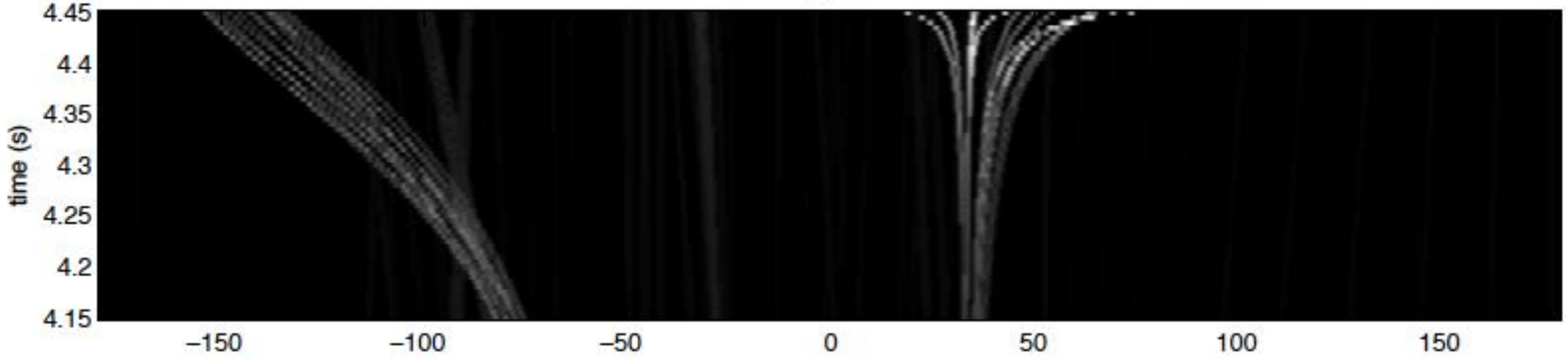
collision n.17: t=4.45, $-\phi_{16}$=59.9346, $-\phi_{45}$=−35.9597



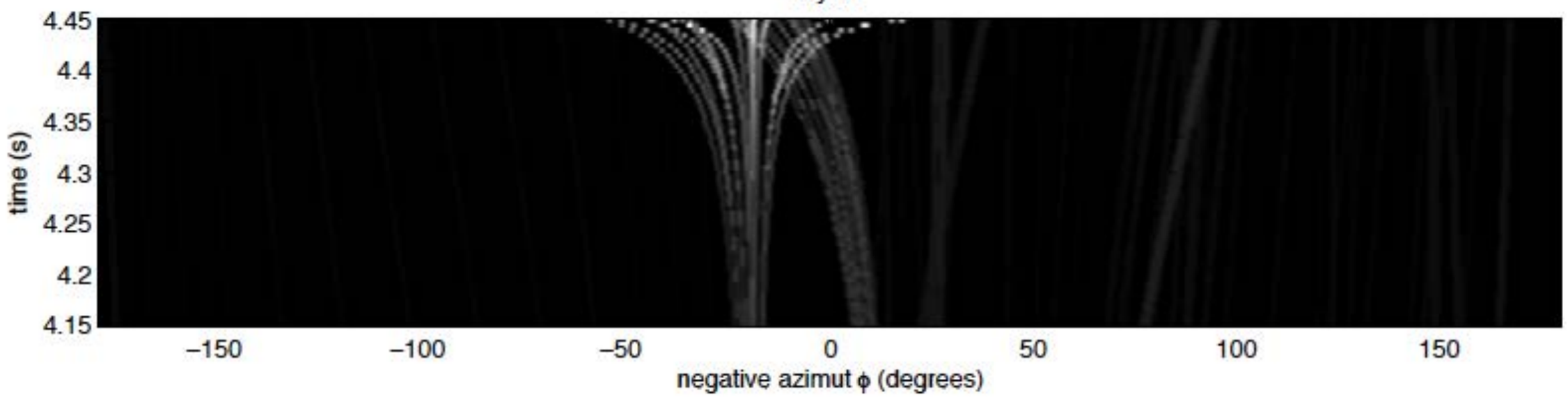
v_{16}=16, v_{45}=28

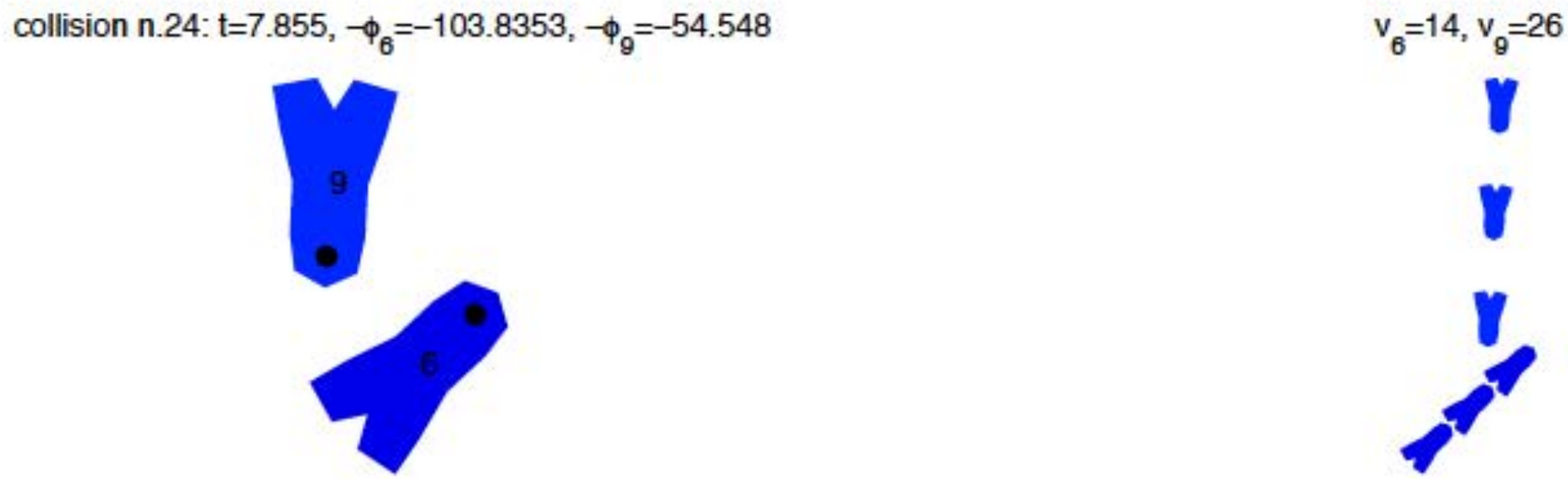


Fly 16



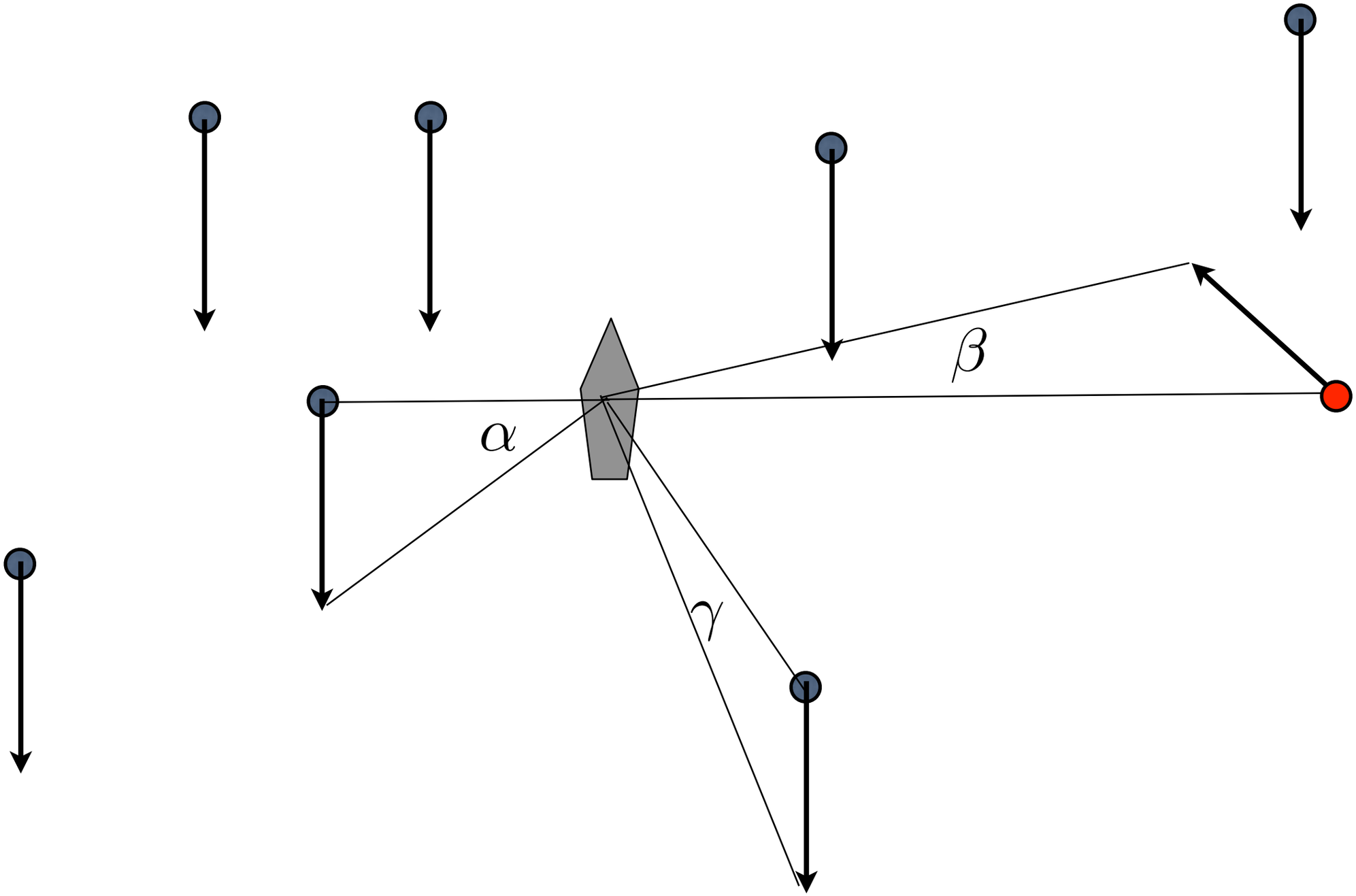
Fly 45

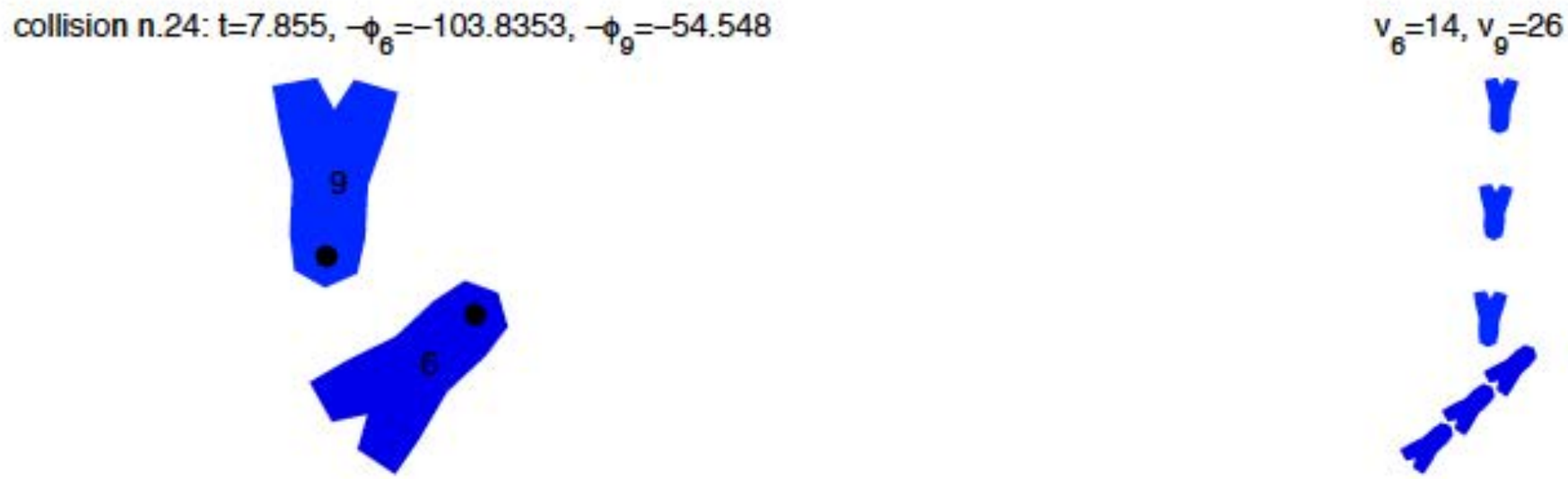



collision n.24: t=7.855, −φ6=−103.8353, −φ9=−54.548
v6=14, v9=26
9
6

Fly 6
Fly 9
time (s)
7.85
7.8
7.75
7.7
7.65
7.6
−150
−100
−50
0
50
100
150
negative azimut ϕ (degrees)

Regressive motion

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Fly 6
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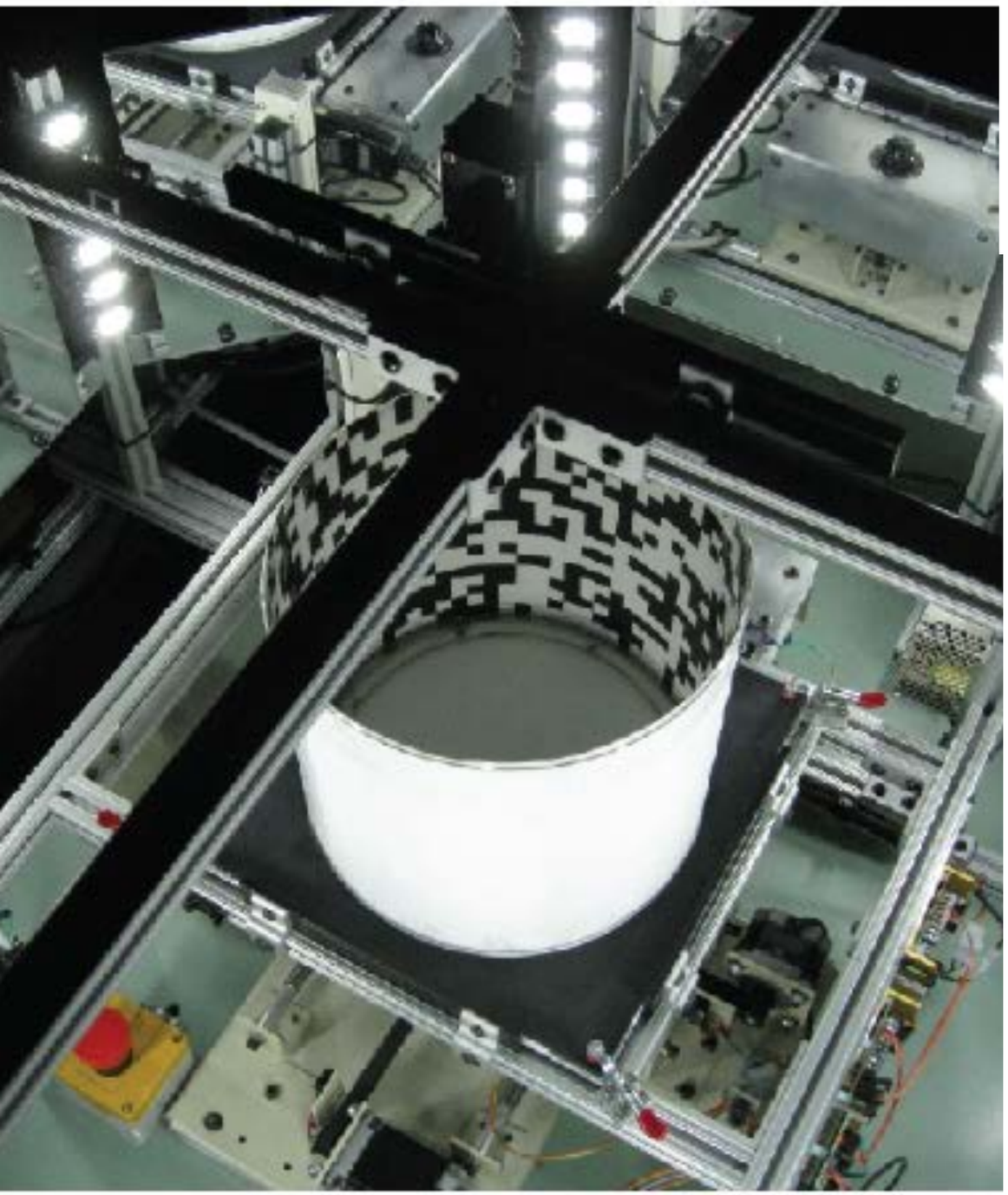
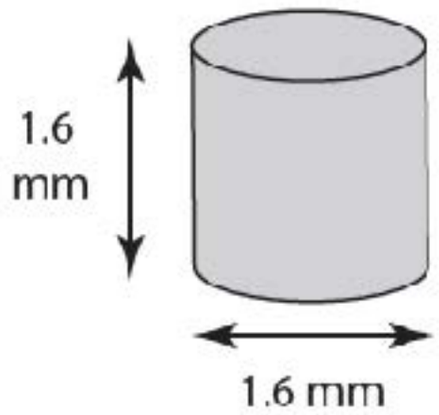
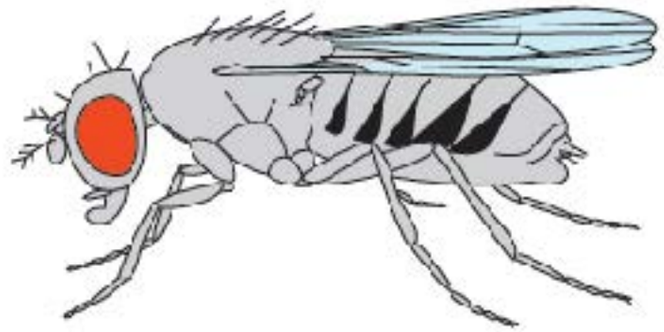
time (s)
7.85
7.8
7.75
7.7
7.65
7.6
−150
−100
−50
0
50
100
150
negative azimut ϕ (degrees)

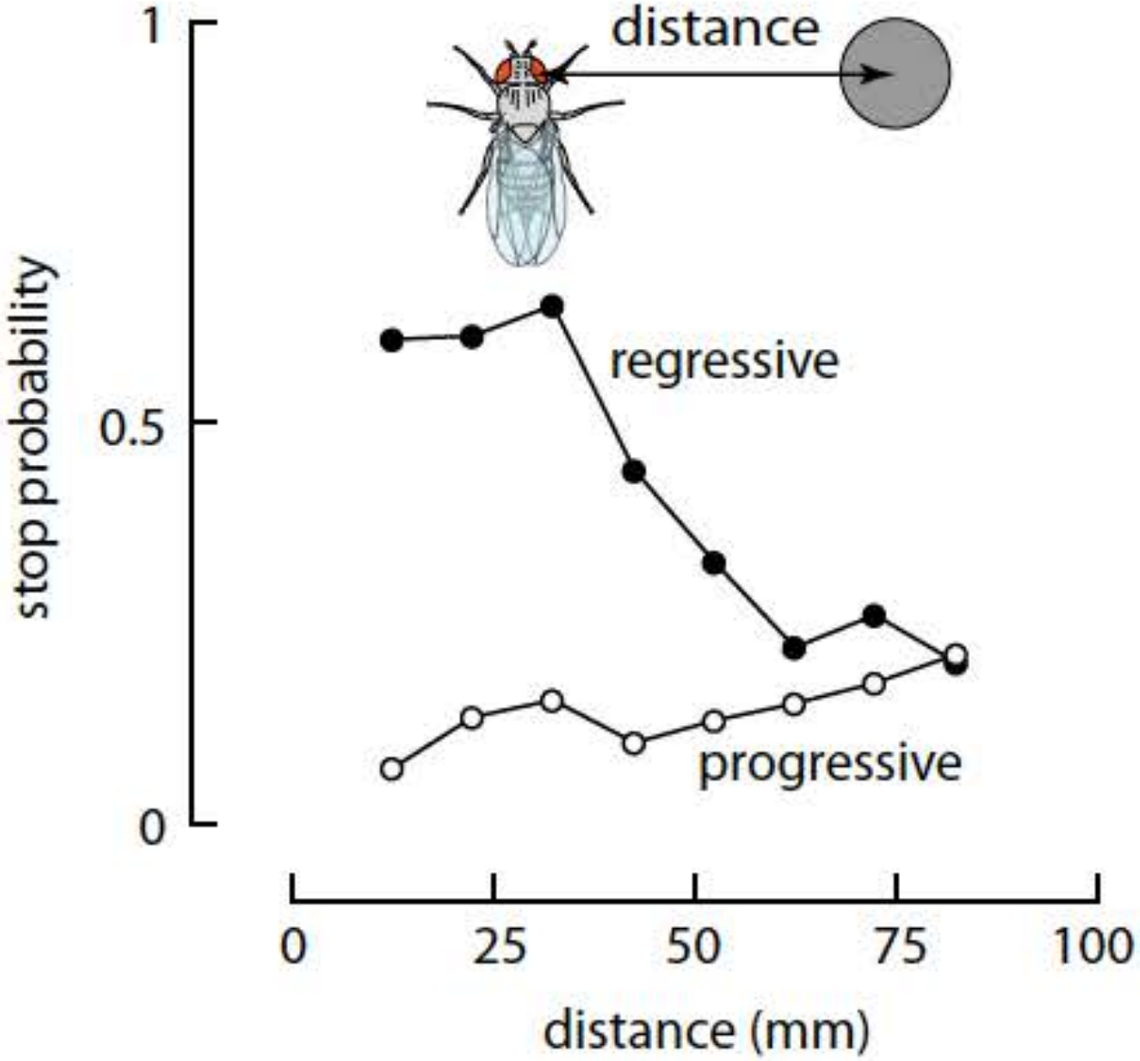
Experiment





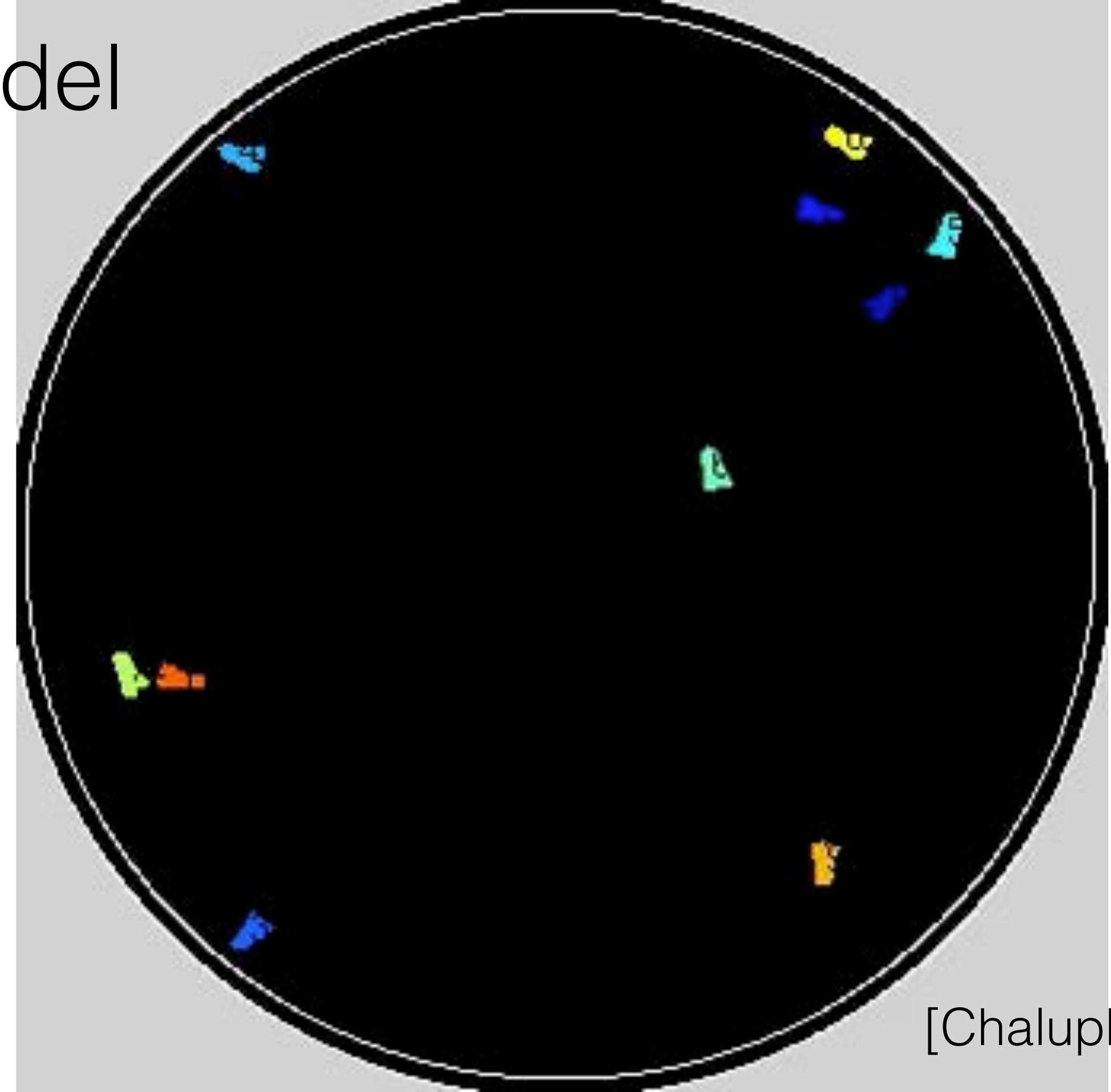


J

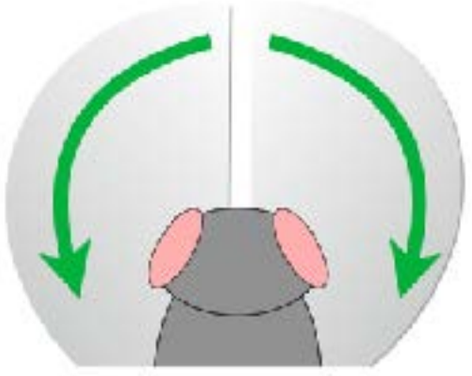


[Zabala ’12]

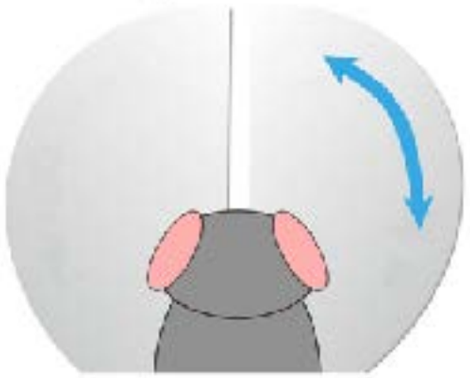
Model



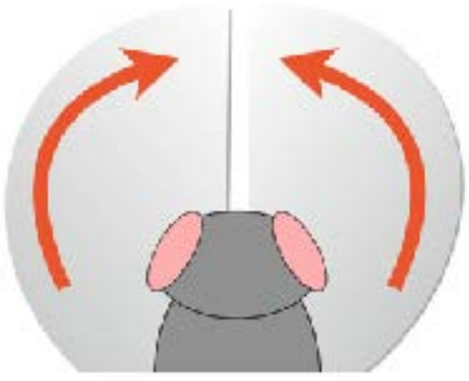
[Chalupka ’15]



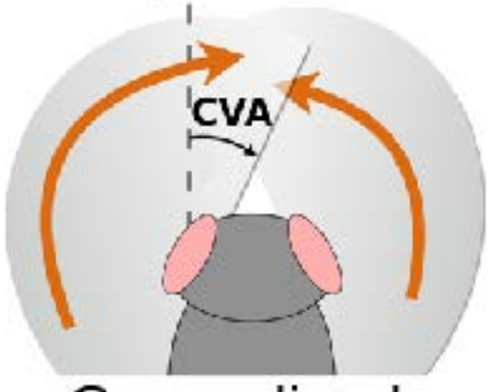
Progressive



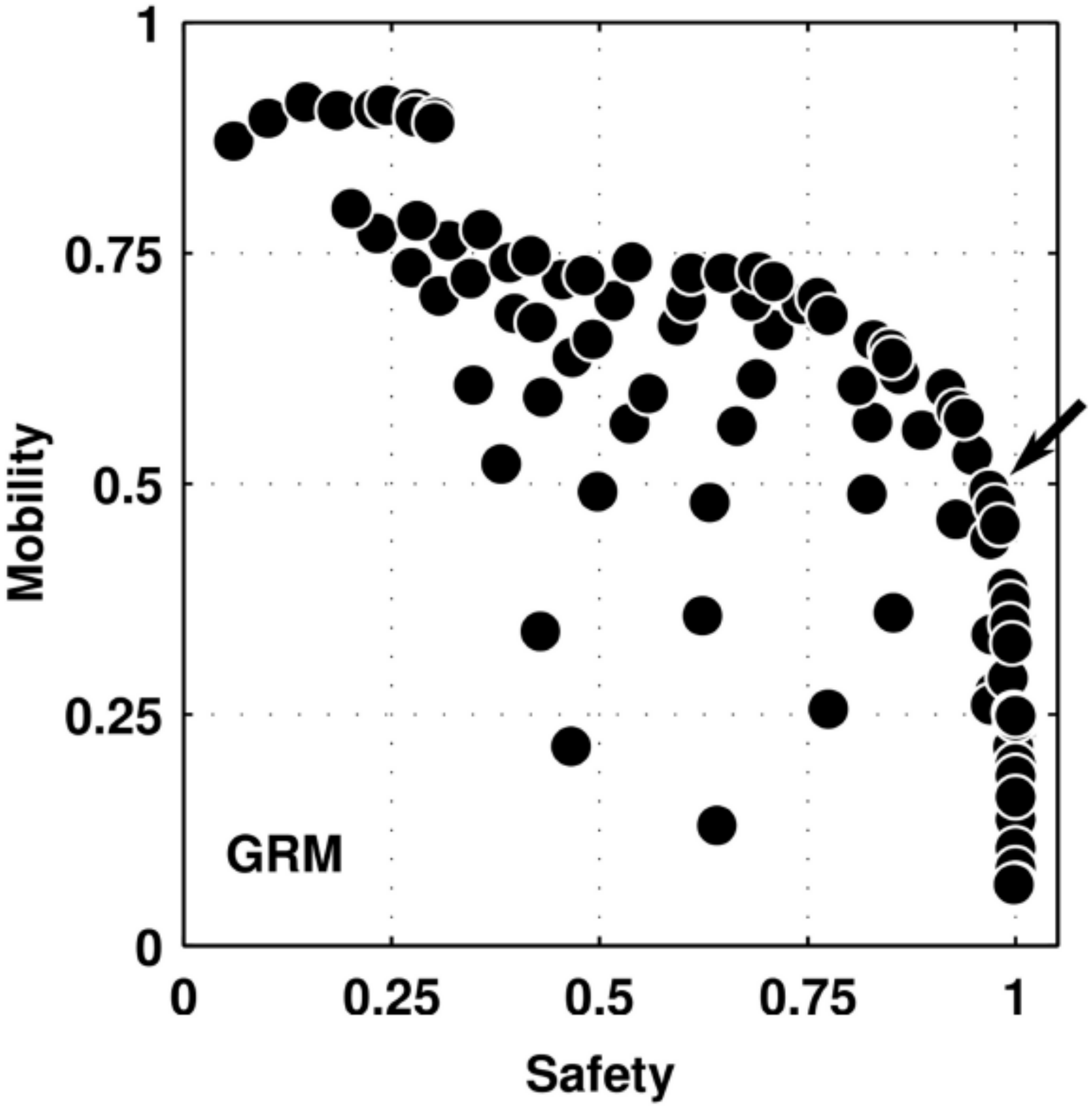
Looming

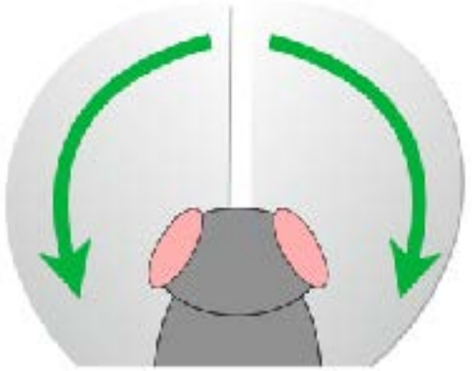


Regressive

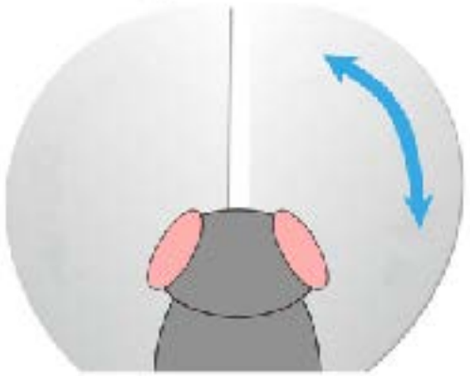


Generalized
Regressive

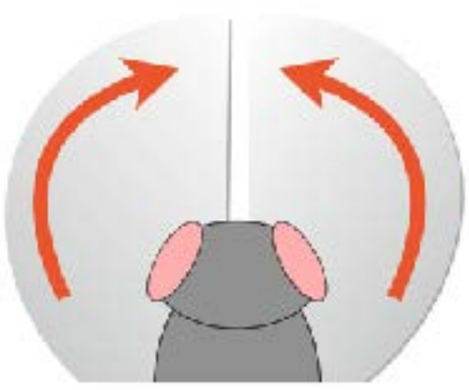




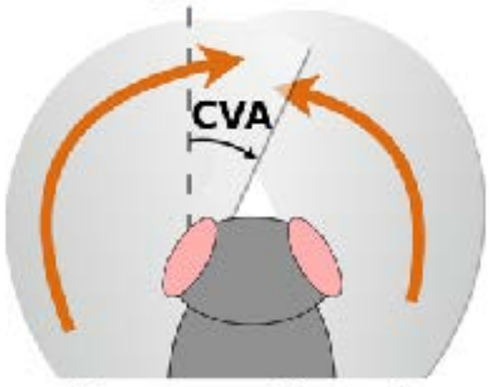
Progressive



Looming

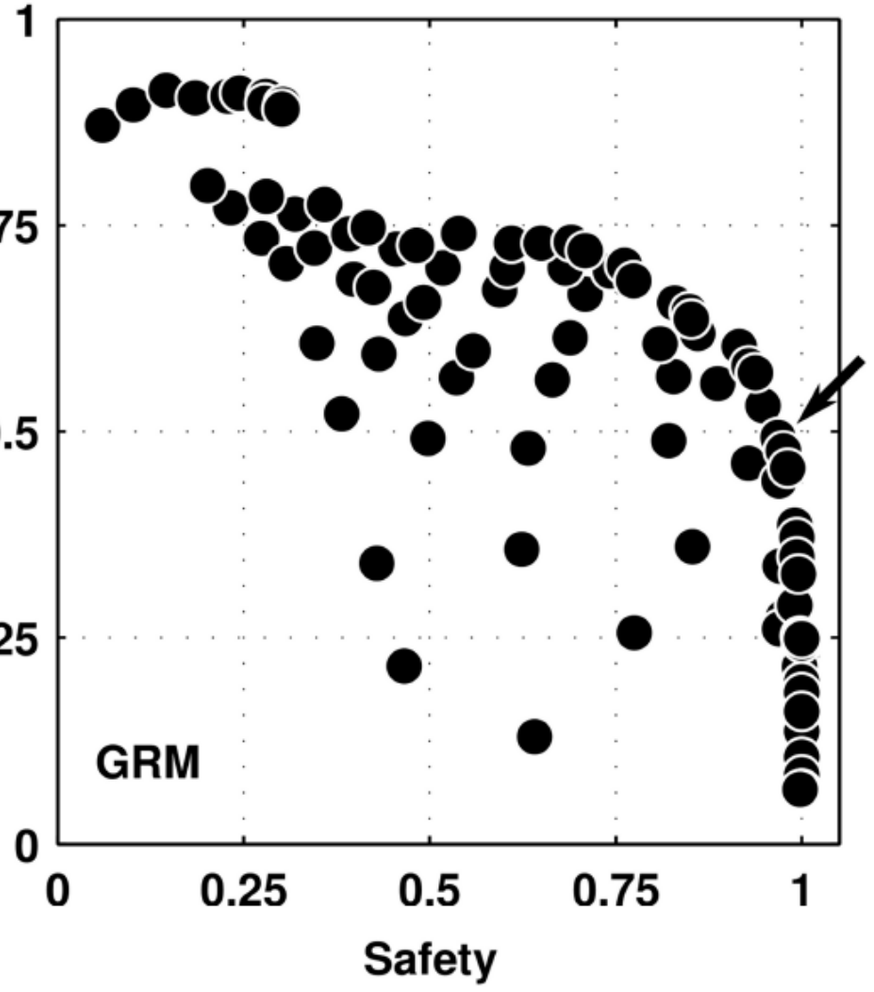


Regressive

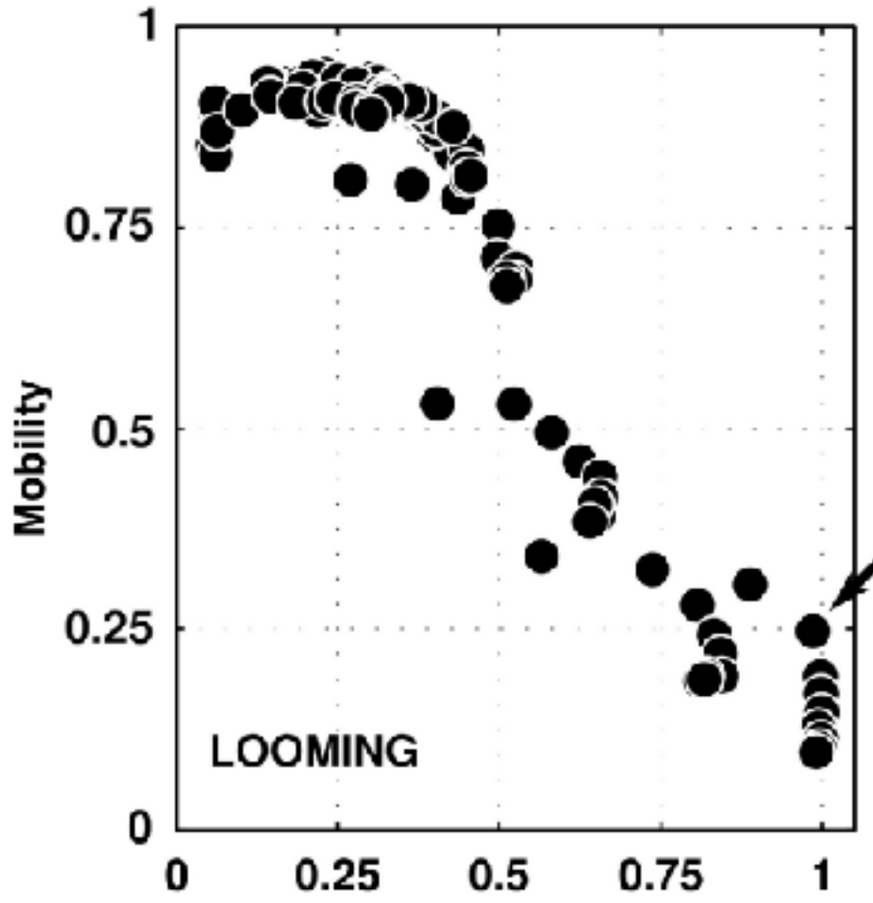


Generalized Regressive

Regressive



Looming



Levels of enlightenment

- Description - `fly trajectories`

- Phenomena - `stops, chases, … (actions)`

- Grammar - `T-stops,X-stops, (interactions)`

- Purpose - `Avoid predation and collisions`

- Mechanisms - `regressive motion(implem.?)`

- Performance - `Mobility,safety`

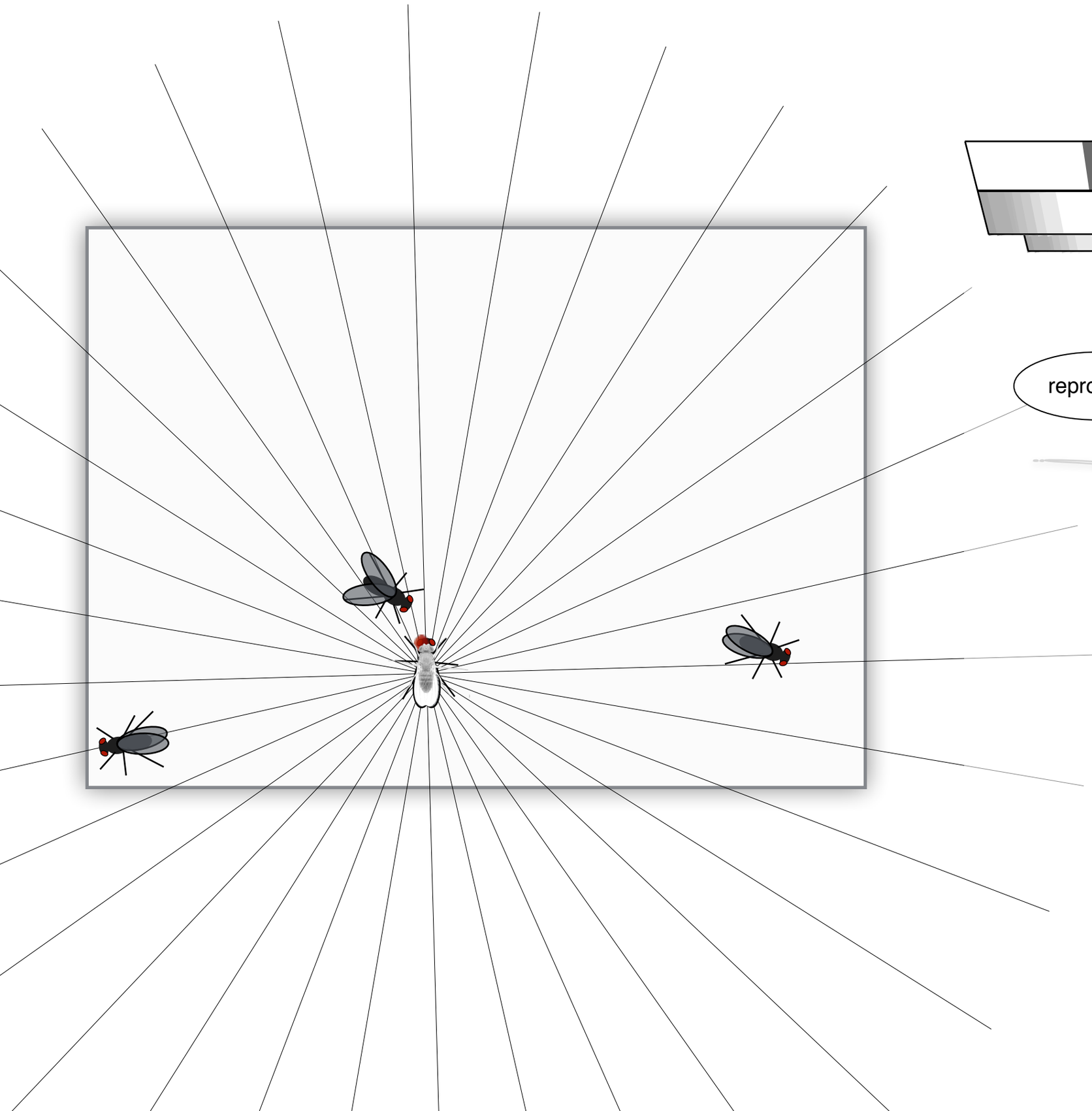
- Ontogeny - `Learning??`

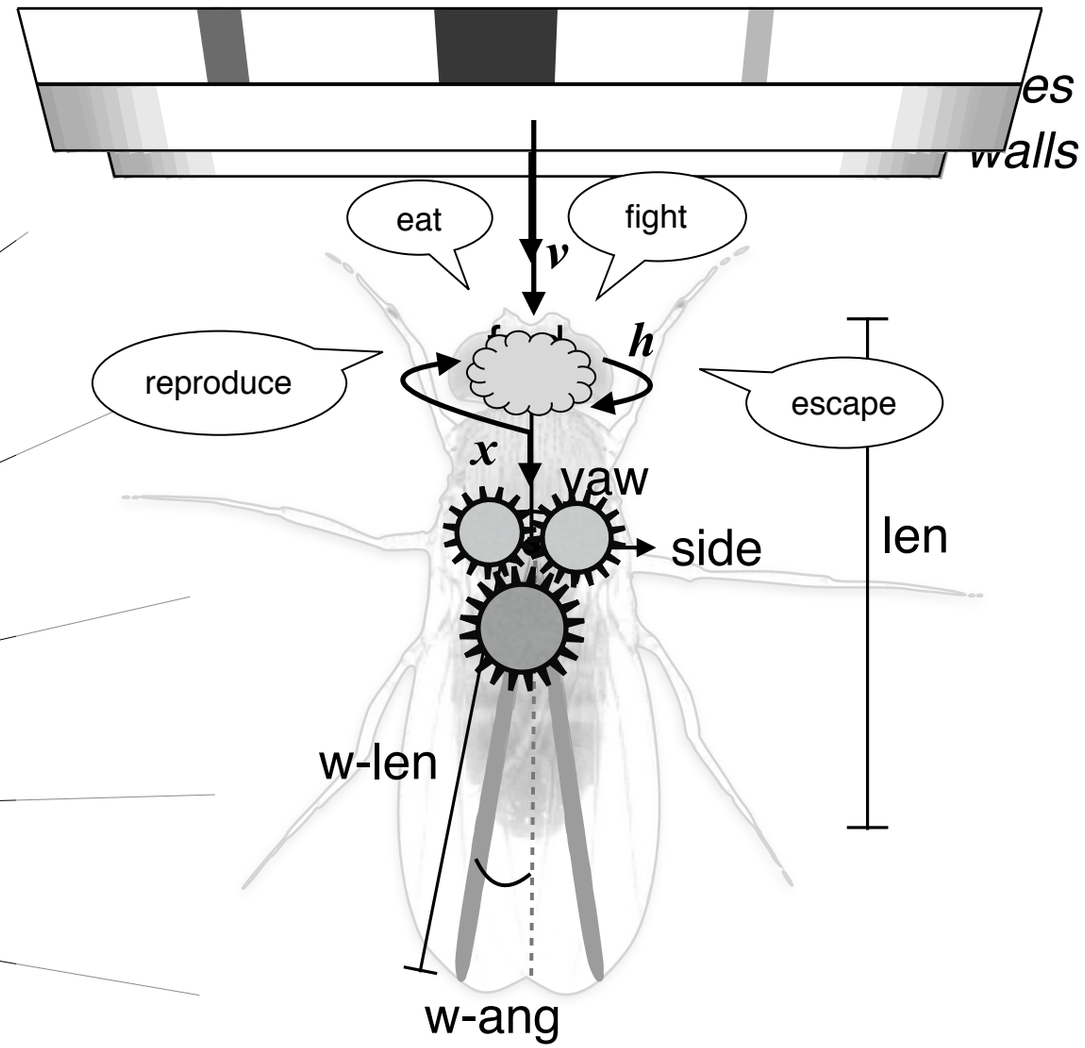
- Phylogeny - `??`

Mechanism inference

[Eyjolfsdottir 2016,2017]

Fly-centric features

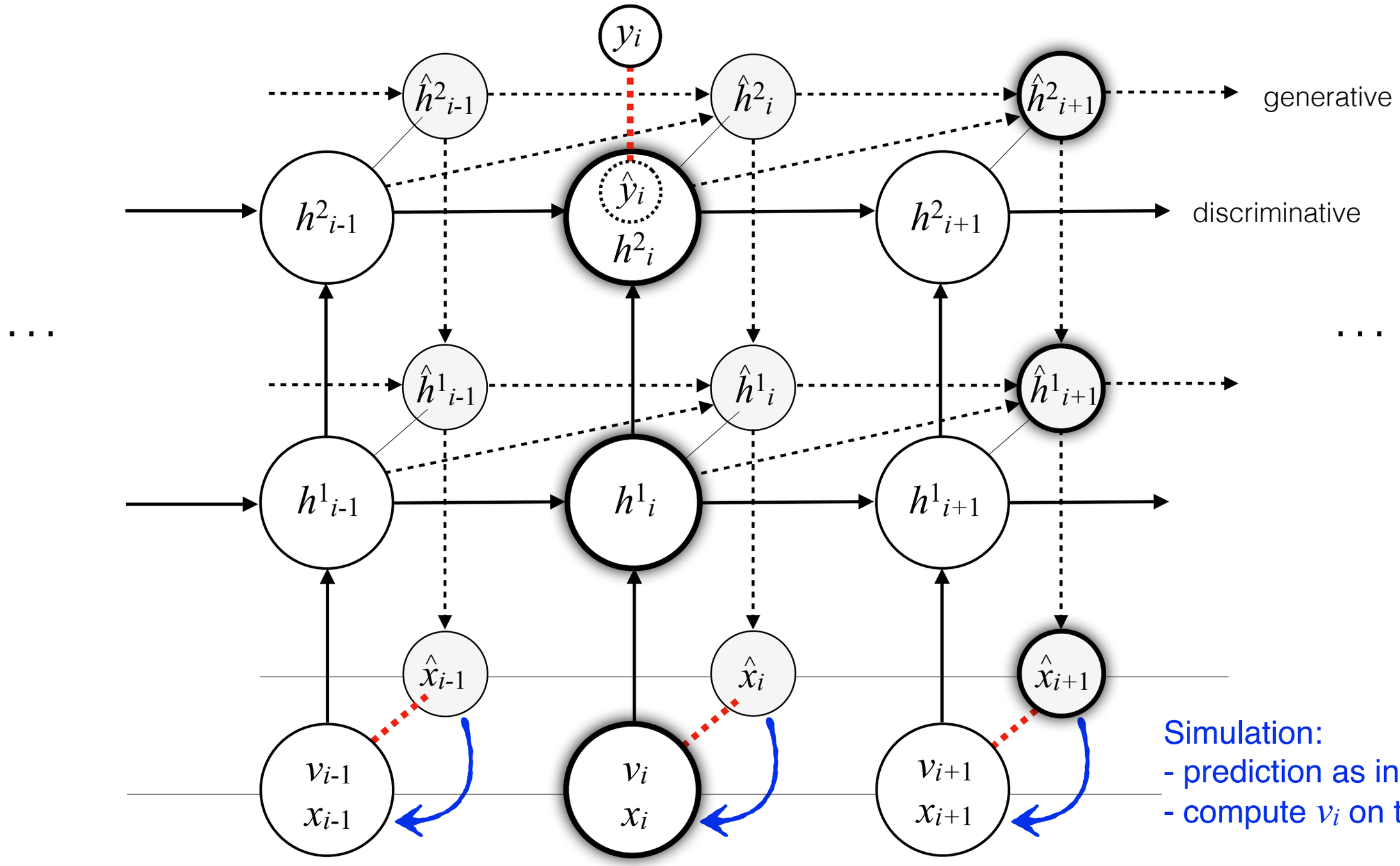




v: sensory input

x: motor control

Model architecture

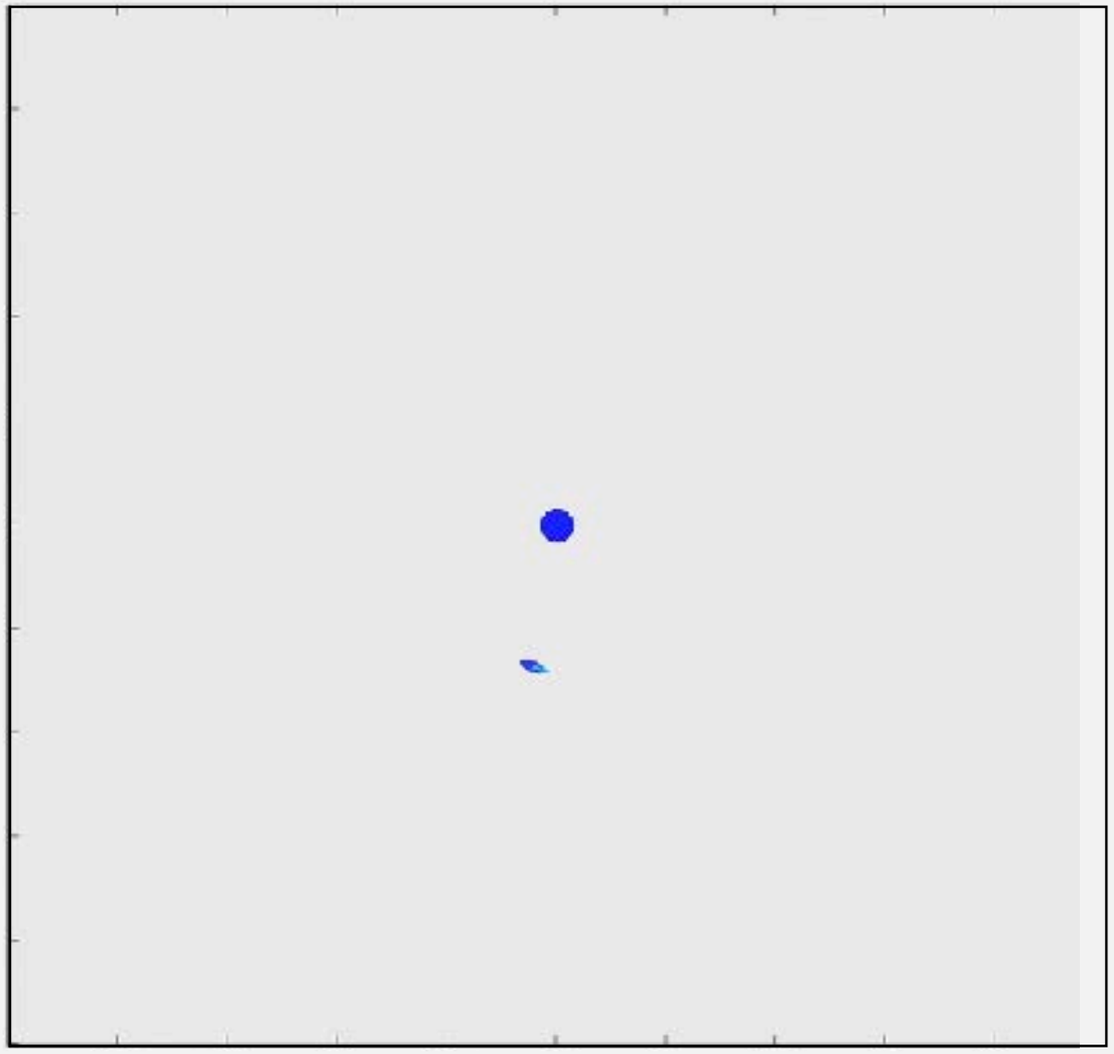


[Eyjolfsdottir 2016,2017]

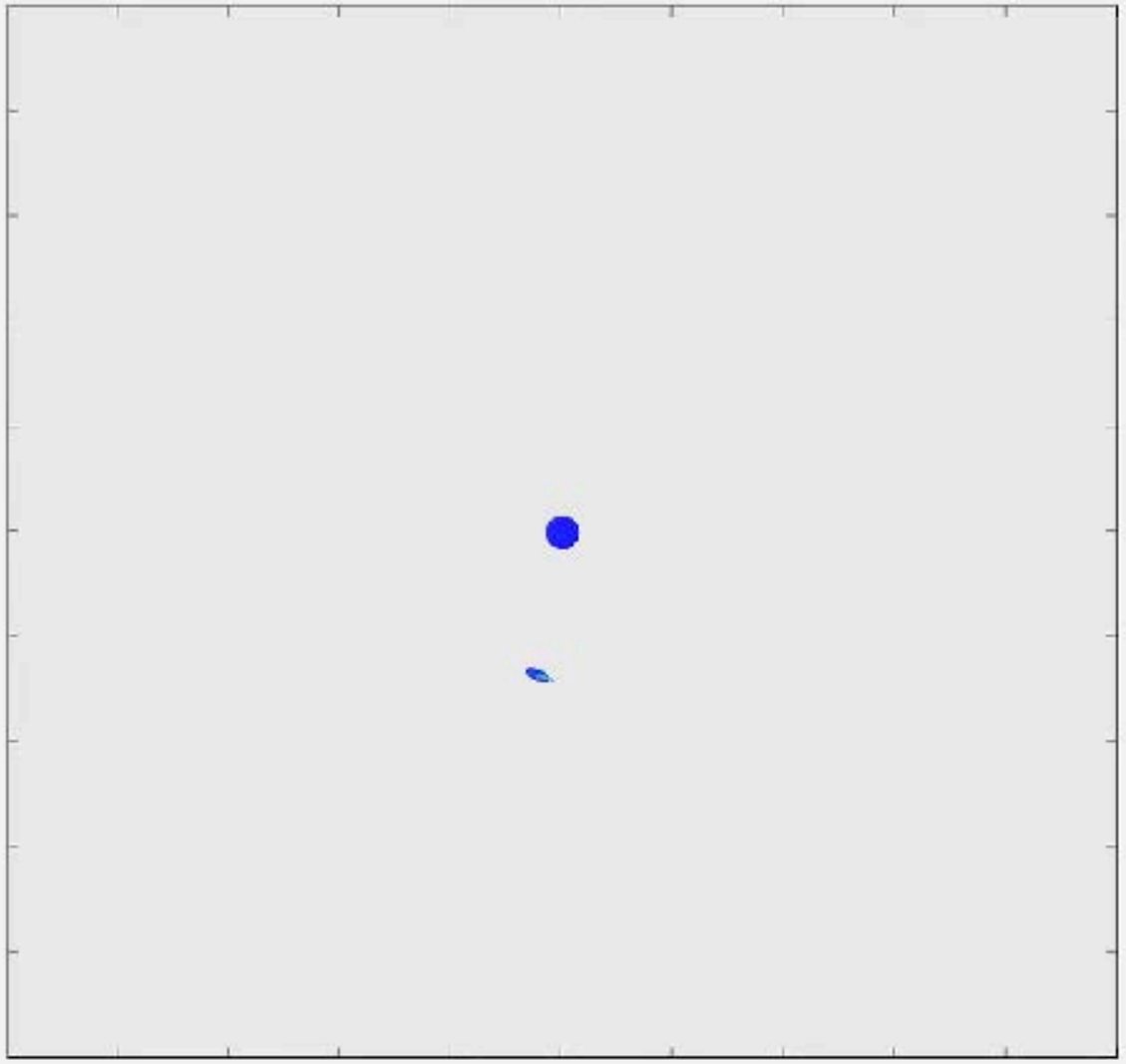
Sanity check: learning on a synthetic fly

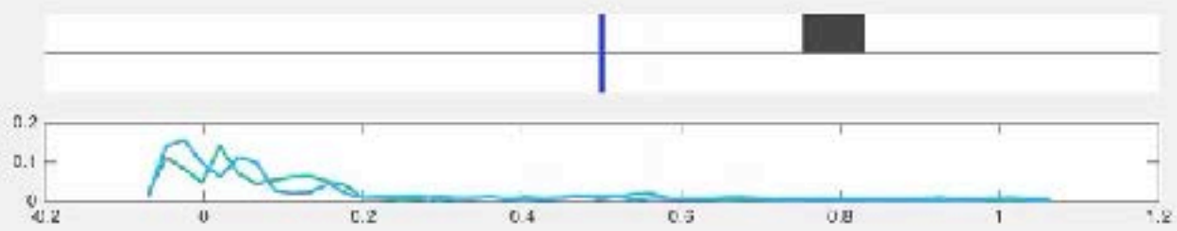
Can the model learn generative control laws?

SynthFly

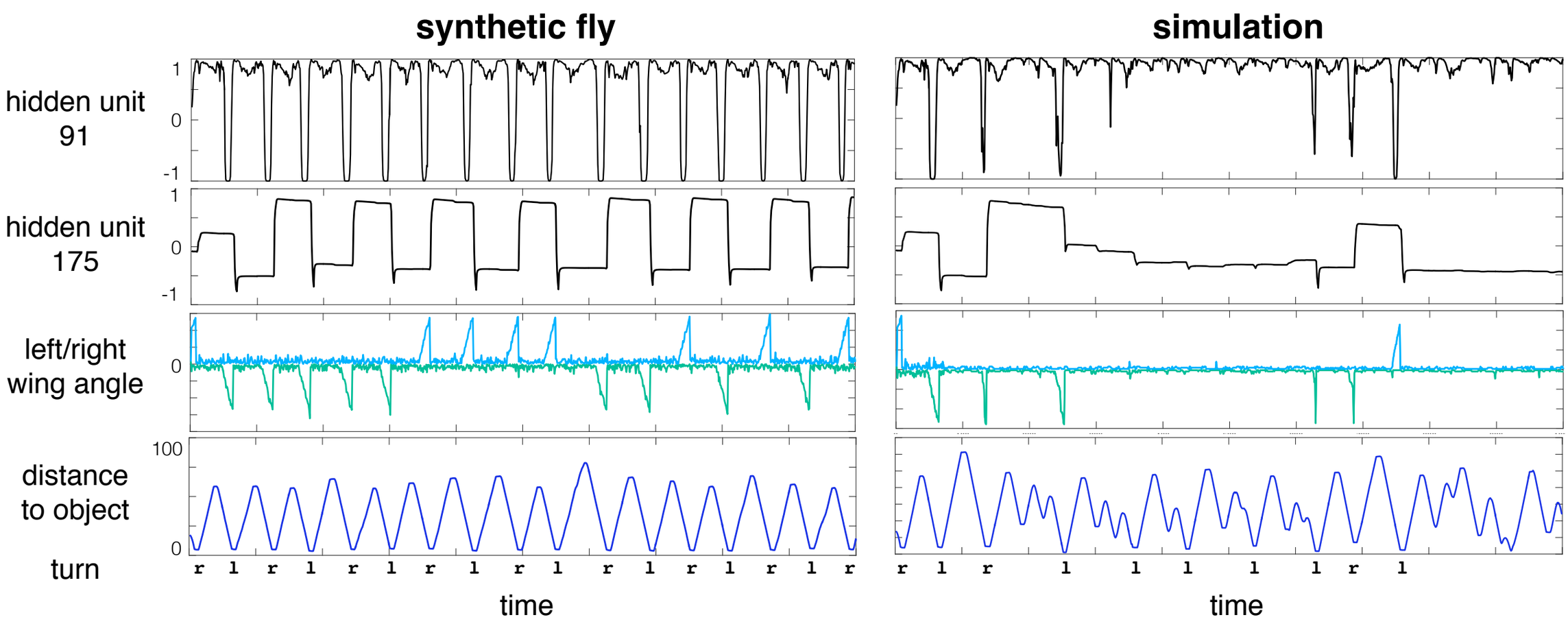


Simulation





Interesting units



Classification


b B

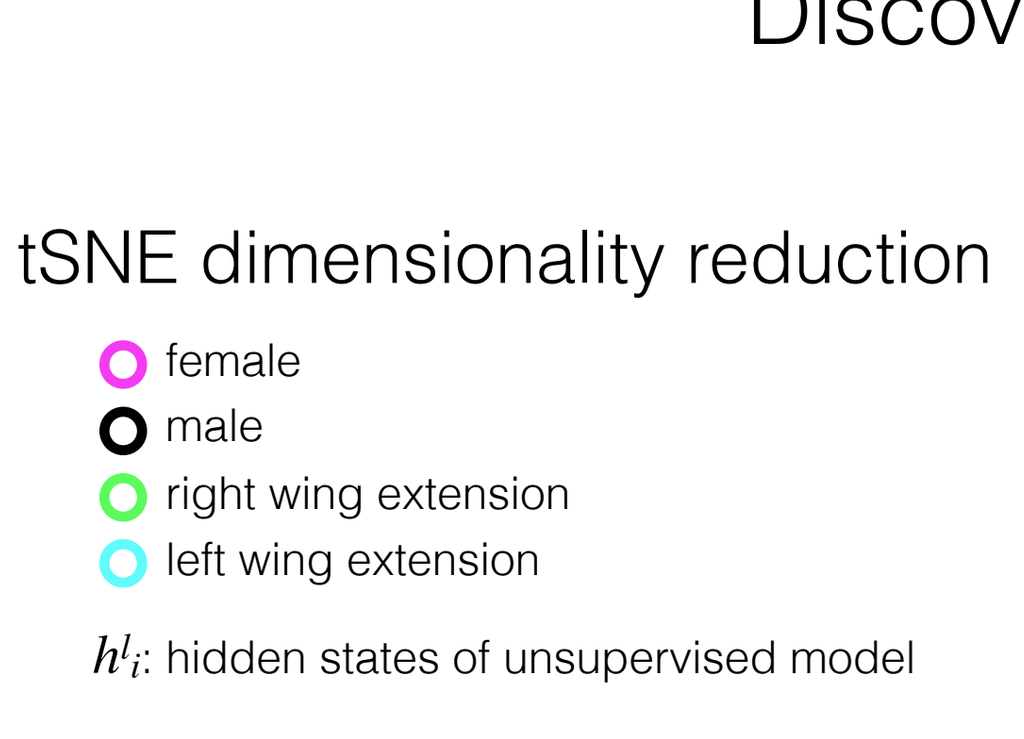
Discovery

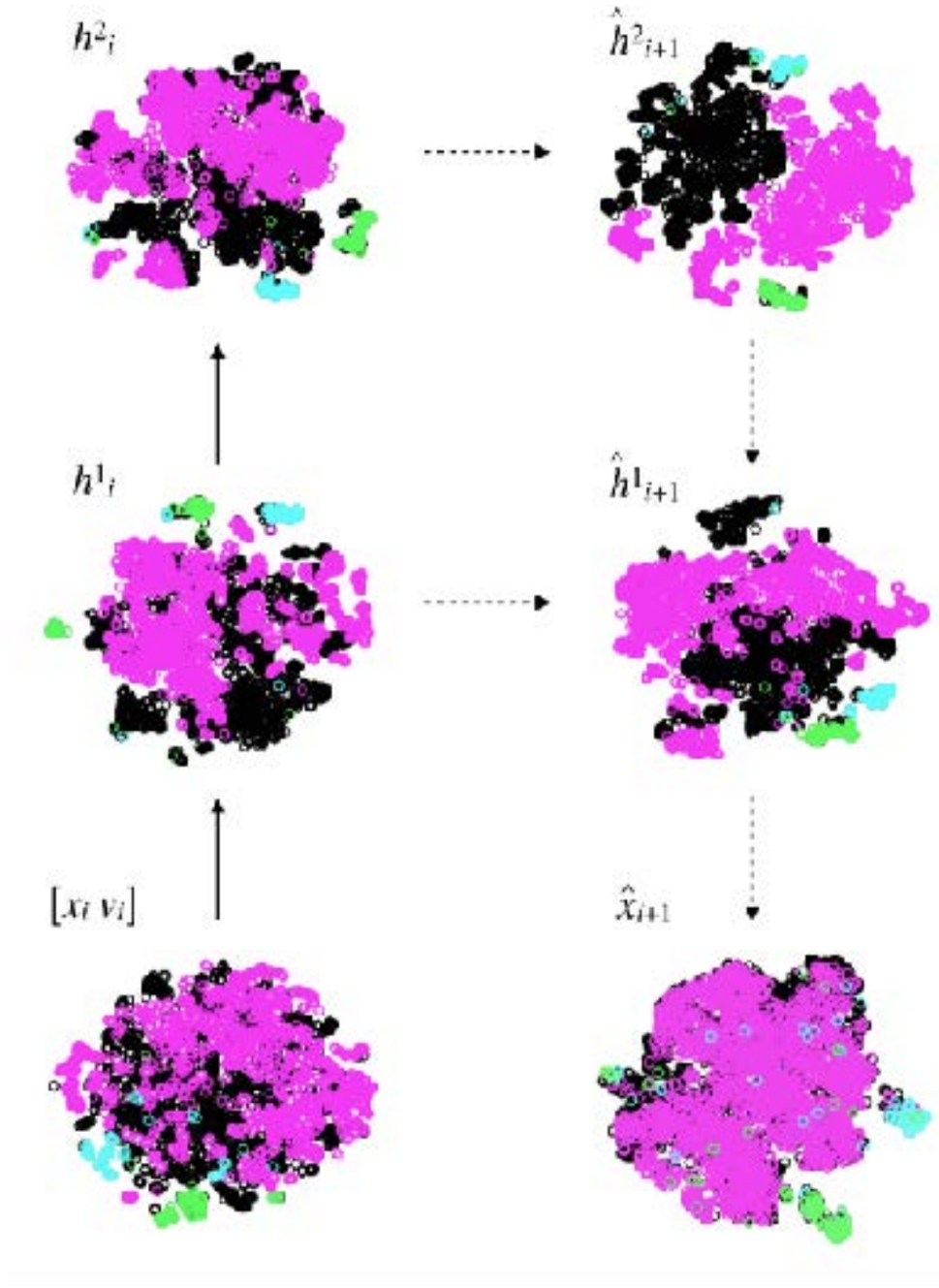
Discovery: FlyBowl

tSNE dimensionality reduction

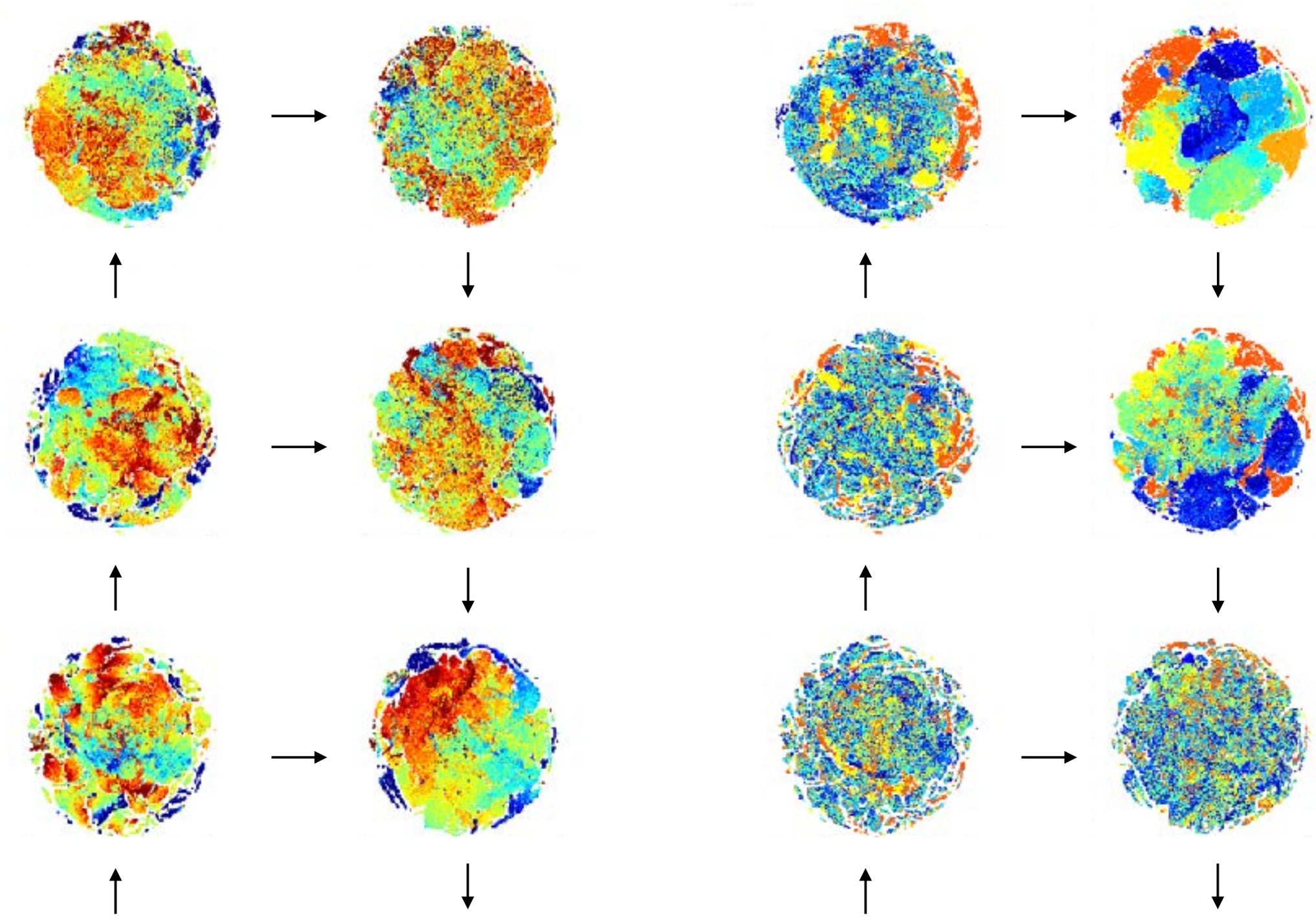
- female
- male
- right wing extension
- left wing extension

h^l_i: hidden states of unsupervised model



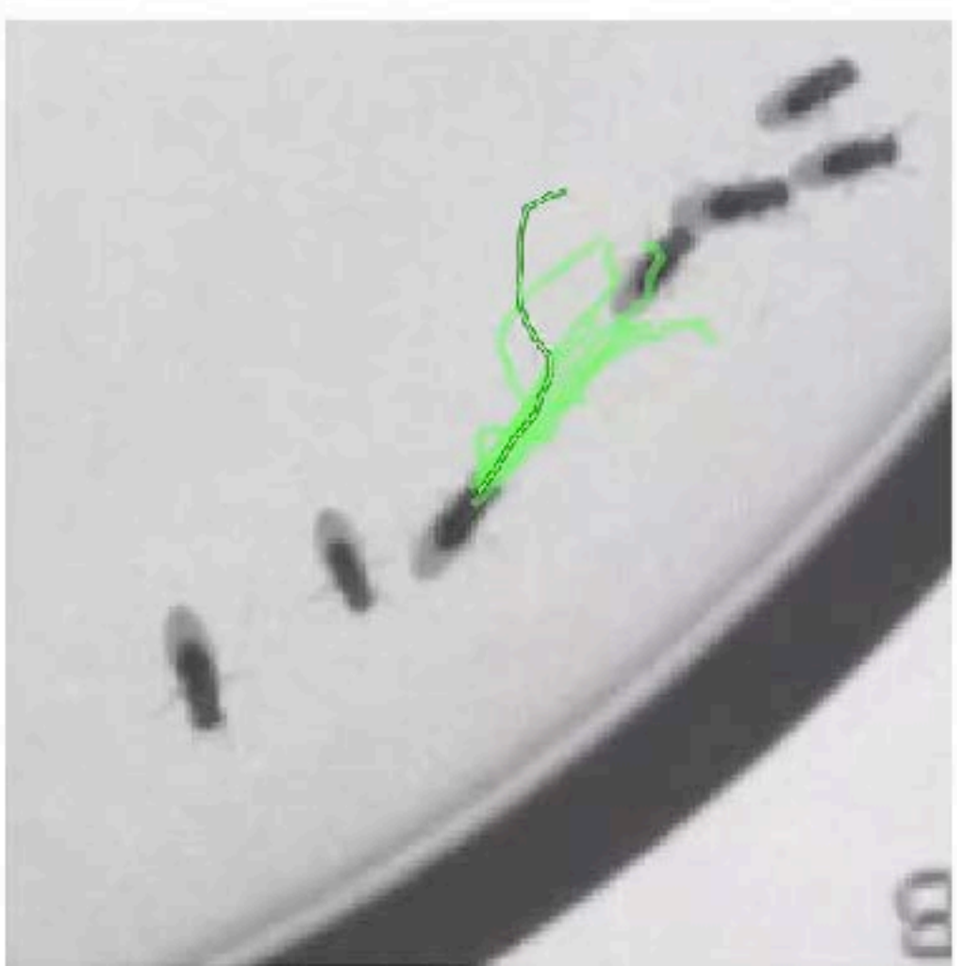


Discovery: IAM-OnDB



Prediction


b B

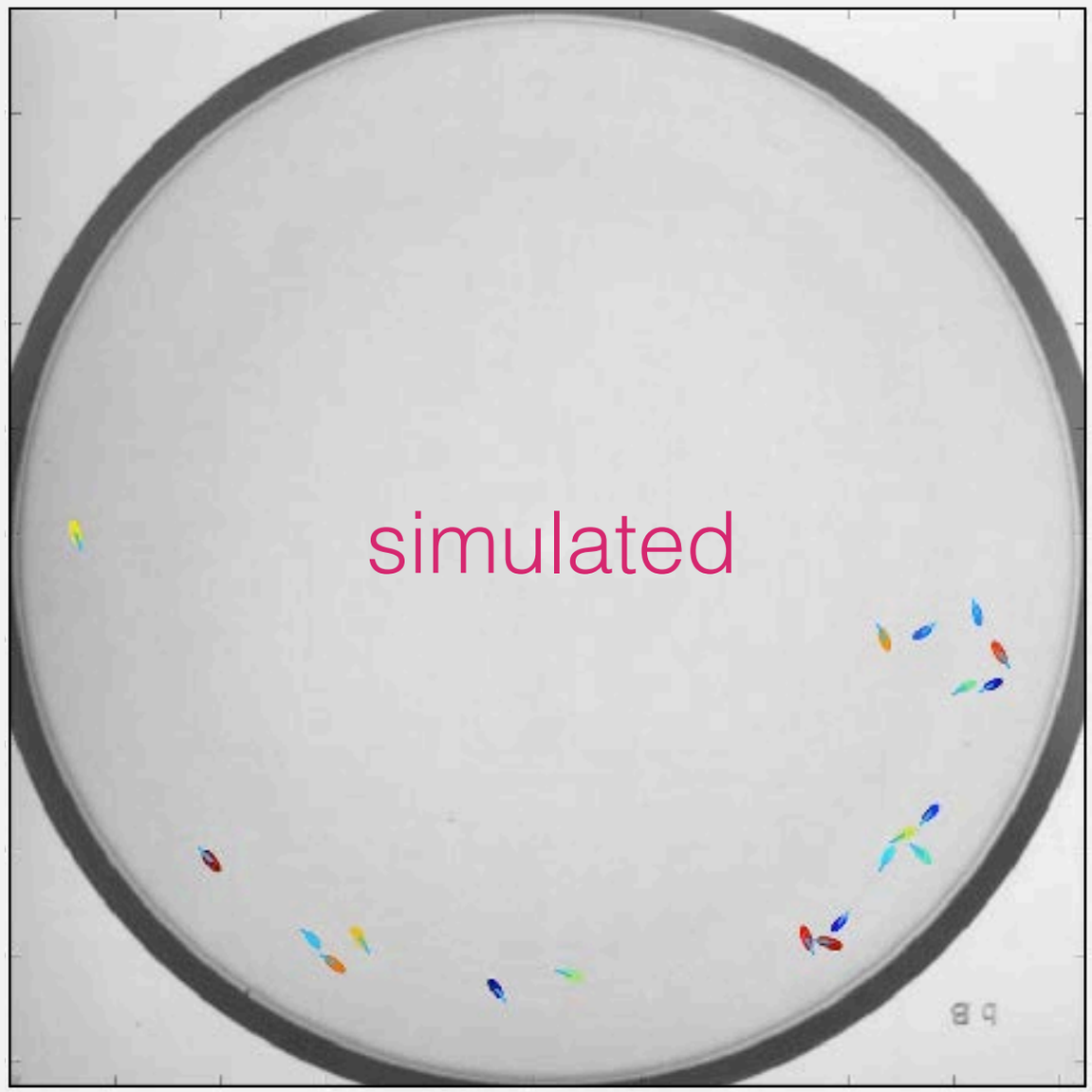


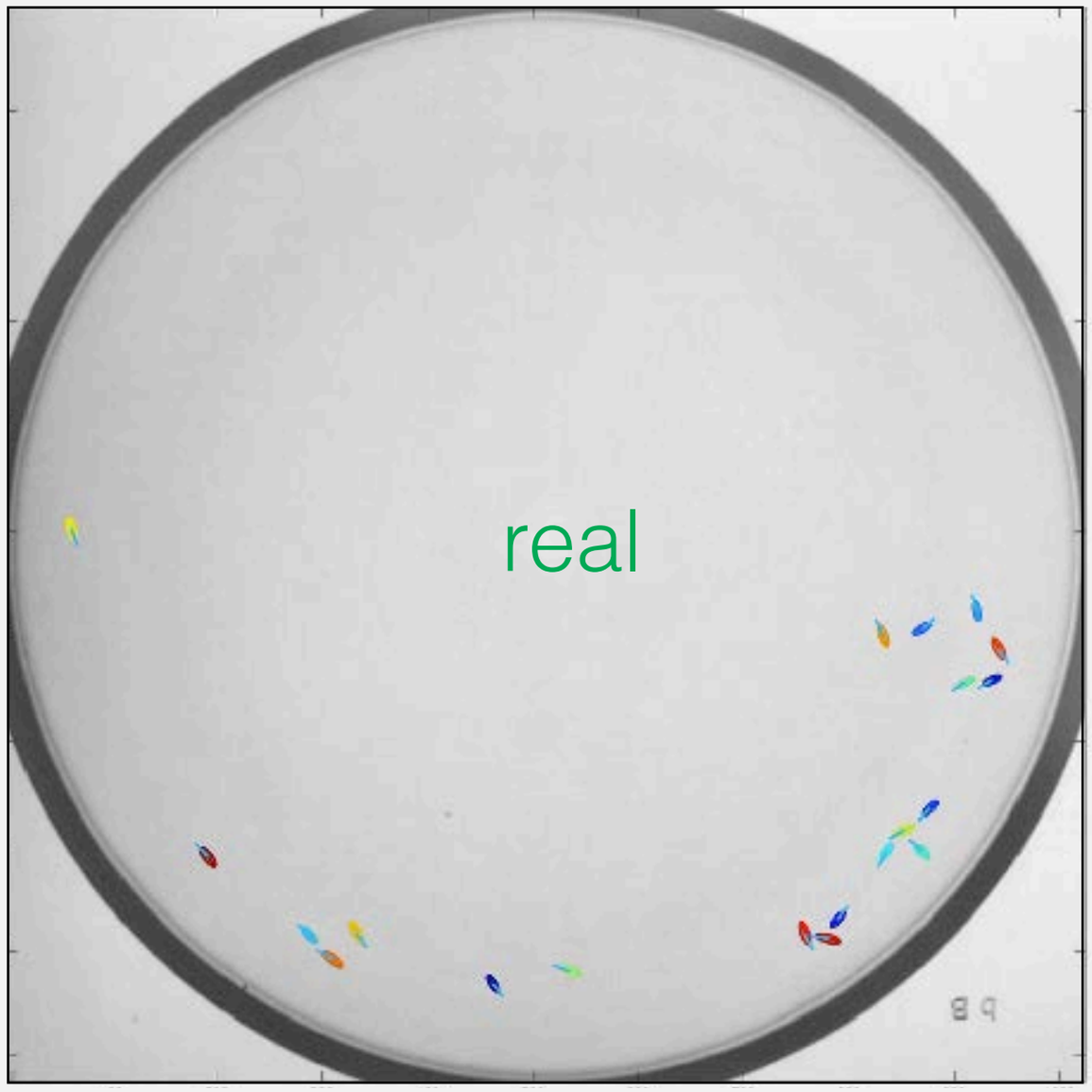
Simulation

Simulation: FlyBowl

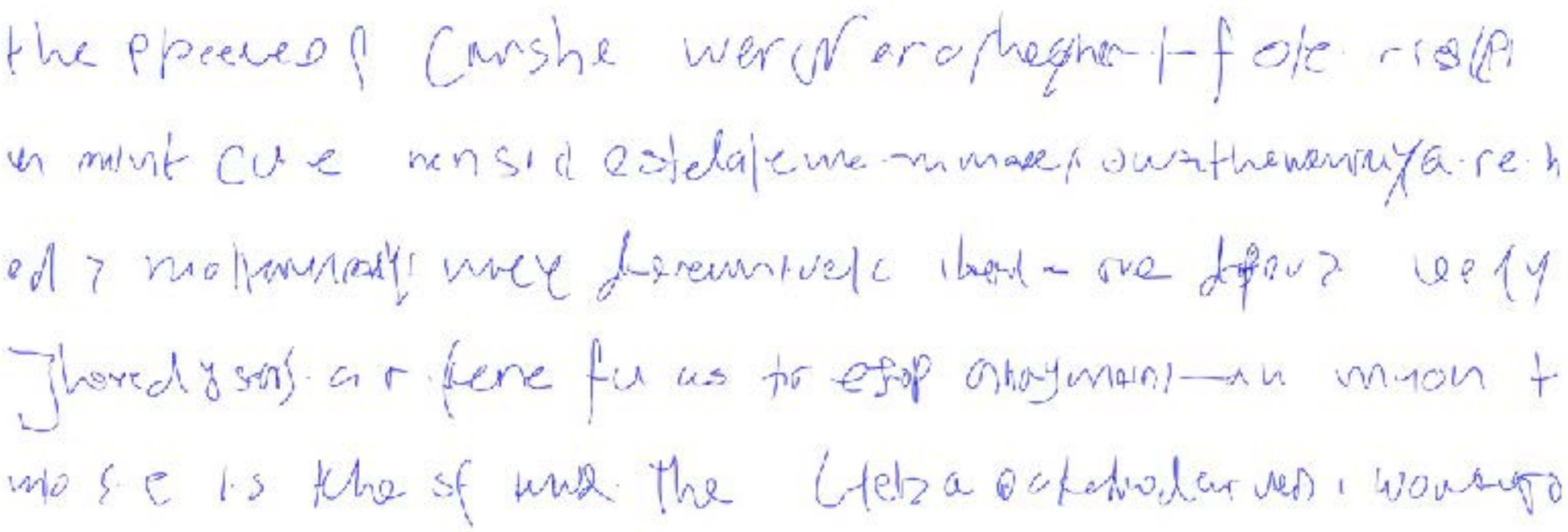
fly vision
chamber vision

Simulation: FlyBowl





Simulation - handwriting



Summary

- Brains, behavior and intelligence
- Description
- Phenomena
- Mechanisms
- Relationship with AI?

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