Computational ethology
(with a focus on social insects)

Yuko Ulrich, Department of Ecology and Evolution, UNIL

Reviews in Quantitative Biology

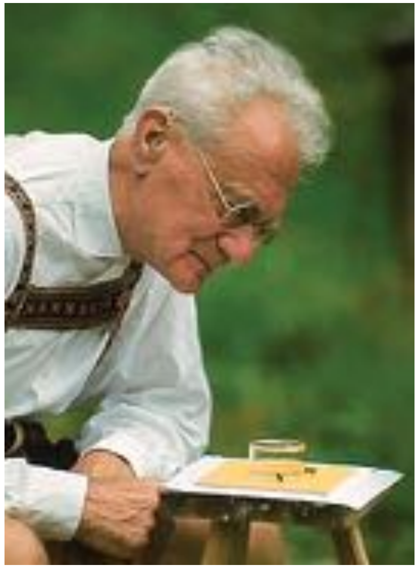
Photo: Daniel Kronauer

Outline

- Motivation
- Automated tracking in social insects
    - Examples
    - Anatomy of a tracking system
- Challenges, outlook

Ethology

Niko Tinbergen
'Instinct'



Karl von Frisch
Honeybee waggle dance

Konrad Lorenz
Imprinting

1973 Nobel Prize in Physiology and Medicine

Methods:

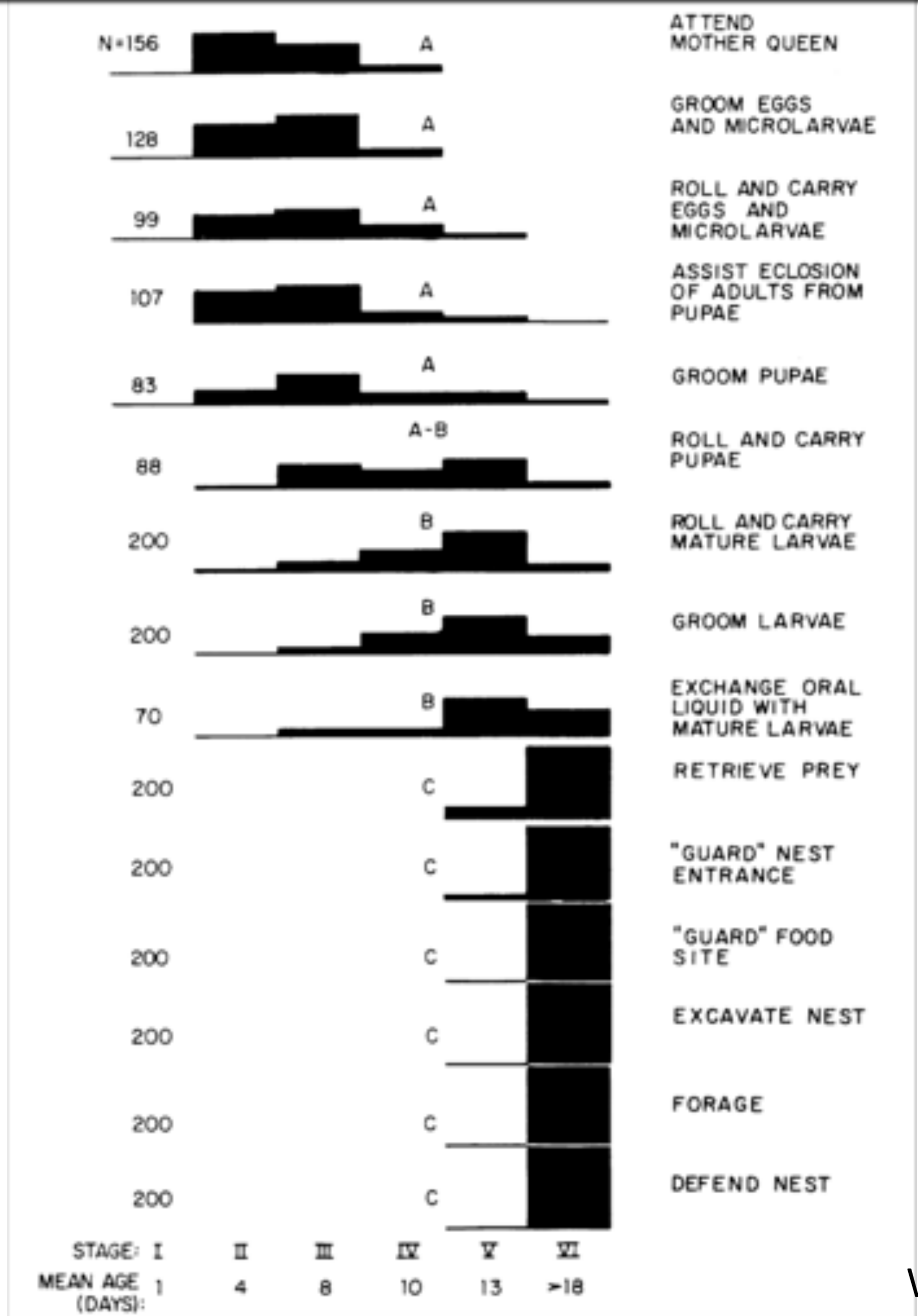
Ethology

Manual scoring of behavior is still the dominant approach in the field

Downsides:

- Labor-intensive, slow, dull

A manual ant ethogram



One colony of *Pheidole* ants
26 behaviors
2331 behavioral acts recorded
over 5 days

Wilson, Behavioral Ecology and Sociobiology (1976)

Ethology

Manual scoring of behavior is still the dominant approach in the field

Downsides:

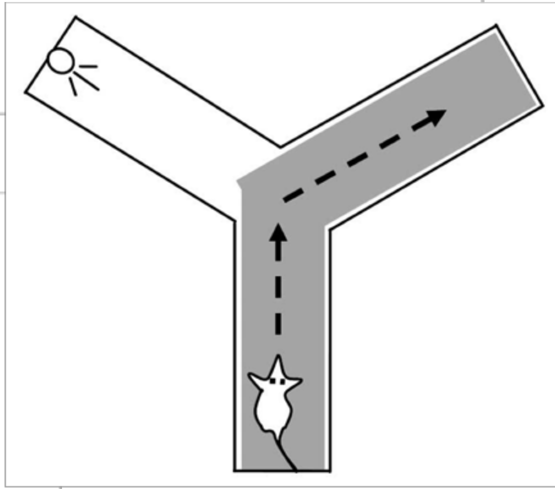
- Labor-intensive, slow, dull
- Imprecise and subjective

Experimenter bias

THE EFFECT OF EXPERIMENTER BIAS ON THE PERFORMANCE OF THE ALBINO RAT

by Robert Rosenthal and Kermit L. Fode

Harvard University and University of North Dakota[1]



Day	Asst.	Bright	Dull	t	p (one-tailed)
1	1.20	1.33	0.73	2.54	.03
2	3.00	1.60	1.10	1.02	NS
3	3.80	2.60	2.23	0.29	NS
4	3.40	2.83	1.83	2.28	.05
5	3.60	3.26	1.83	2.37	.03
Mean	3.00	2.32	1.54	4.01	.01

Rosenthal et al., Behavioral Science (1963)

Ethology

Manual scoring of behavior is still the dominant approach in the field

Downsides:

- Labor-intensive, slow, dull
- Imprecise and subjective
- Low-dimensional

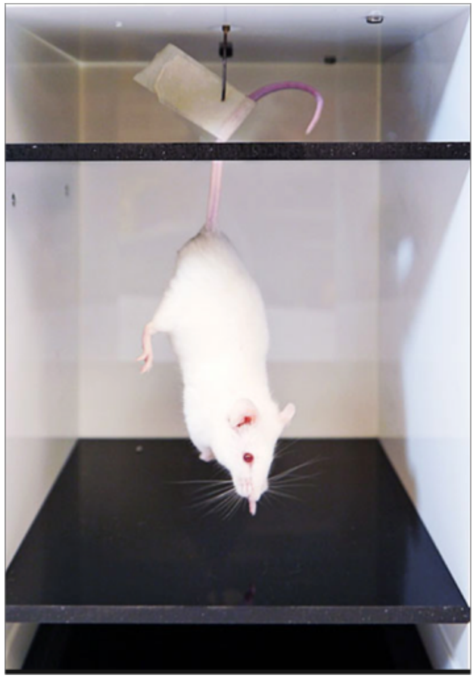
Ethology

Widely used methods to screen putative drugs

Significant controversy over interpretation and usefulness (Fonio et al. 2012)

Low repeatability across drugs and labs (Carobrez et al. 2015)

Tail suspension test
Model of “depression”



Elevated plus maze
Model of “anxiety”
2500 published papers in 2005

Ethology

Manual scoring of behavior is still the dominant approach in the field

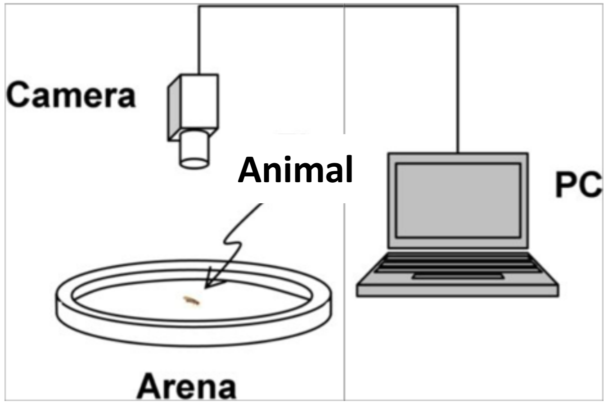
Downsides:

- Labor-intensive, slow, dull
- Imprecise and subjective
- Low-dimensional
- Limited by human vision and language

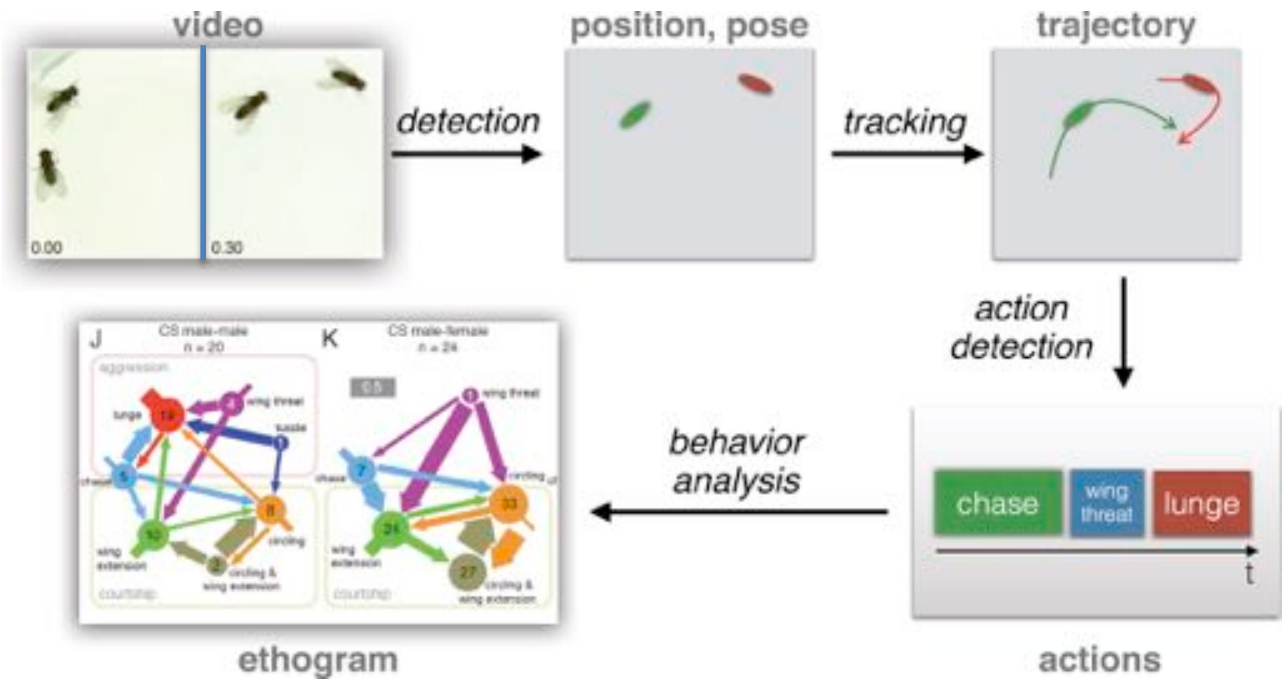
Computational Ethology

Automated acquisition and analysis of behavioral data

HARDWARE



SOFTWARE



Anderson and Perona, Neuron (2014)

Computational Ethology

Automated acquisition and analysis of behavioral data

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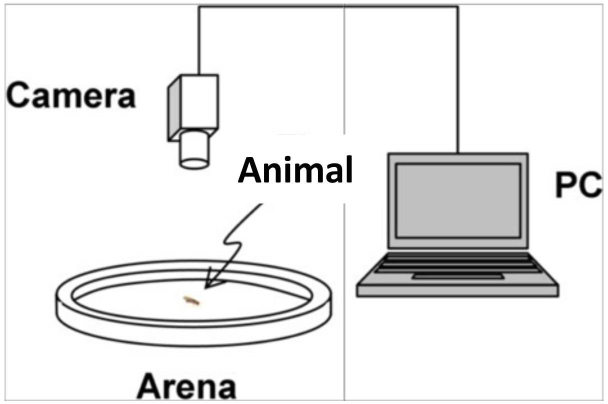
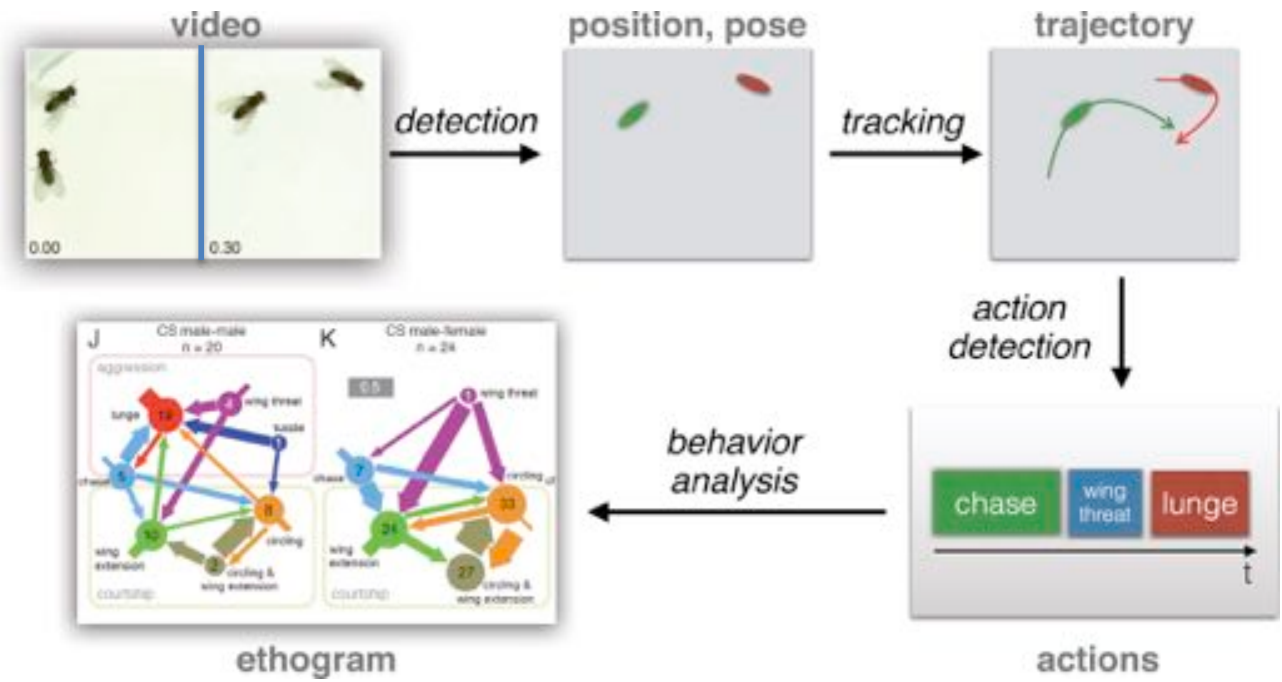




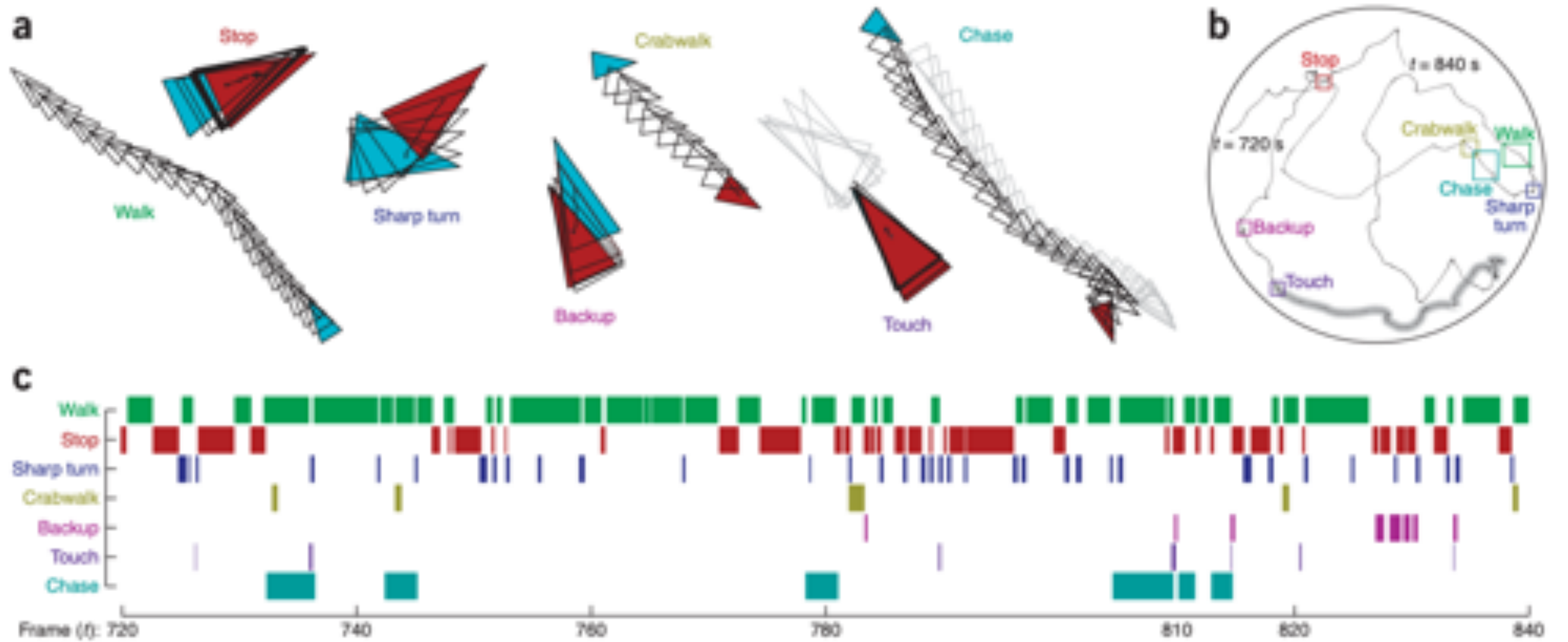
Increase in throughput (genetic, pharmacological screens)

Unbiased

Increase in scope (e.g. discovery of behaviors missed by Humans)

Anderson and Perona, Neuron (2014)

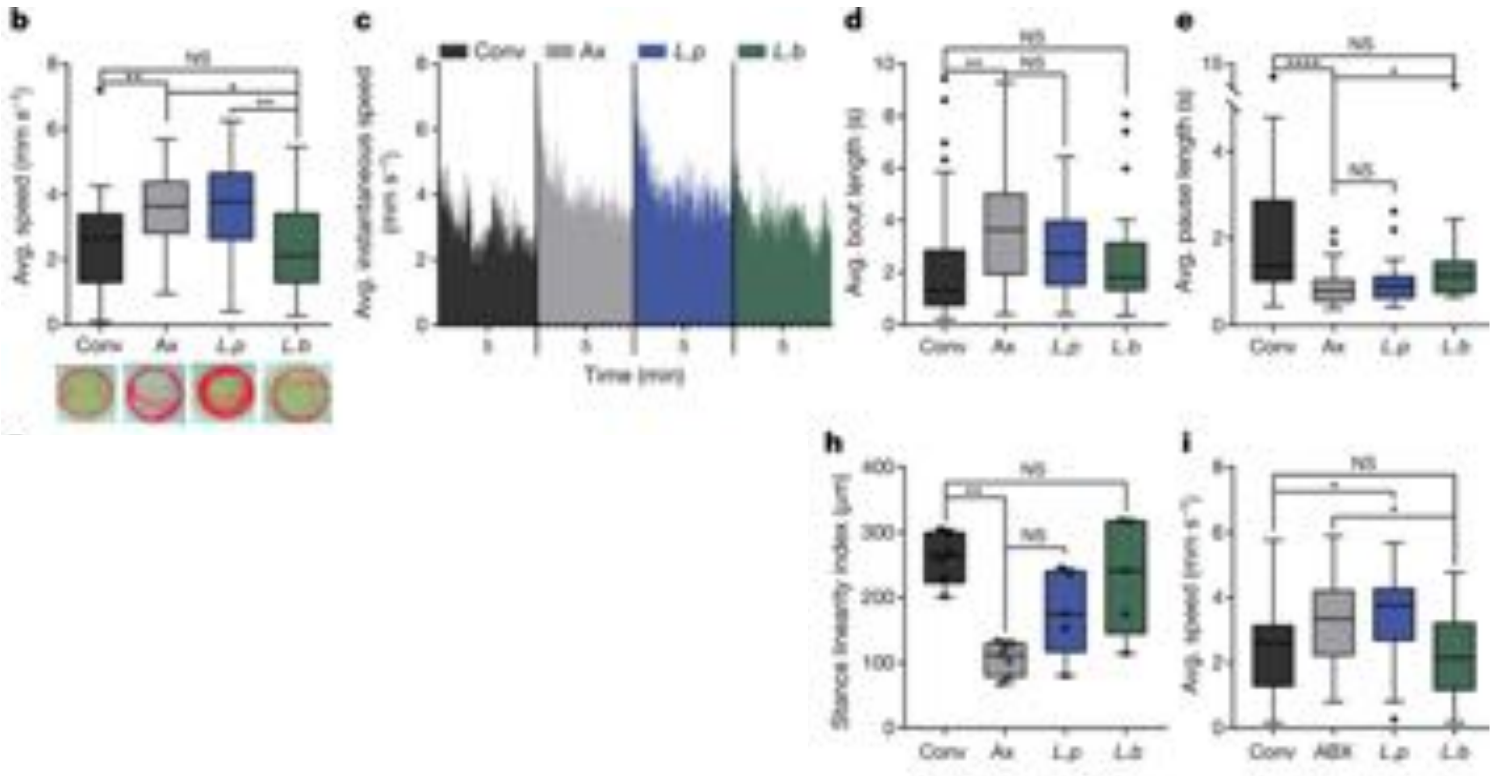
An automated Drosophila ethogram



Supervised machine learning for behavior classification

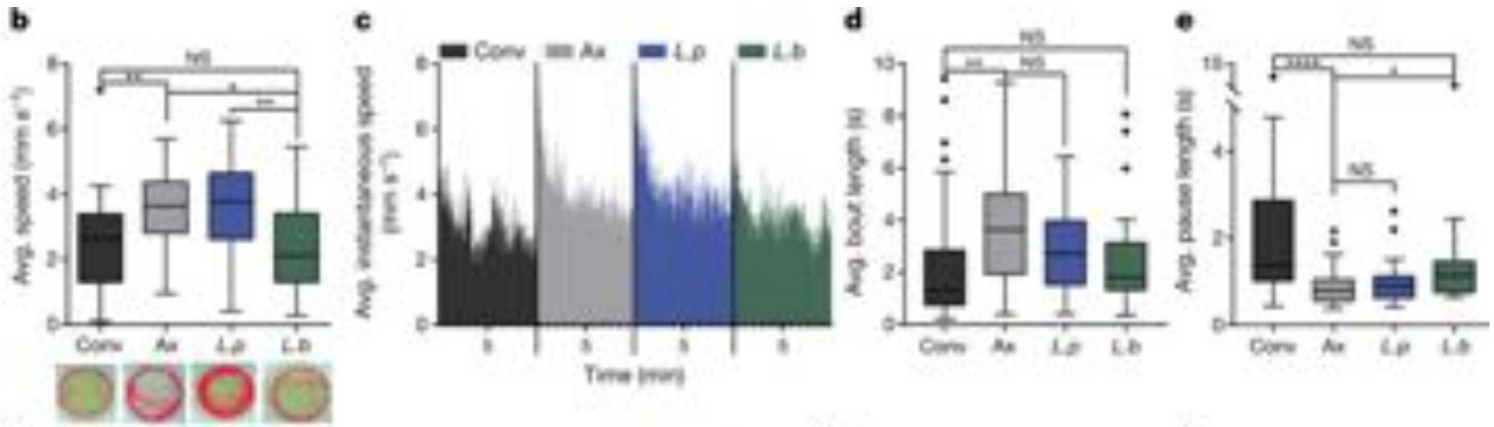
Branson et al., Nature Methods (2009)
http://ctrax.sourceforge.net/

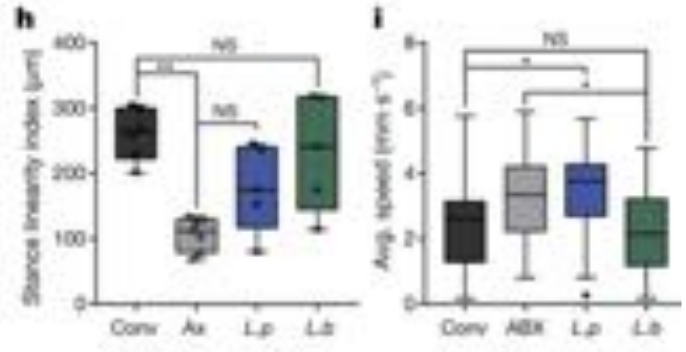
Behavioral screen in Drosophila

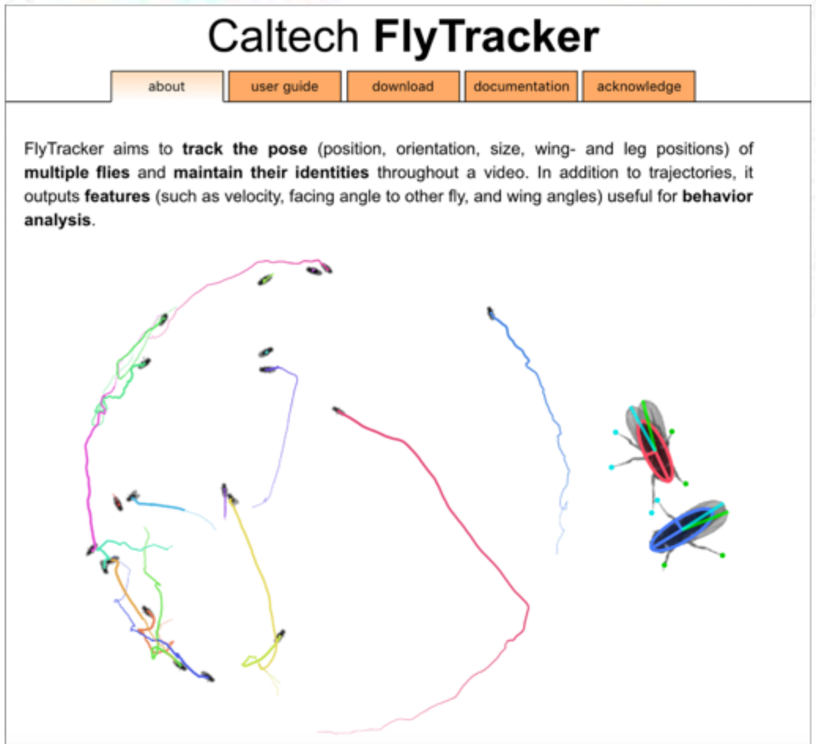


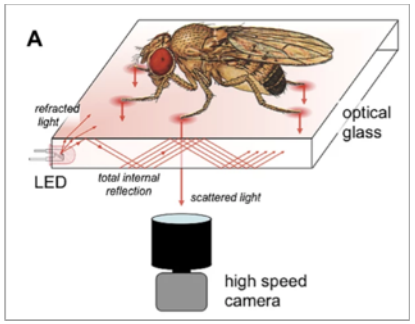
“A gut microbial factor modulates locomotor behaviour in Drosophila”. Schretter et al., Nature (2018)

Behavioral screen in Drosophila







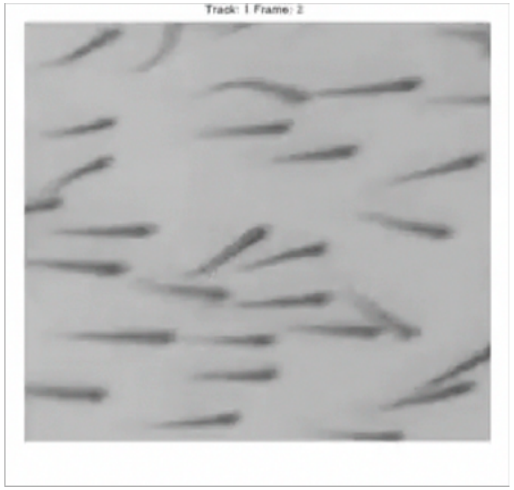


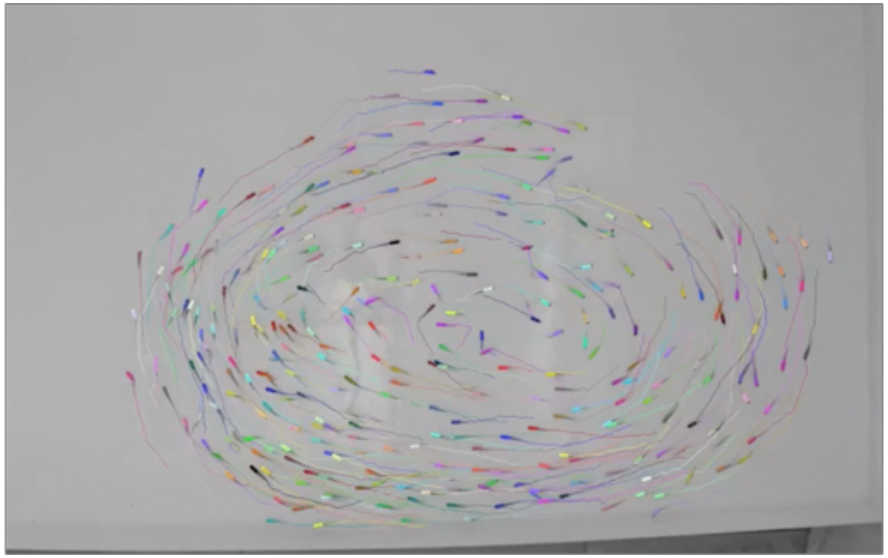
Gait analysis

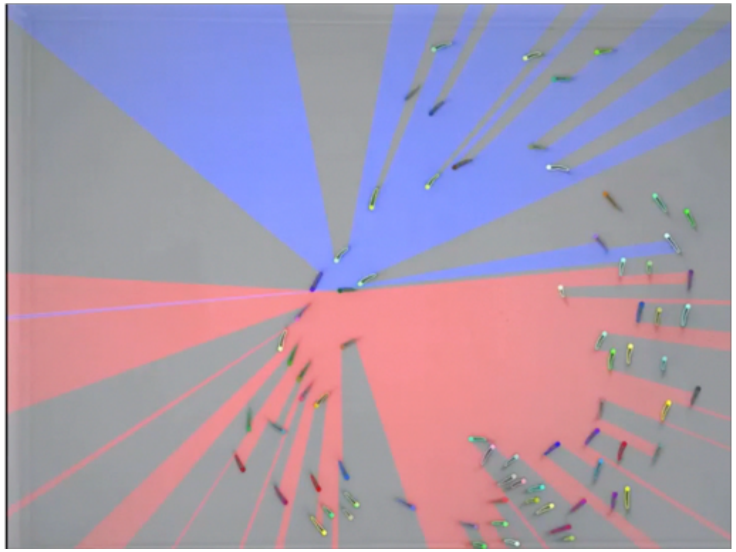
Schretter et al., Nature (2018)
Mendes et al., eLife (2013)

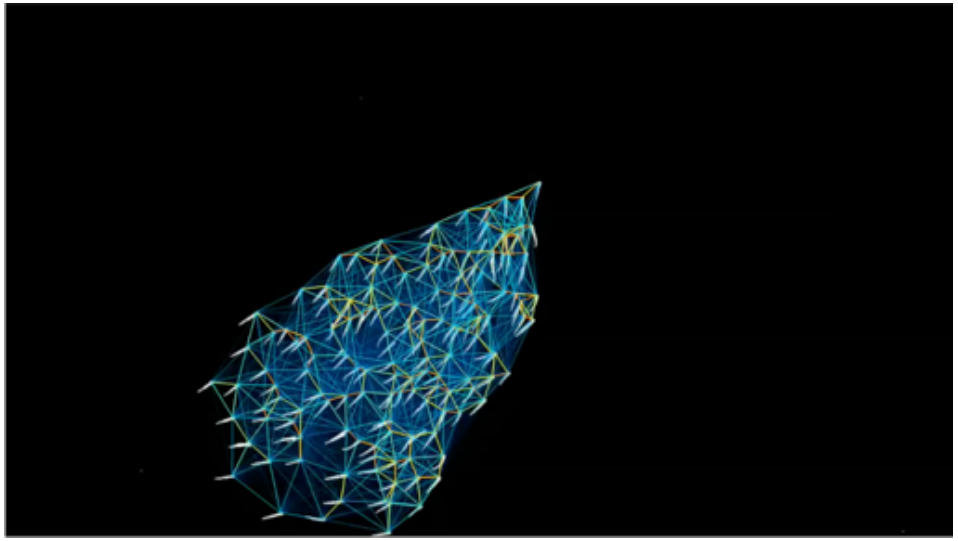
http://www.vision.caltech.edu/Tools/FlyTracker/

Example: fish schooling behavior









“Hidden” interaction networks underlie behavioral contagion during collective evasion maneuvers

Rosenthal et al., PNAS (2015)

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Social insects

Integrated units of 10 – 1’000’000 individuals

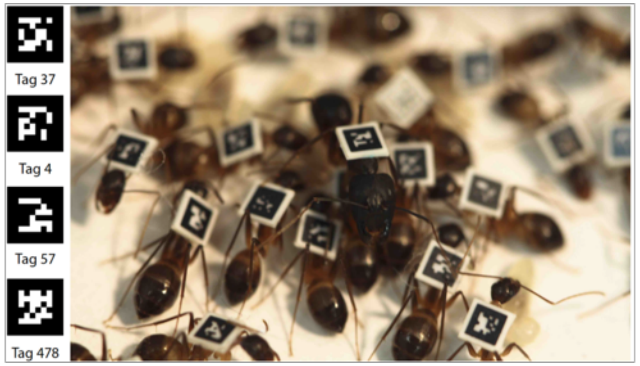
Sophisticated division of labor and behavioral specialization

Complex communication, collective behavior

Social insects : challenges

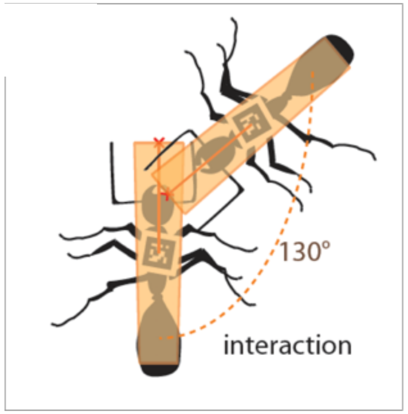
Dense clusters, frequent and long-lasting visual occlusion
→ maintaining individual identity over time almost always requires individual tags

Tracking social insects: example 1

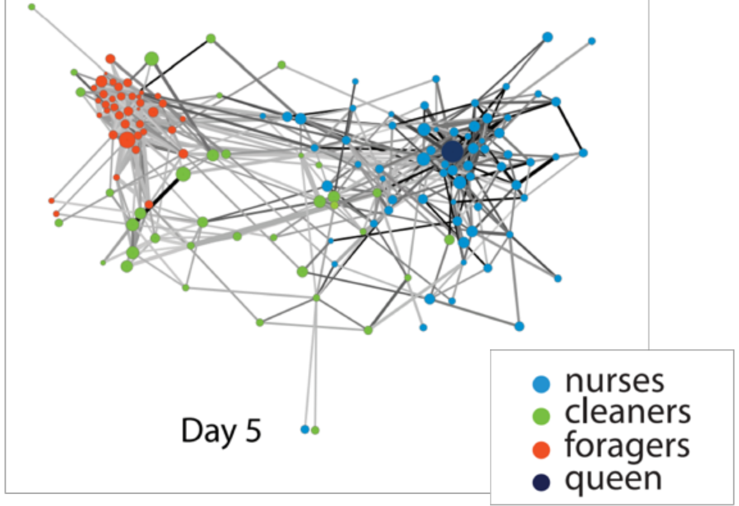


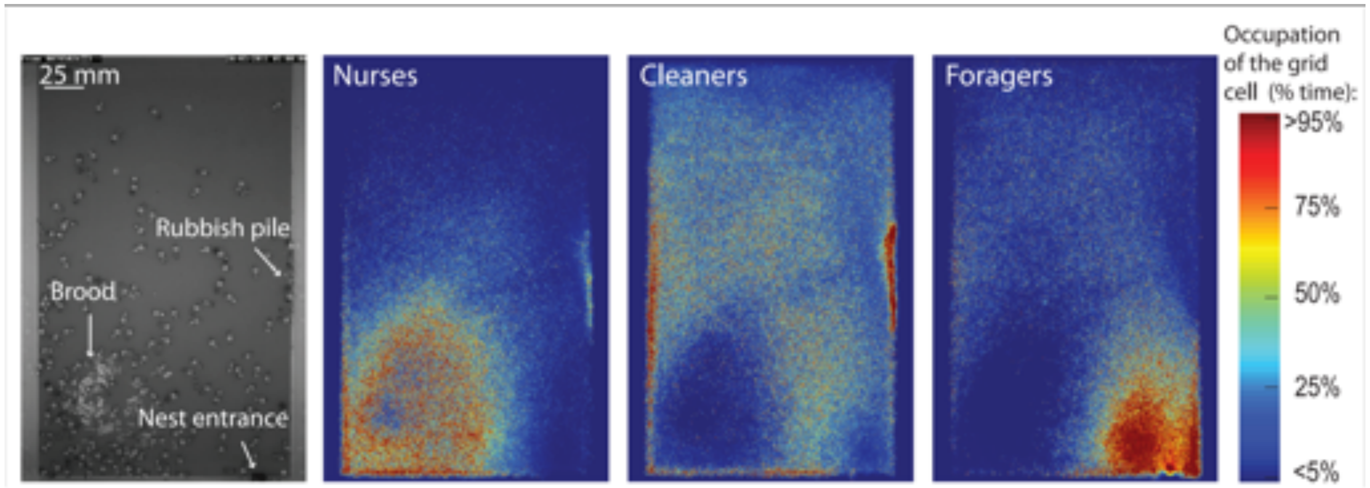
QR codes on *Camponotus* ants

Scoring pairwise interactions



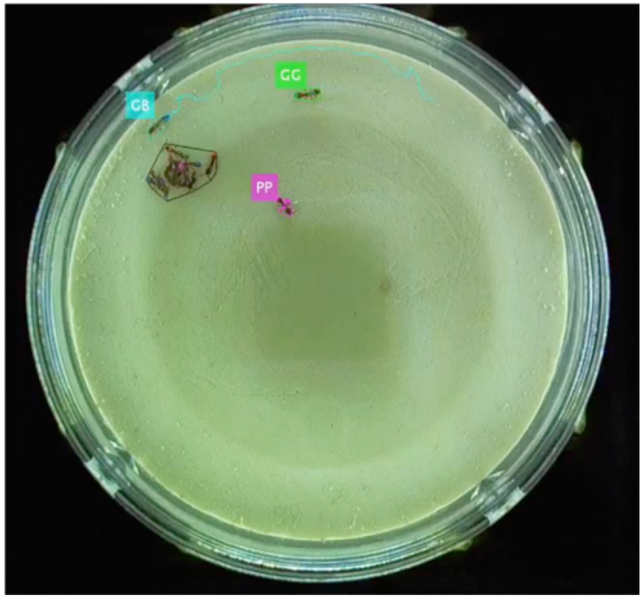
Social interaction network





Mersch et al., Science (2013)

Tracking social insects: example 2

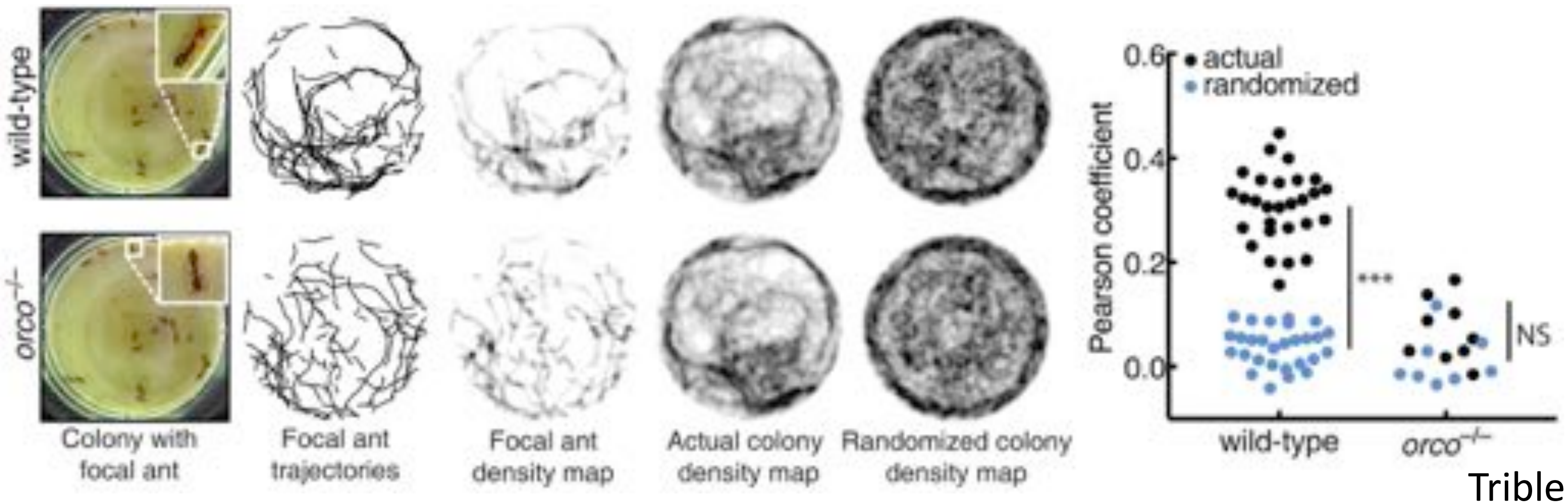


Paint-marked *Ooceraea biroi* ants

Olfactory mutant shows impaired social behavior:

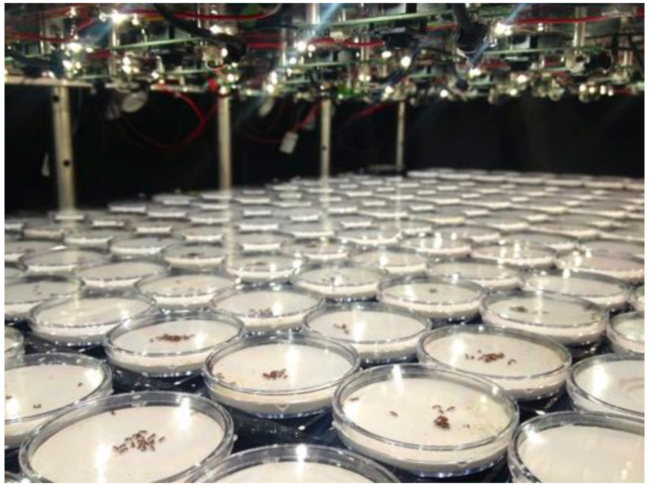
Wandering phenotype

No trail following

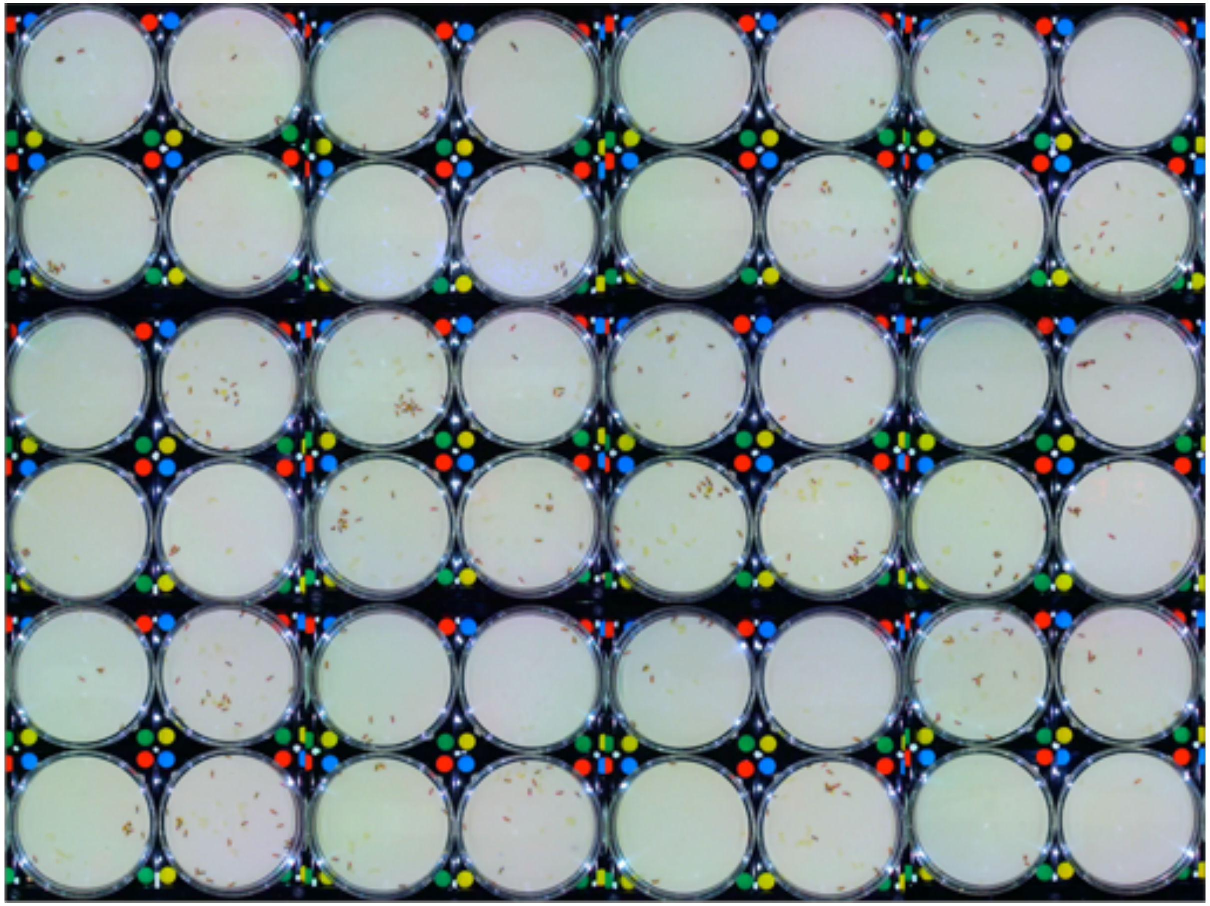


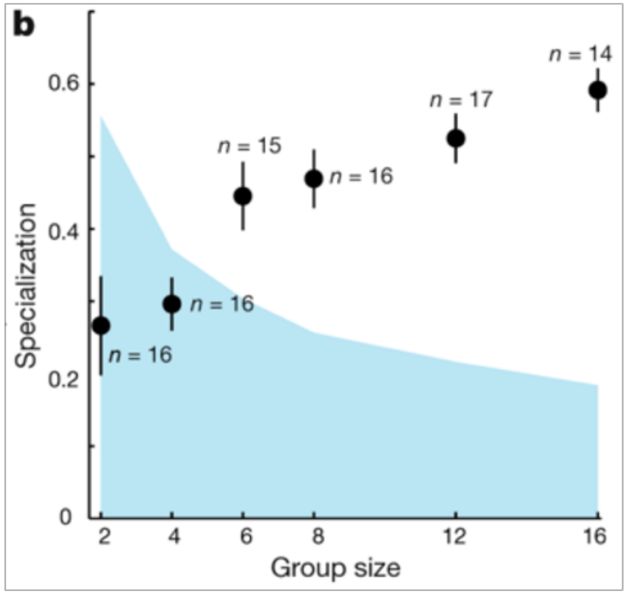
Trible et al., Cell (2017)

Tracking social insects: example 3



28 cameras, 112 colonies
Paint-marked *Ooceraea biroi*

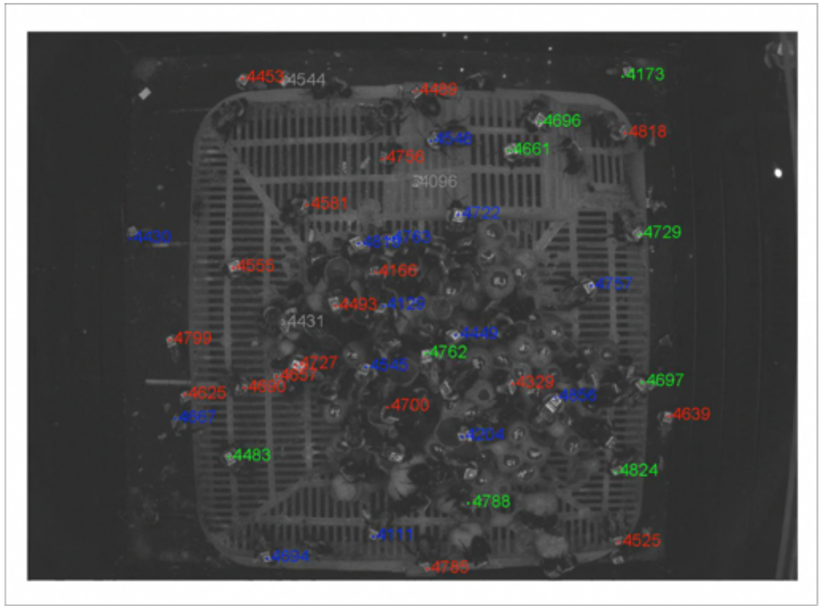




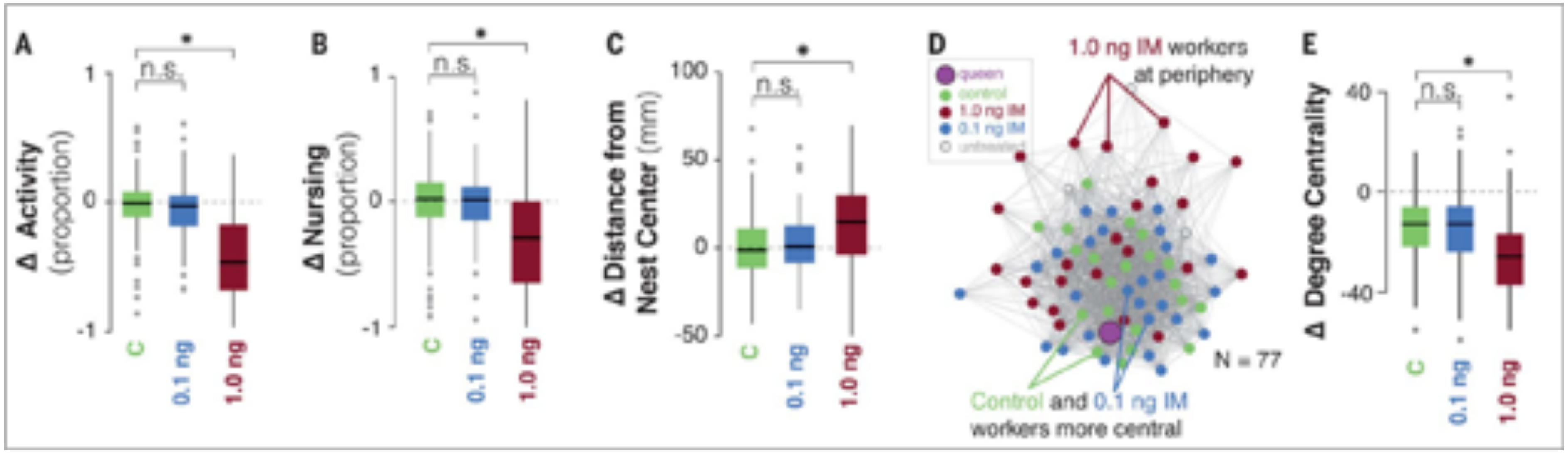
Individual specialization increases with group size

Ulrich et al., Nature (2018)

Tracking social insects: example 4

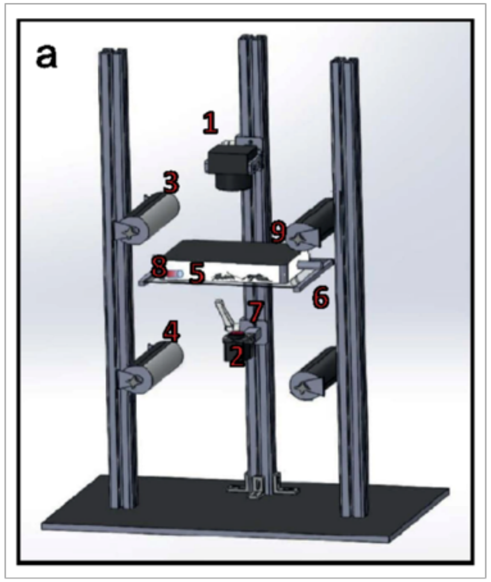


Neonicotinoid pesticides (imidacloprid IM) disrupt bumblebee nest behavior and social networks

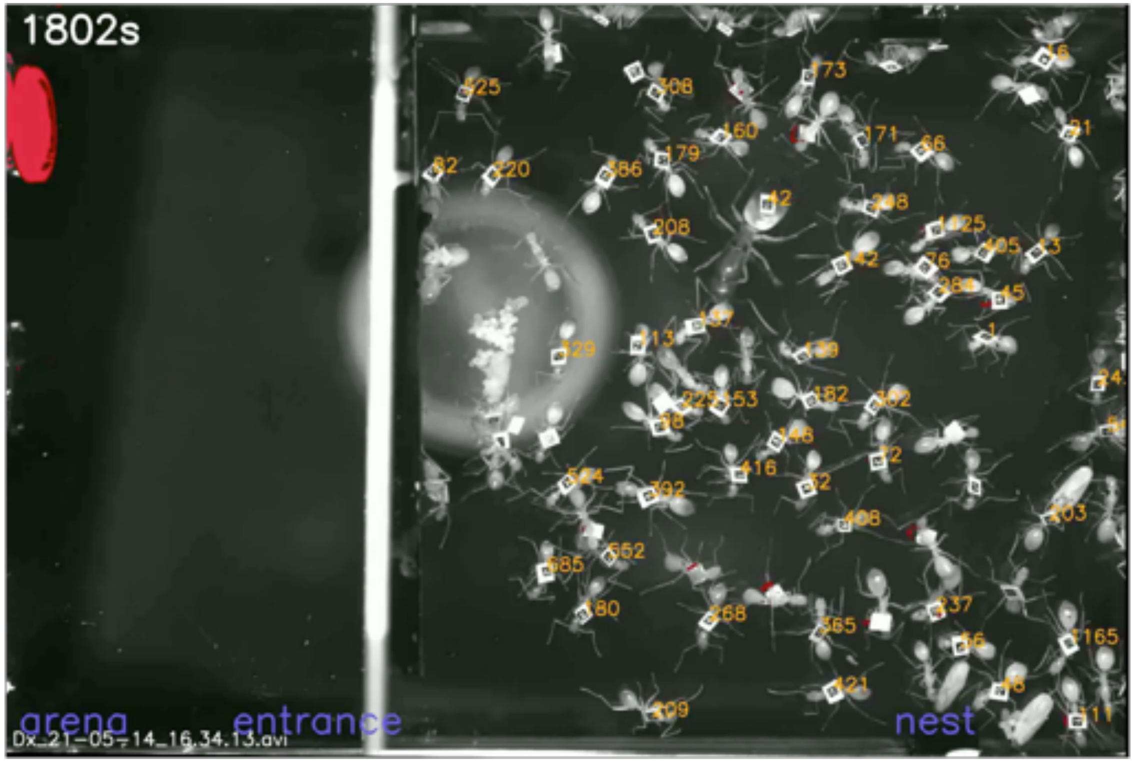


Crall et al., Science (2018)

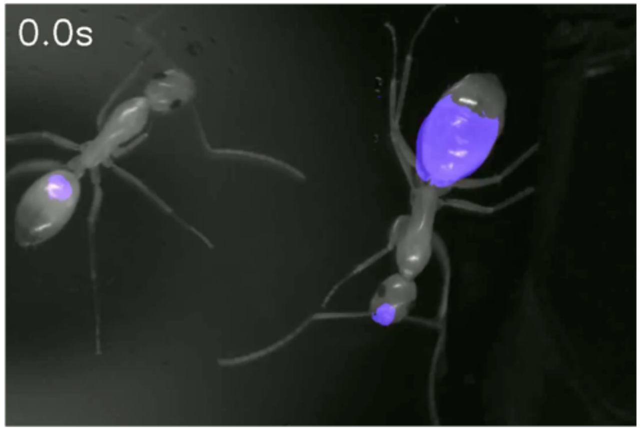
Tracking social insects: example 5



Infrared camera (top)
Fluorescence camera (bottom)
QR labeled *Camponotus* ants



Fluorescently labeled food



Exchange of liquid food (trophallaxis)

Individual crop loads provide local control for collective food intake in ant colonies

Greenwald et al., eLife (2018)

Anatomy of a tracking system

The clonal aider ant *Ooceraea biroi*

No queens, all workers reproduce (clonally)

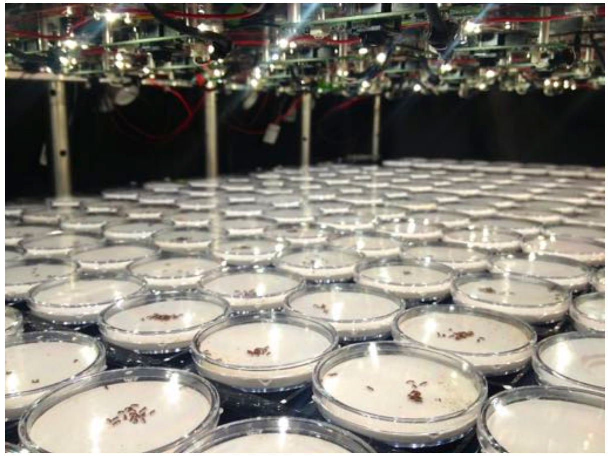
→ small colonies (≥10) are fully functional

→ individual color tags (thorax abdomen)

Blind

→ Tracking under visible white light

2mm long



1 webcam monitors 4-6 colonies

Simultaneous recording from 6 webcams w/ one computer

Up to 144 colonies can be monitored in parallel

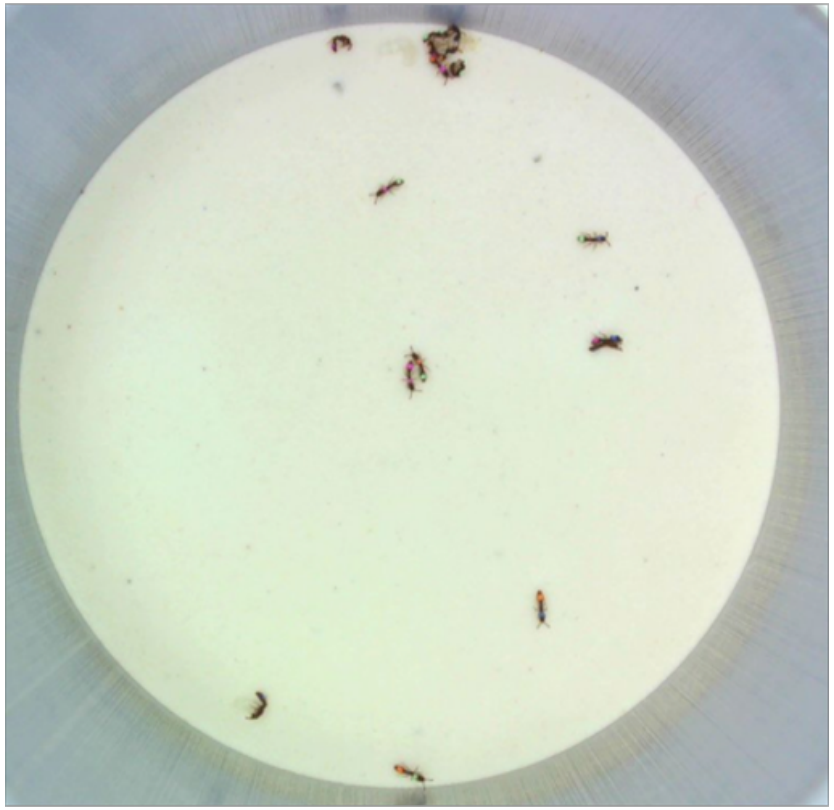
5MP, color (RBG) images at 10 frames per second

Continuous (≤ 48h) or discontinuous (e.g. 10 min every 2h)

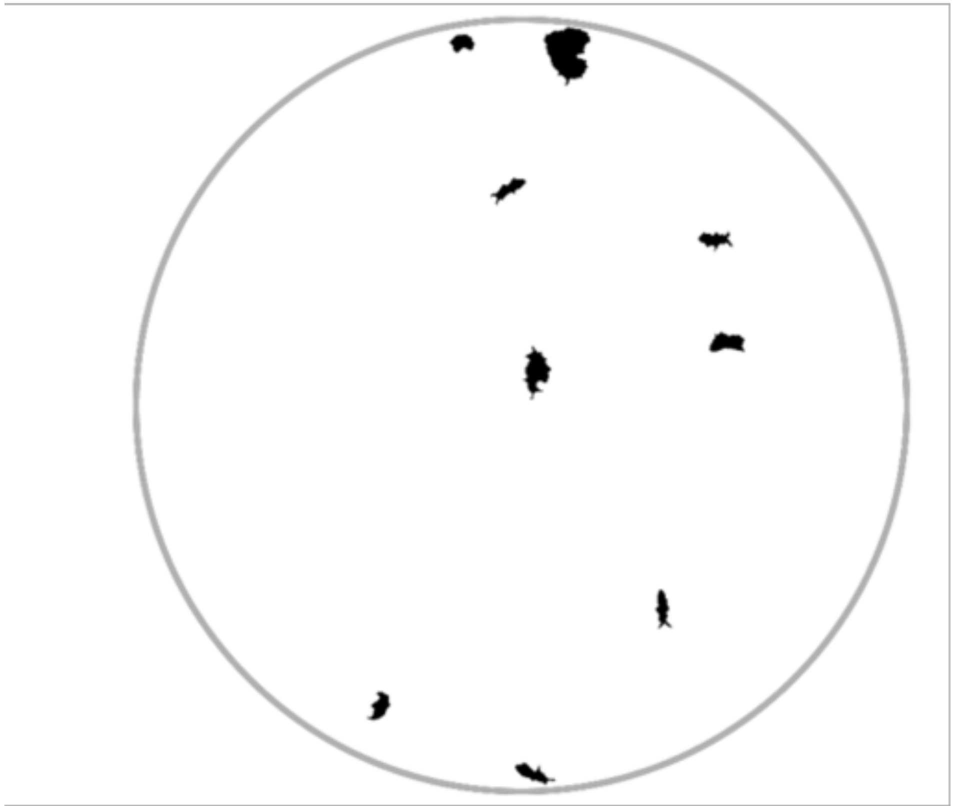
Jonathan Saragosti & Asaf Gal

Anatomy of a tracking system

RBG image



Anatomy of a tracking system



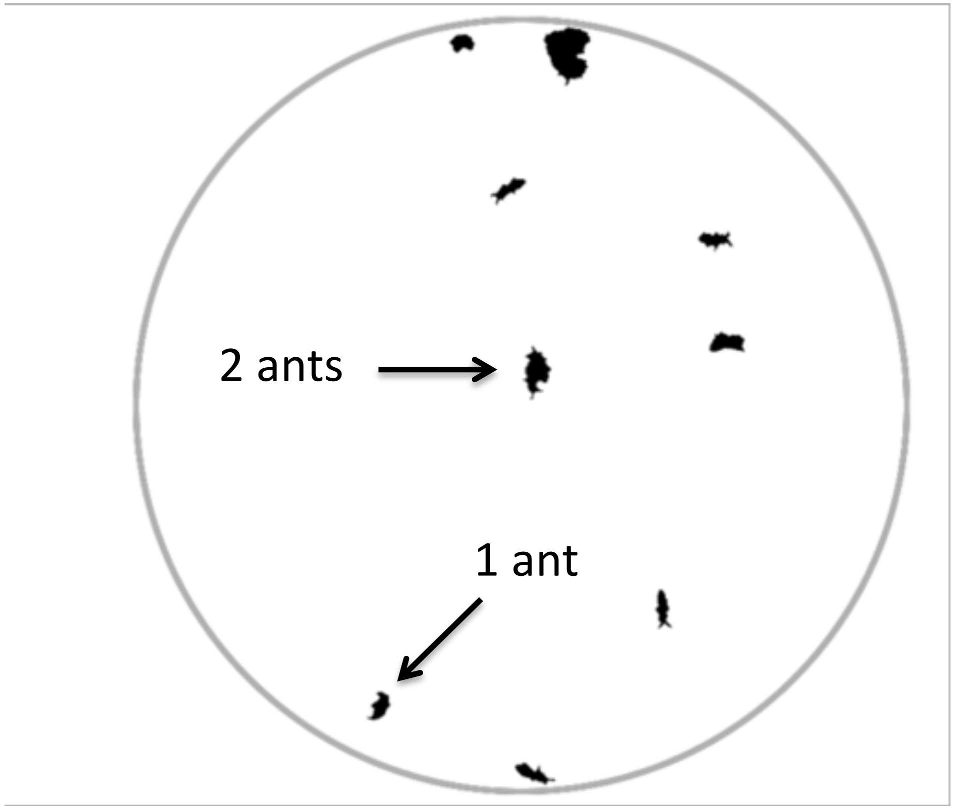
RBG image

↓ Segmentation (e.g. edge detection, thresholding)

Binary image

Connected image regions: “blobs”
- Size
- Centroid

Anatomy of a tracking system



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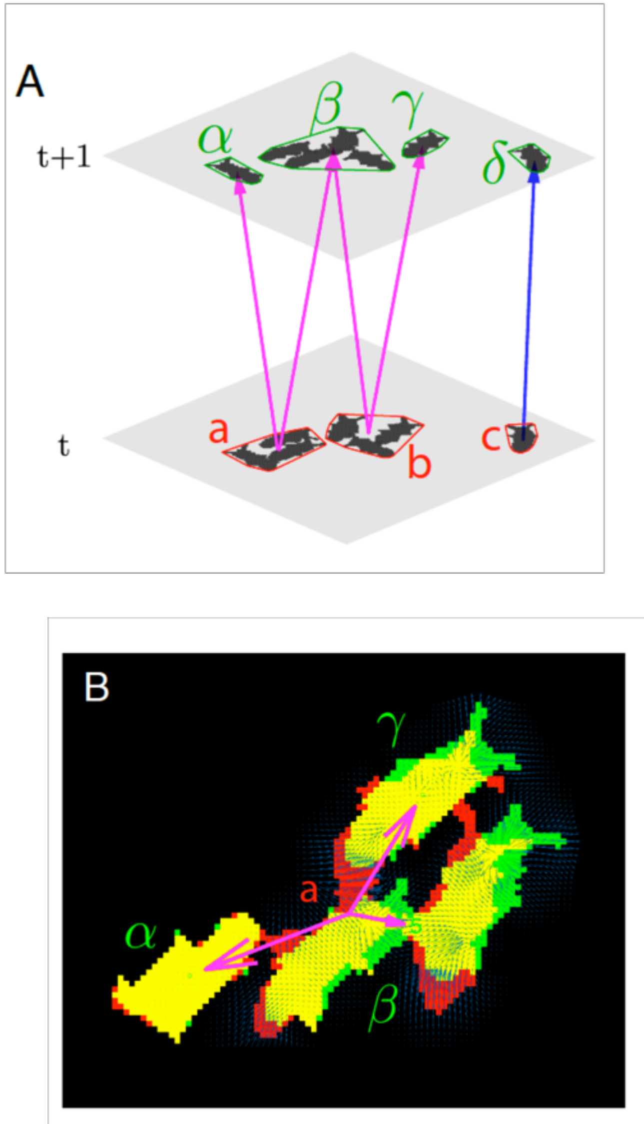


RBG image

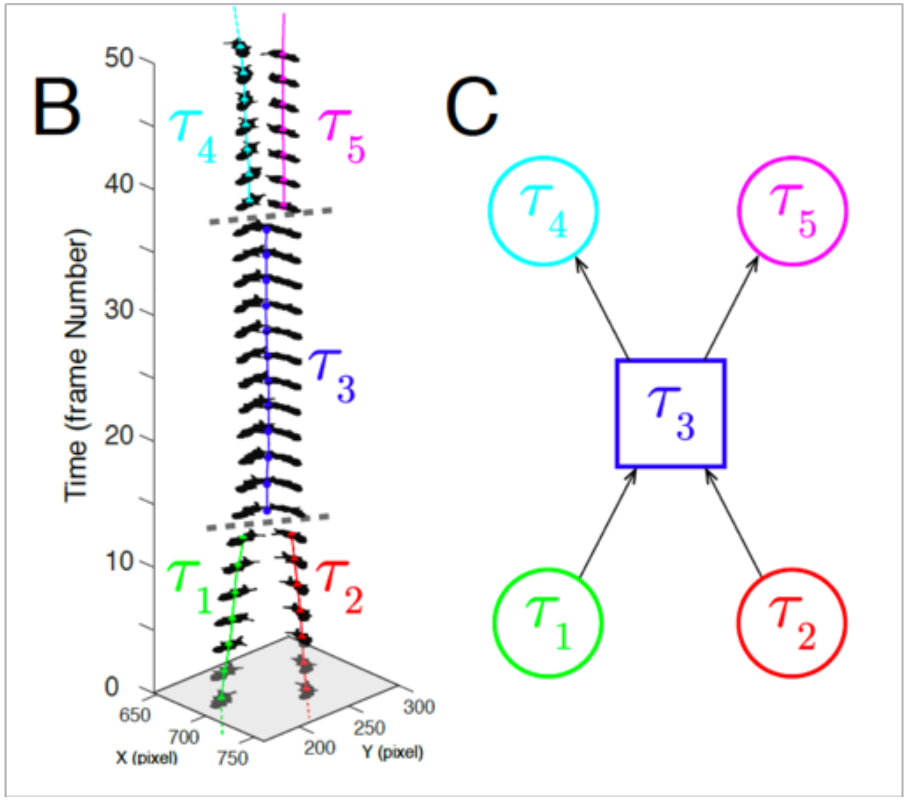
Segmentation (e.g. edge detection, thresholding)

Binary image

Connect blobs across time (optical flow linking, assignment algorithms)

Jonathan Saragosti & Asaf Gal

Anatomy of a tracking system



RBG image

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Tracklet network

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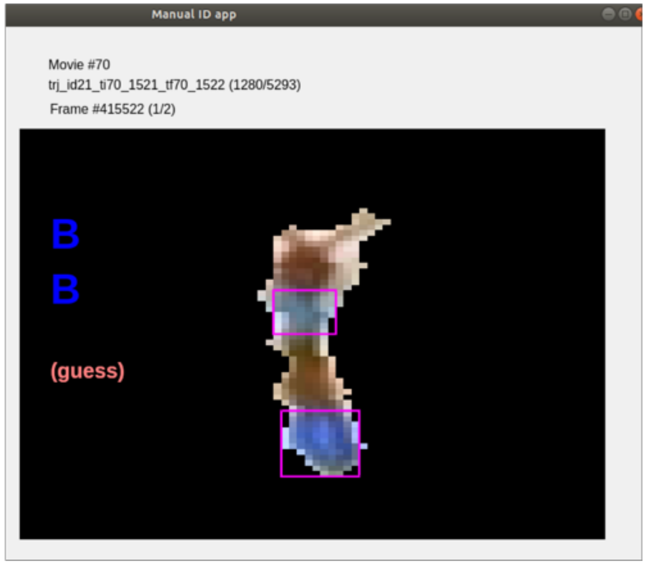
Anatomy of a tracking system



Color tag identification:

Create a training set of single ant blobs with well-defined thorax and abdomen tags

Train a (supervised) tag classifier

Classify candidate single-ant tracklets

ID-ed tracklets

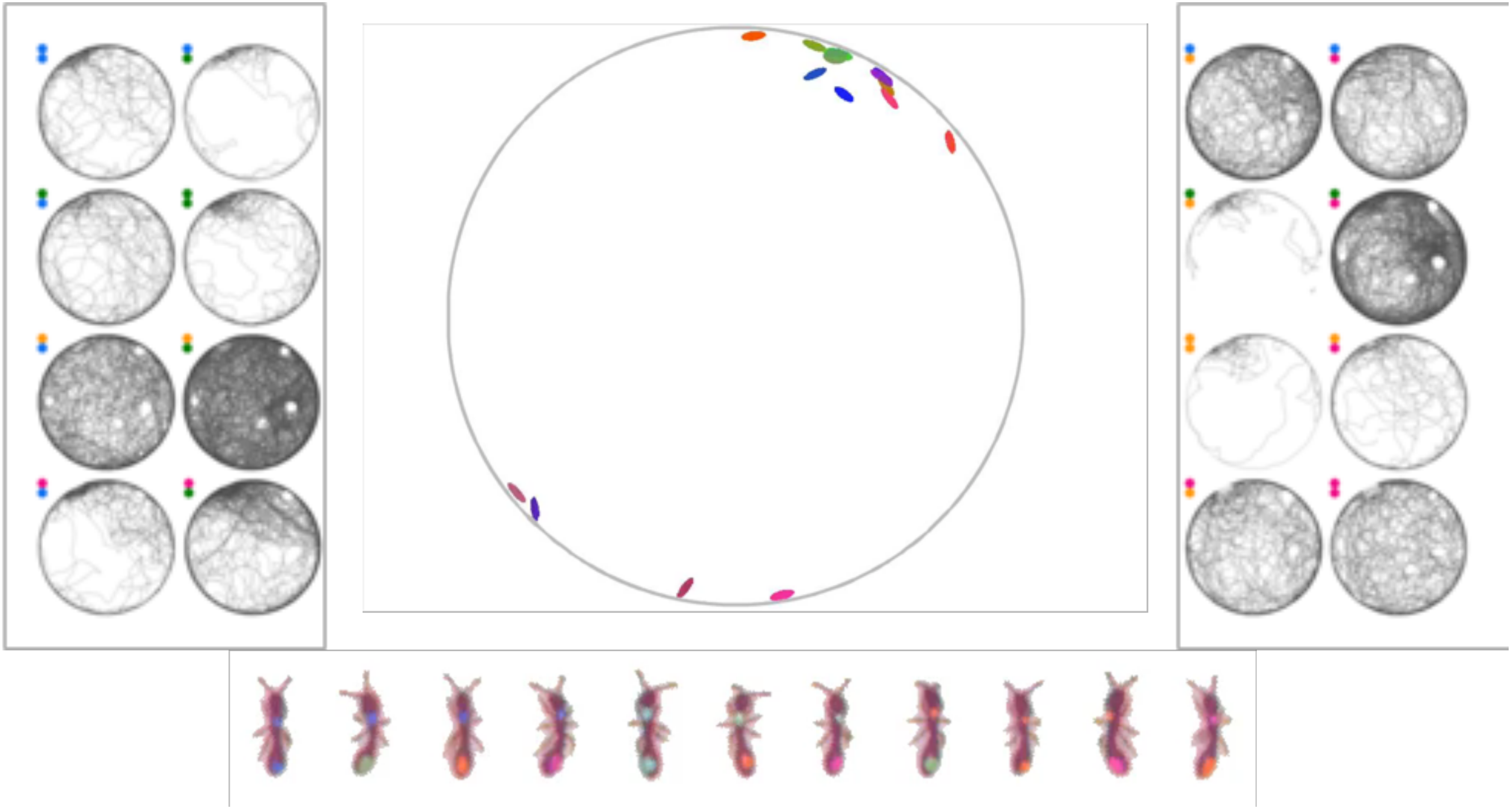
Propagate ID's over tracklet network

Individual trajectories

(x, y), t, ID

Jonathan Saragosti & Asaf Gal

Anatomy of a tracking system



Asaf Gal

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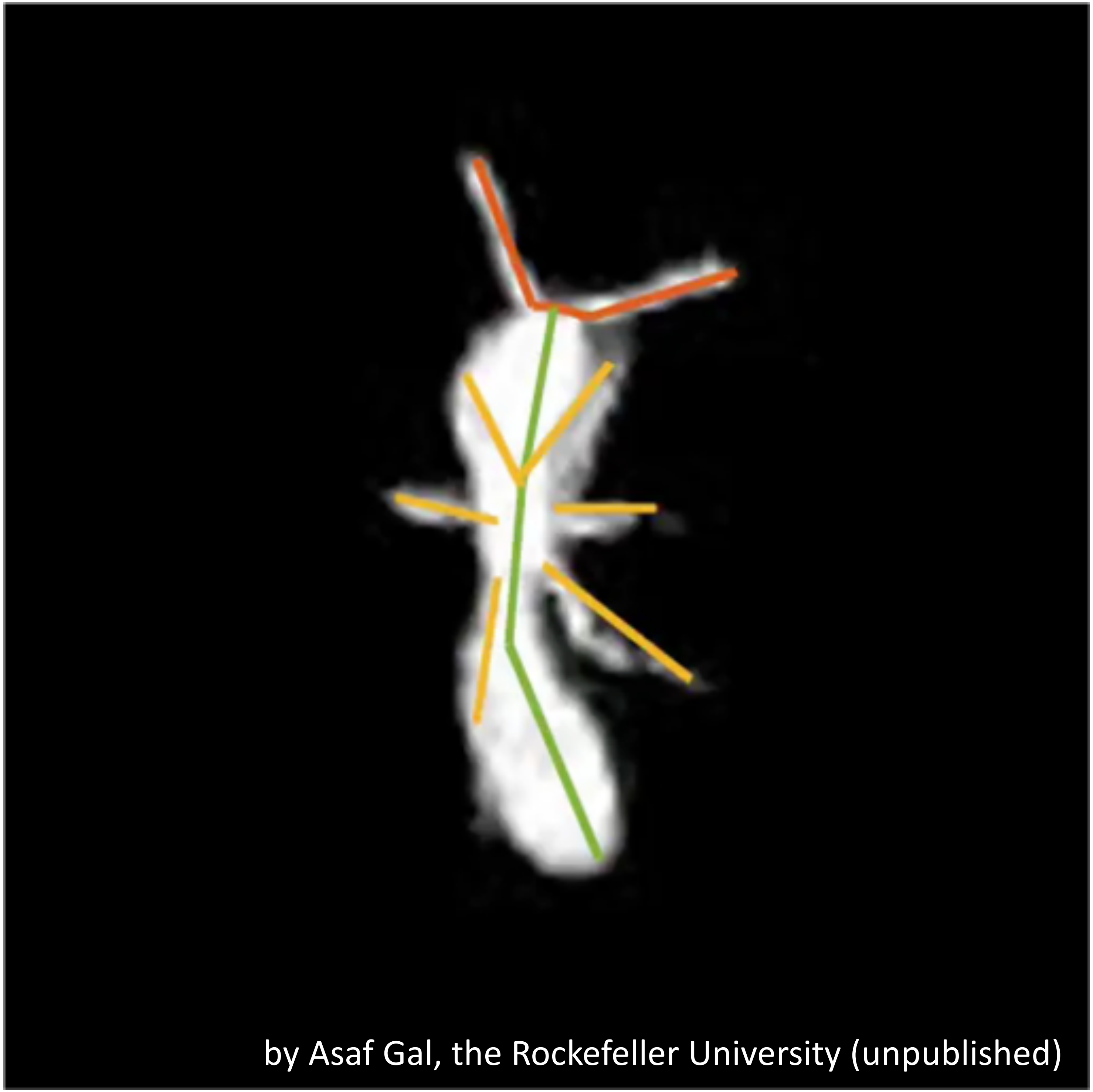
Going beyond (x, y) data

Fast animal pose estimation using deep neural networks

Talmo D. Pereira, Diego E. Aldarondo, Lindsay Willmore, Mikhail Kislin, Samuel S.-H. Wang, Mala Murthy, Joshua W. Shaevitz

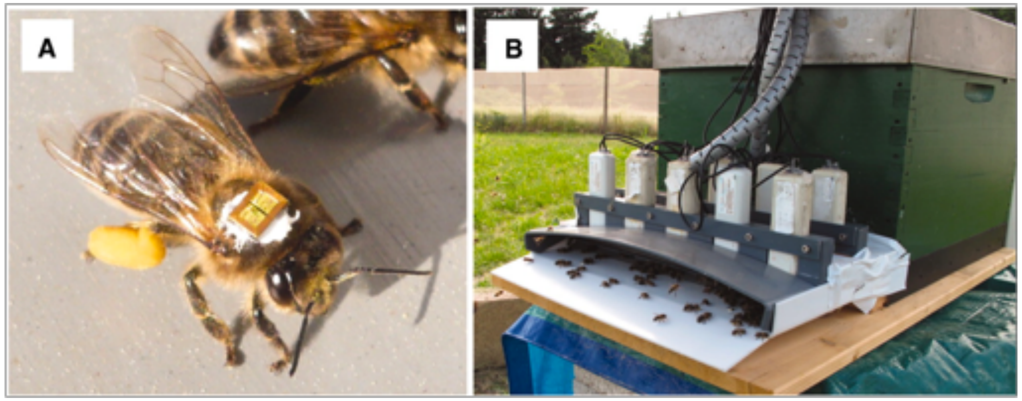
doi: https://doi.org/10.1101/331181


Raw
Confidence Maps
Tracked
t = 0.00s


by Asaf Gal, the Rockefeller University (unpublished)

Behavior in the wild

Bird ringing



RFID: entry/exits from hive

GPS

ICARUS project

http://www.orn.mpg.de/ICARUS

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- Jaguar: https://blog.londolozi.com/2013/09/14/the-jaguars-we-track/
- RFID bees: http://science.sciencemag.org/content/336/6079/348/F1
- Bird ringing: http://nc.audubon.org/news/how-banding-supports-bird-conservation-science
- Basic tracking setup: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0001083
- Most social insects pictures: https://www.alexanderwild.com/