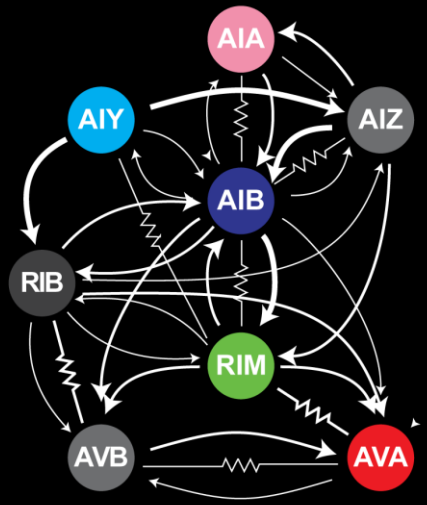
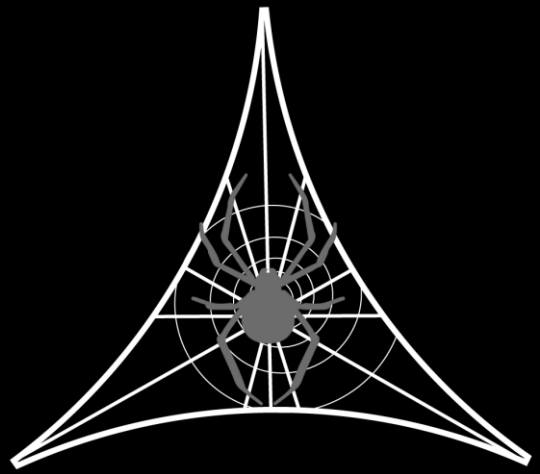
Foraging and the roles of neuromodulators



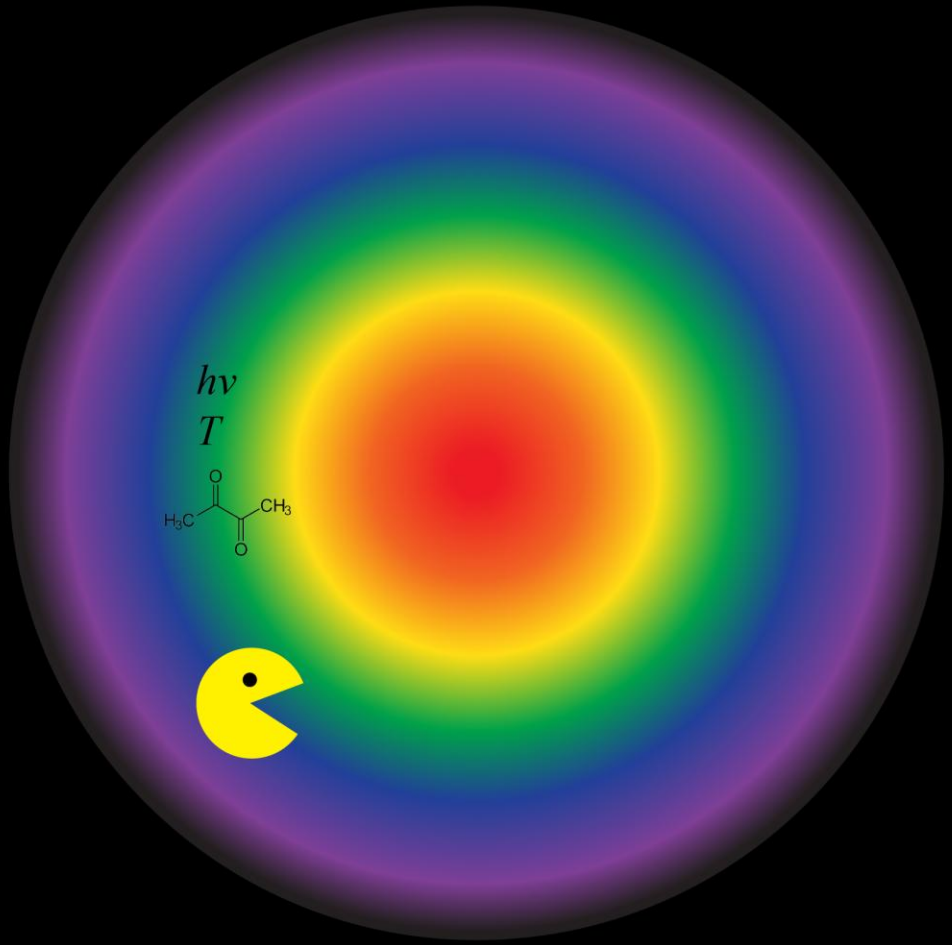
Andrew Gordus

KITP SNAV18

08.16.2018



JOHNS HOPKINS UNIVERSITY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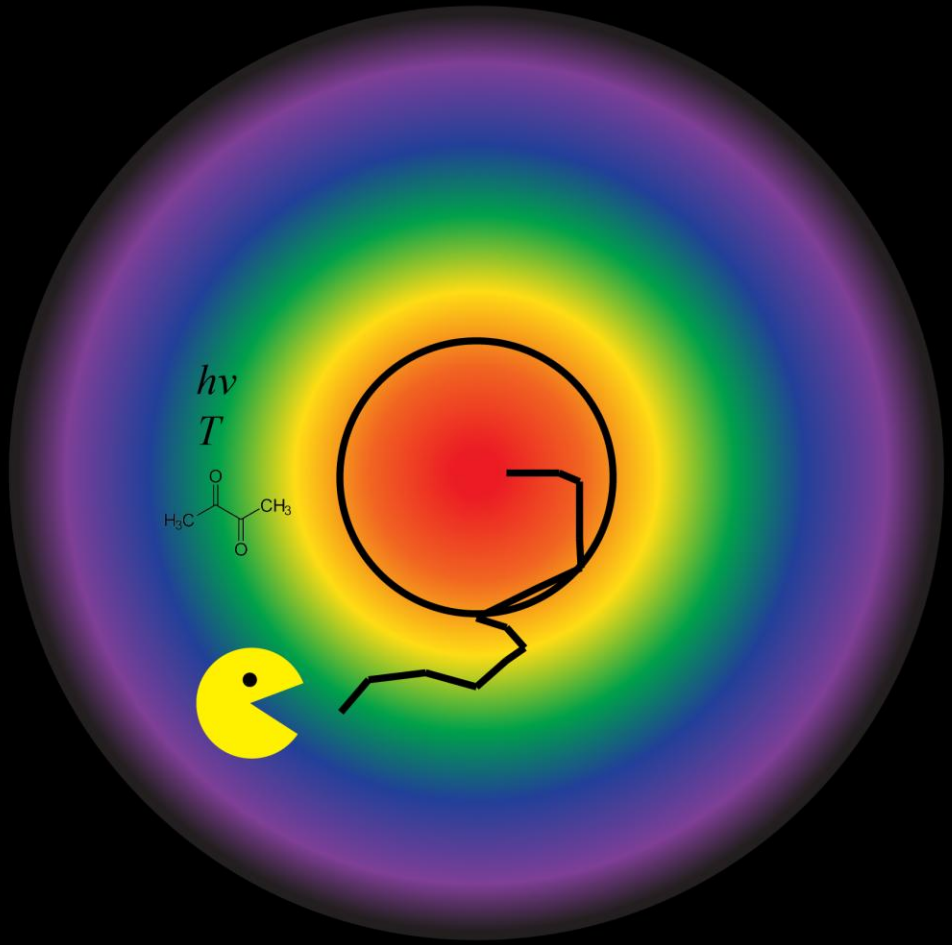
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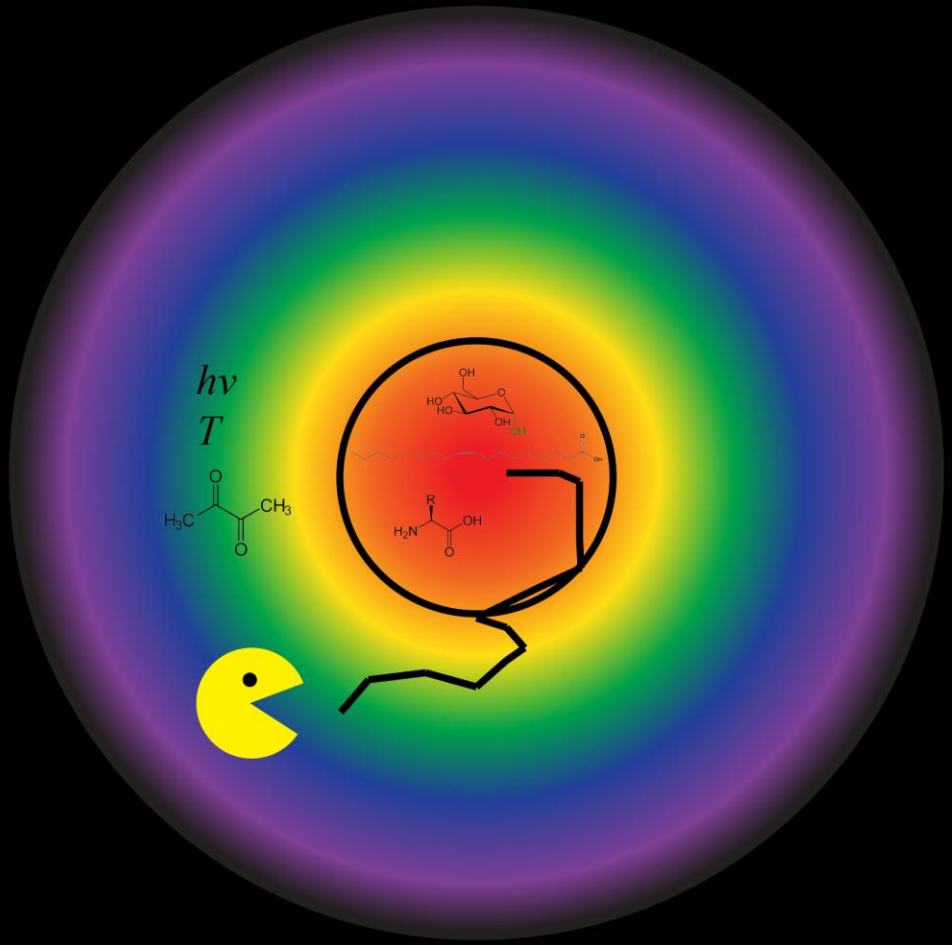
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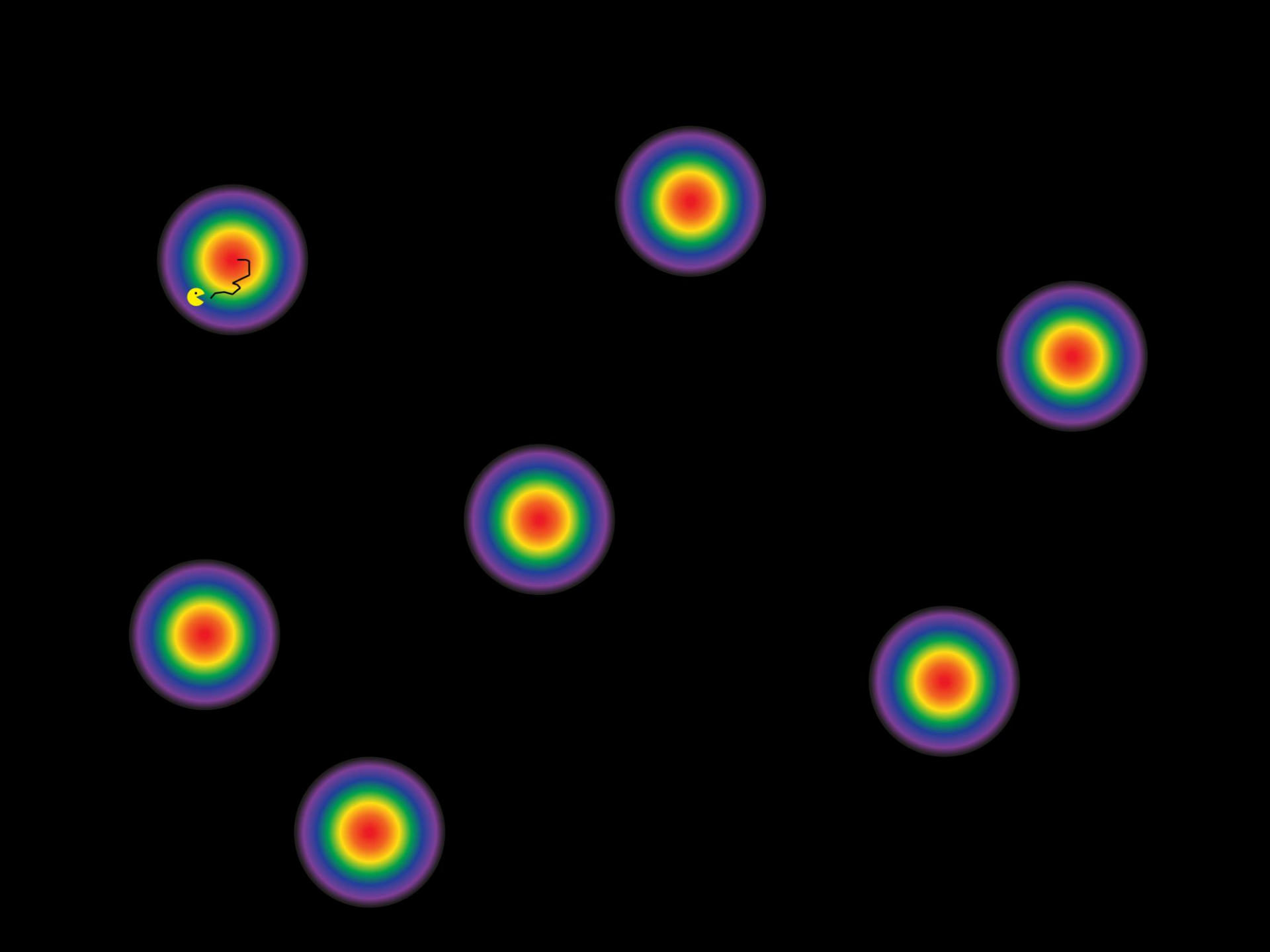

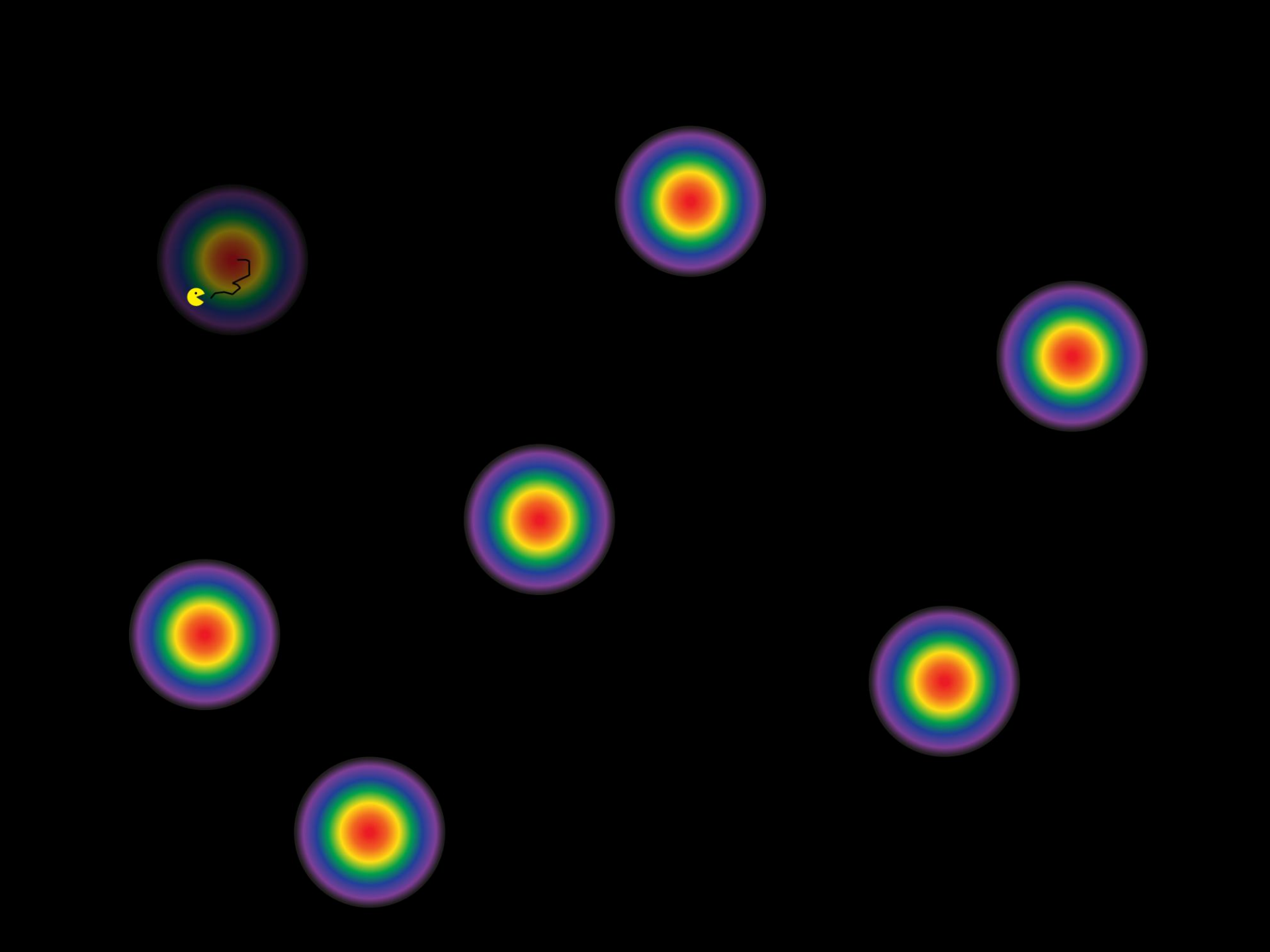

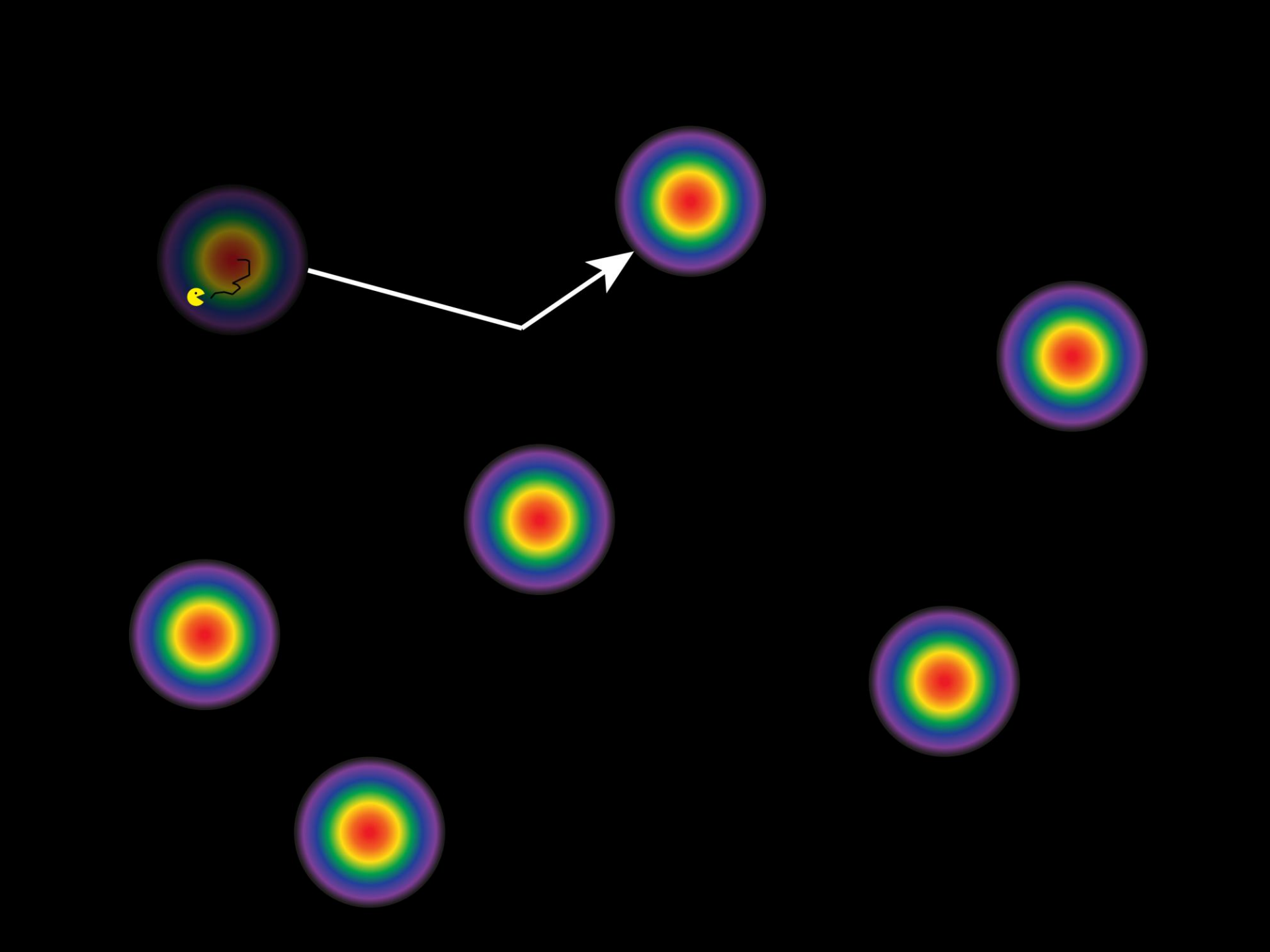
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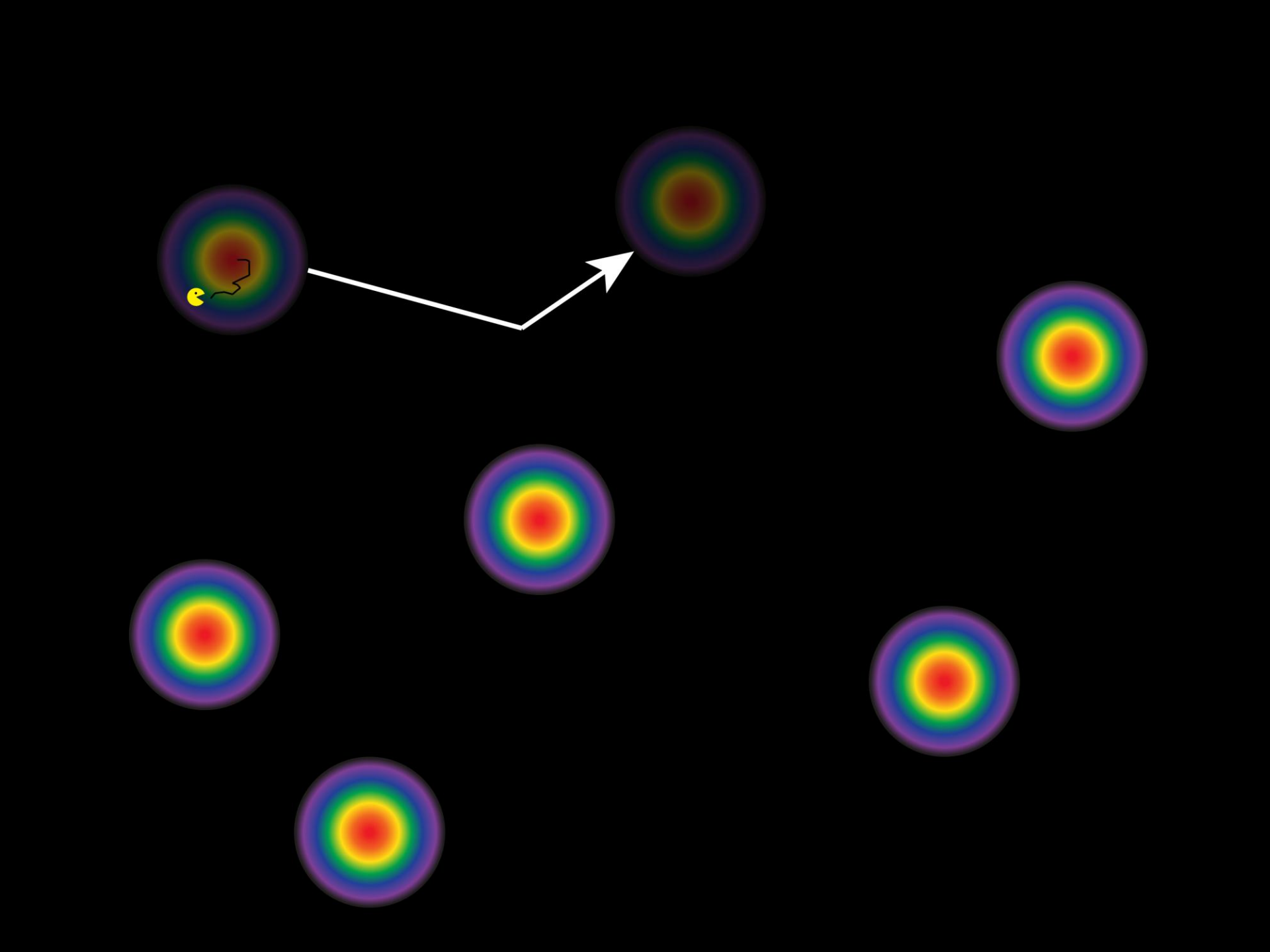
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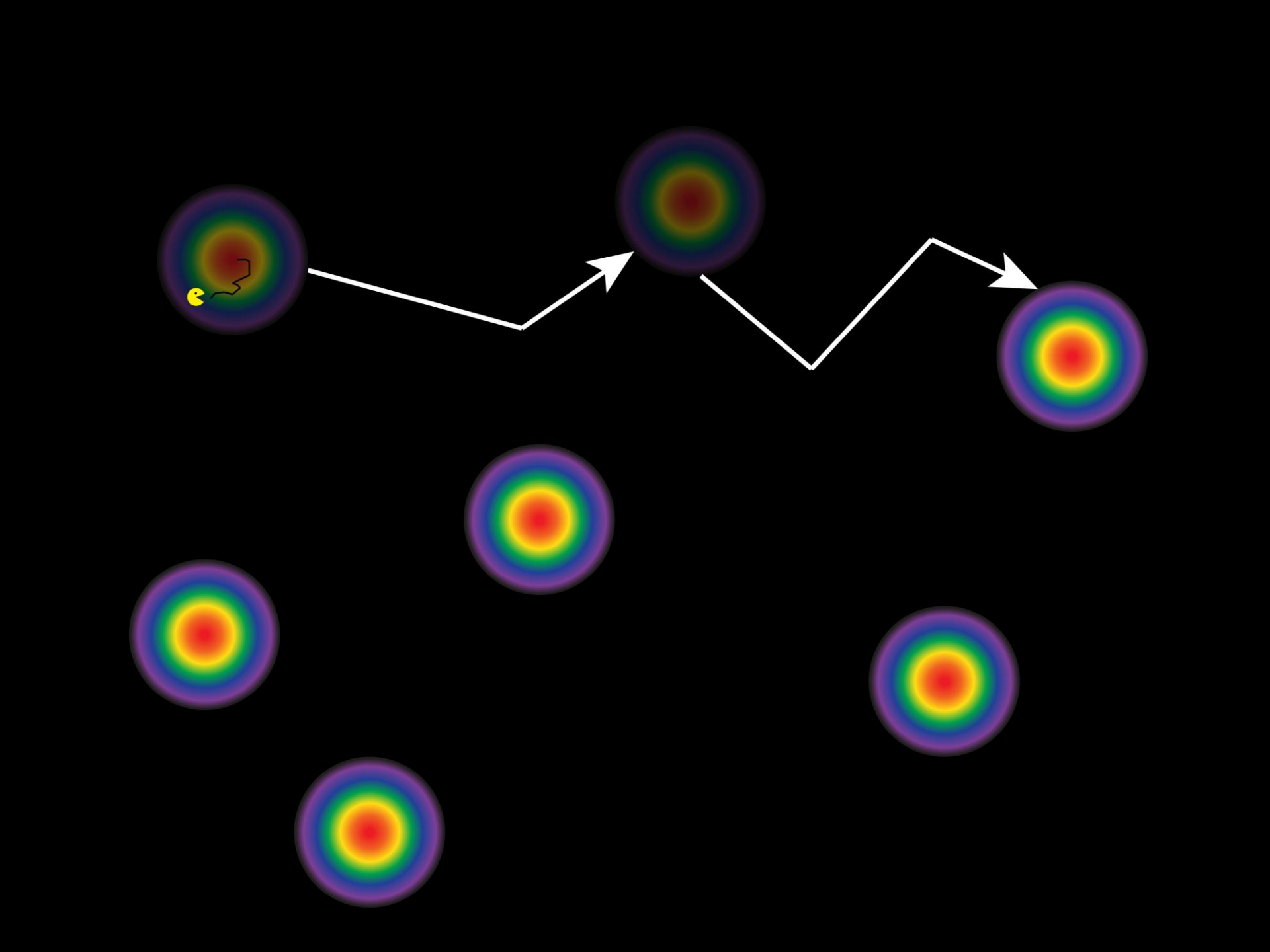

Questions

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Marginal Value Theorem

THEORETICAL POPULATION BIOLOGY 9, 129–136 (1976)

Optimal Foraging, the Marginal Value Theorem

ERIC L. CHARNOV*

Center for Quan. Science in Forestry, Fisheries, and Wildlife, University of Washington, Seattle, Washington 98195; and Institute of Animal Resource Ecology UBC, Vancouver 8, Canada

Received December 26, 1974

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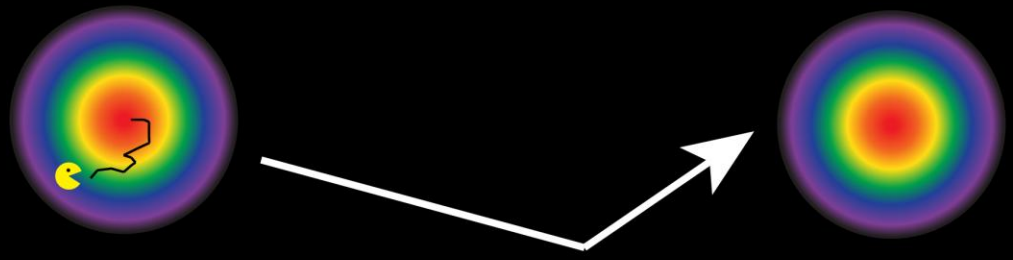

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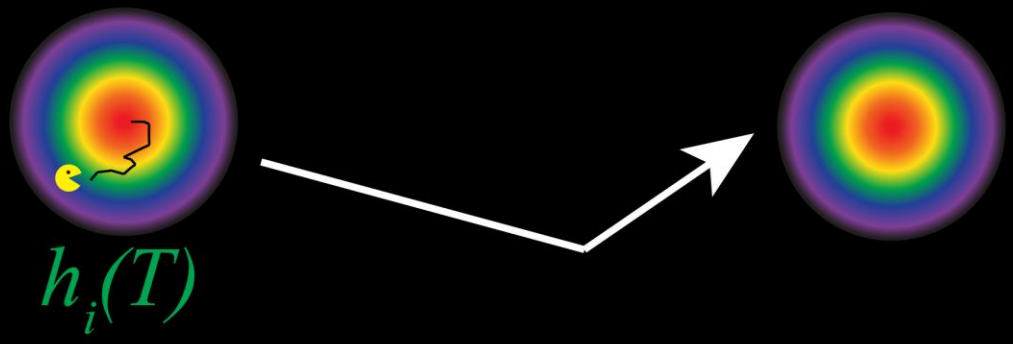

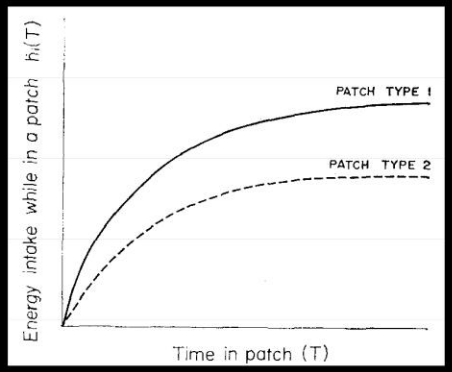

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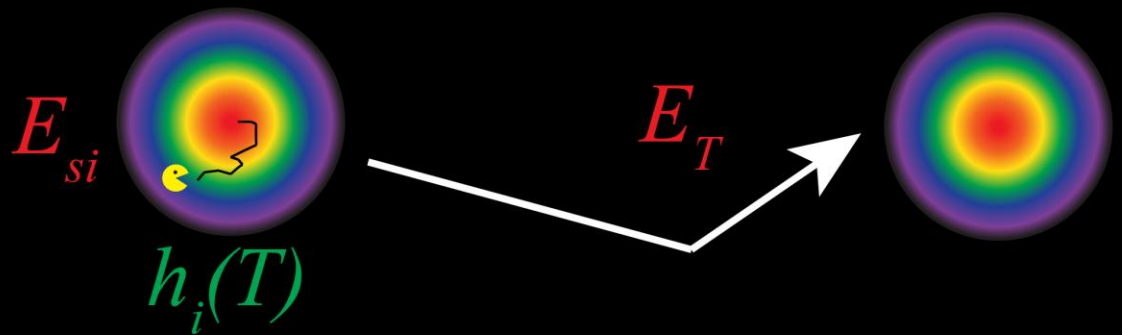

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E_T = energy cost per unit time in traveling between patches.

E_{si} = energy cost per unit time while searching in a patch of type i.

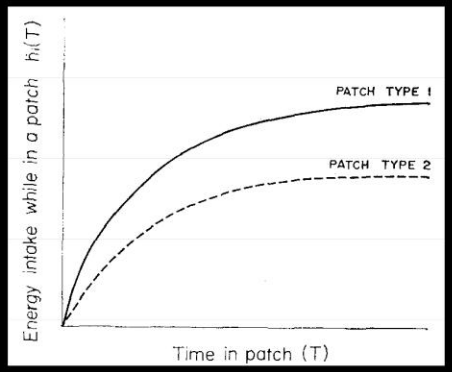
$h_i(T)$ = assimilated energy from hunting for T time units in a patch of type i minus all energy costs except the cost of searching.

$g_i(T) = h_i(T) - E_{si} \cdot T$ = assimilated energy corrected for the cost of searching.

$$T_u = t + \sum P_i \cdot T_i .$$

$$E_e = \sum P_i \cdot g_i(T_i).$$

$$En = \frac{E_e - t \cdot E_T}{T_u}.$$



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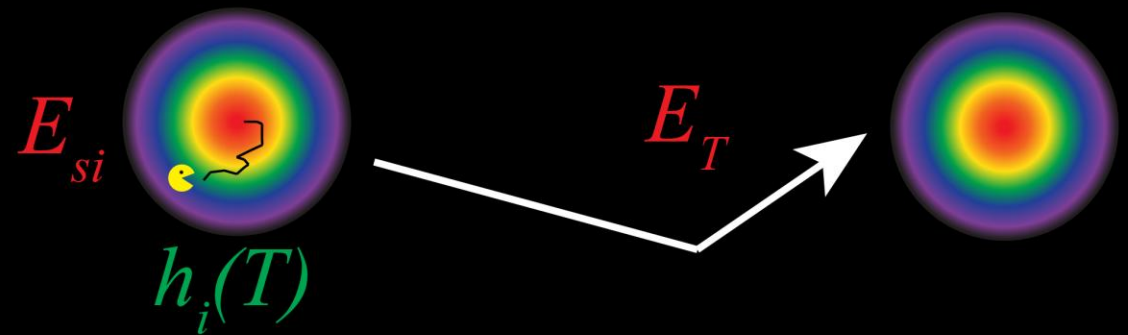

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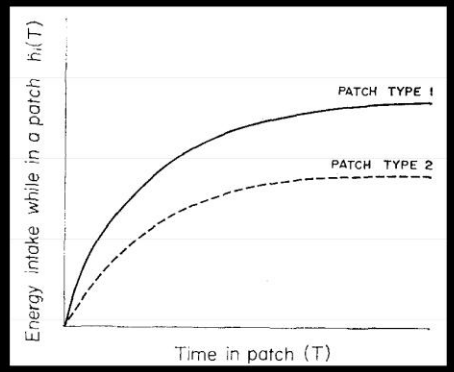

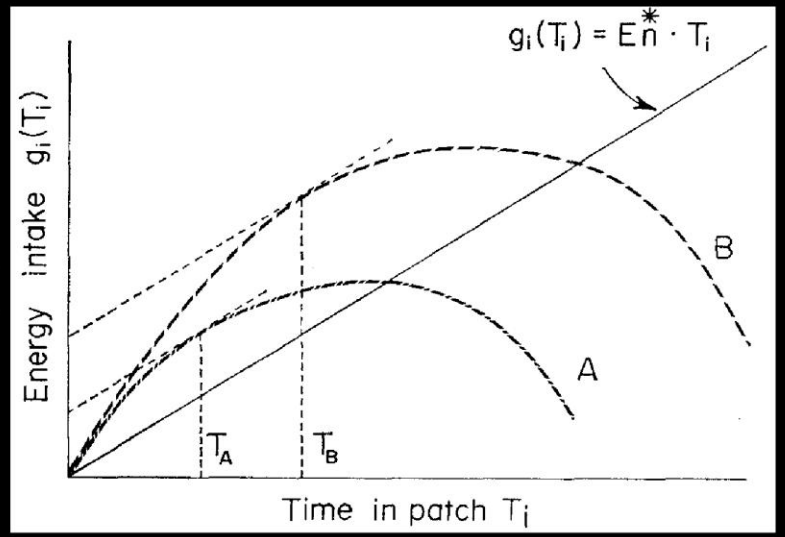

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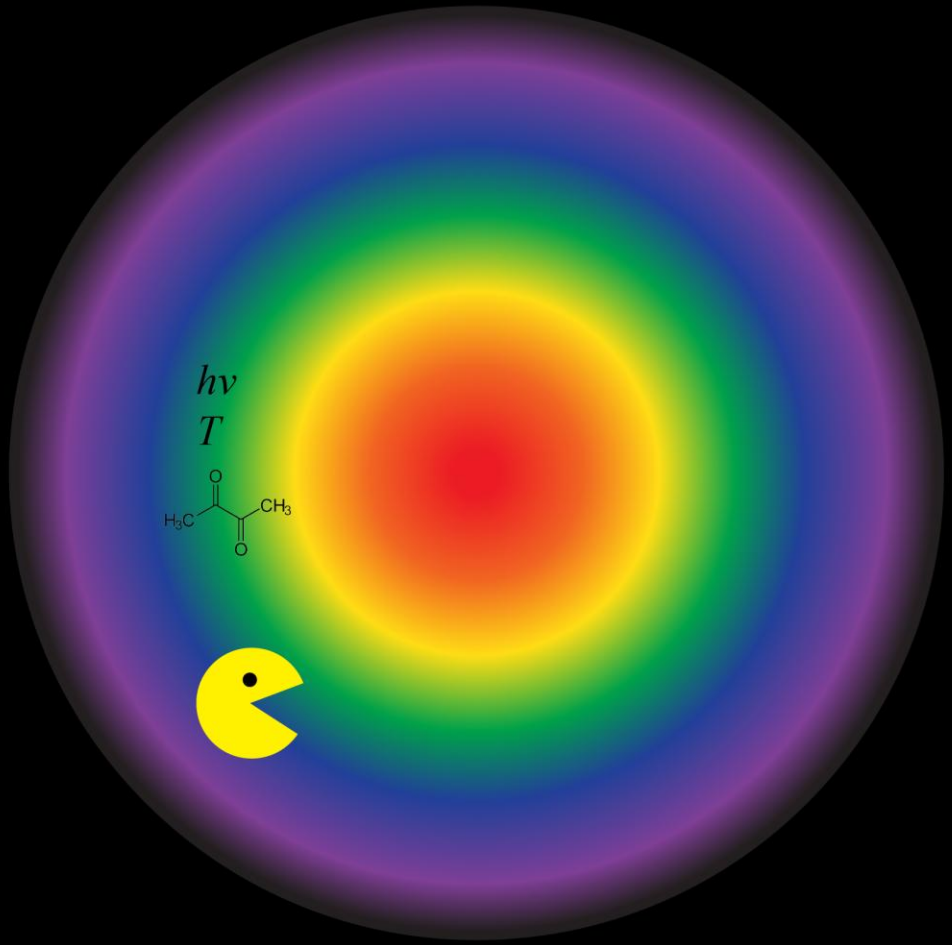

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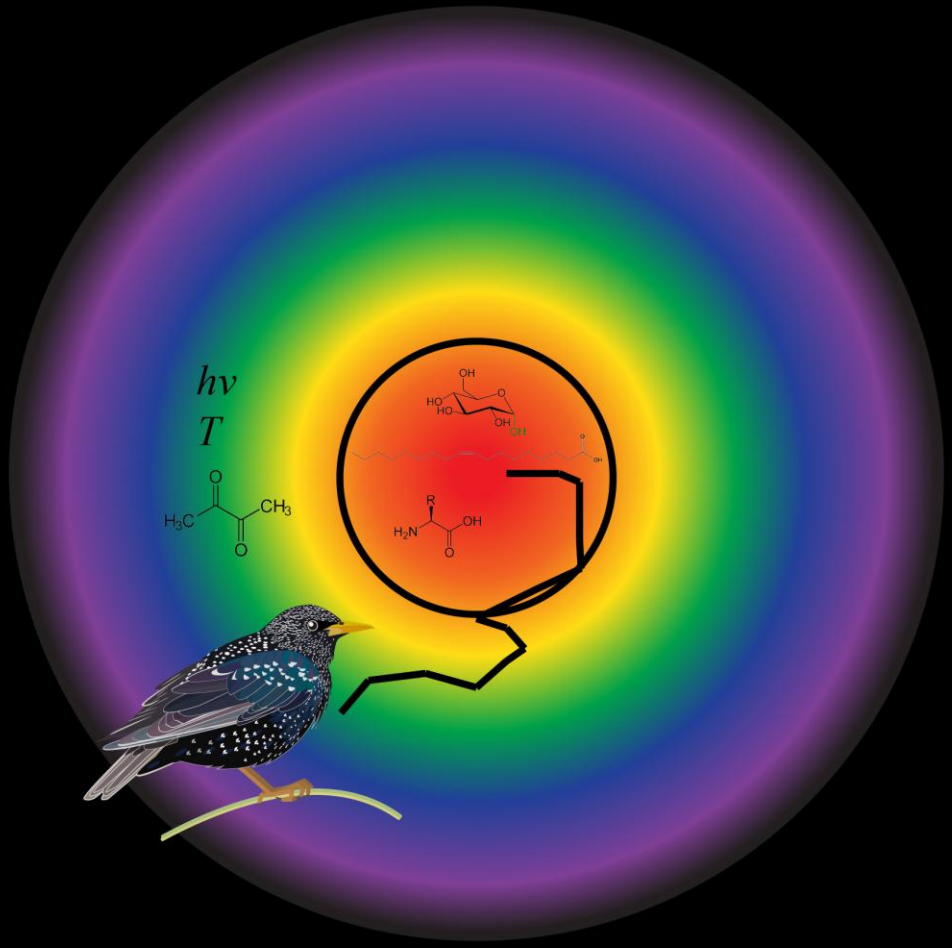

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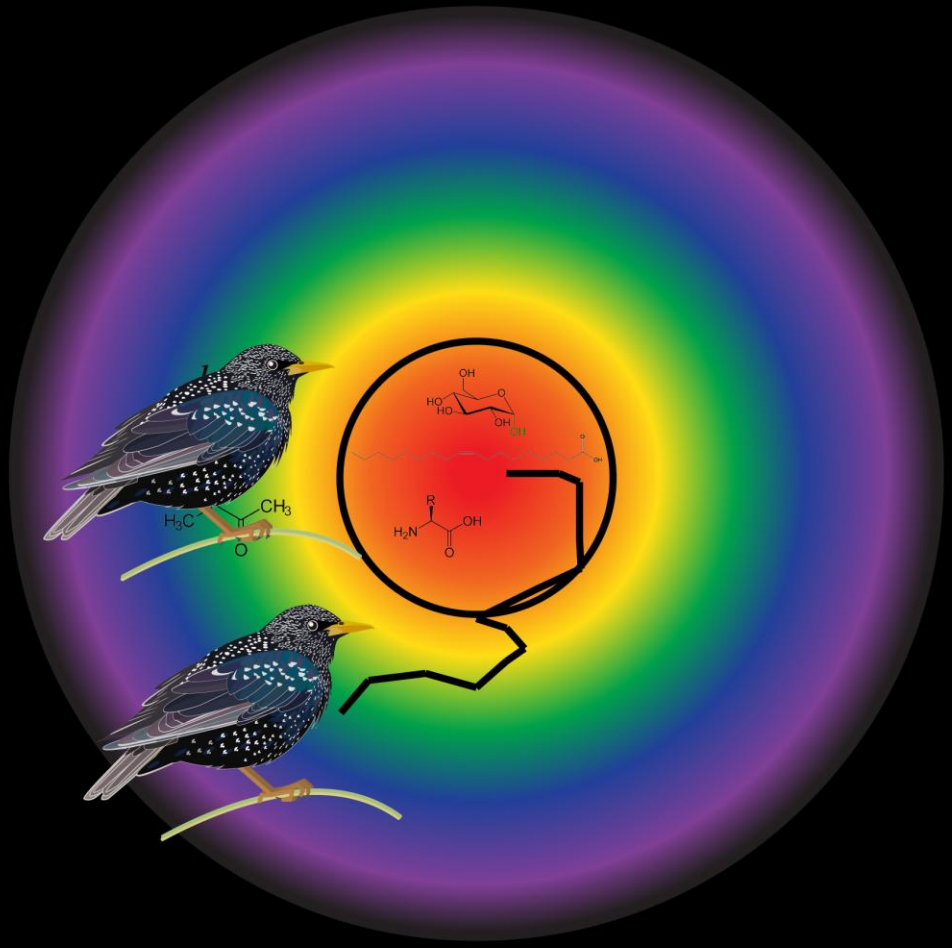

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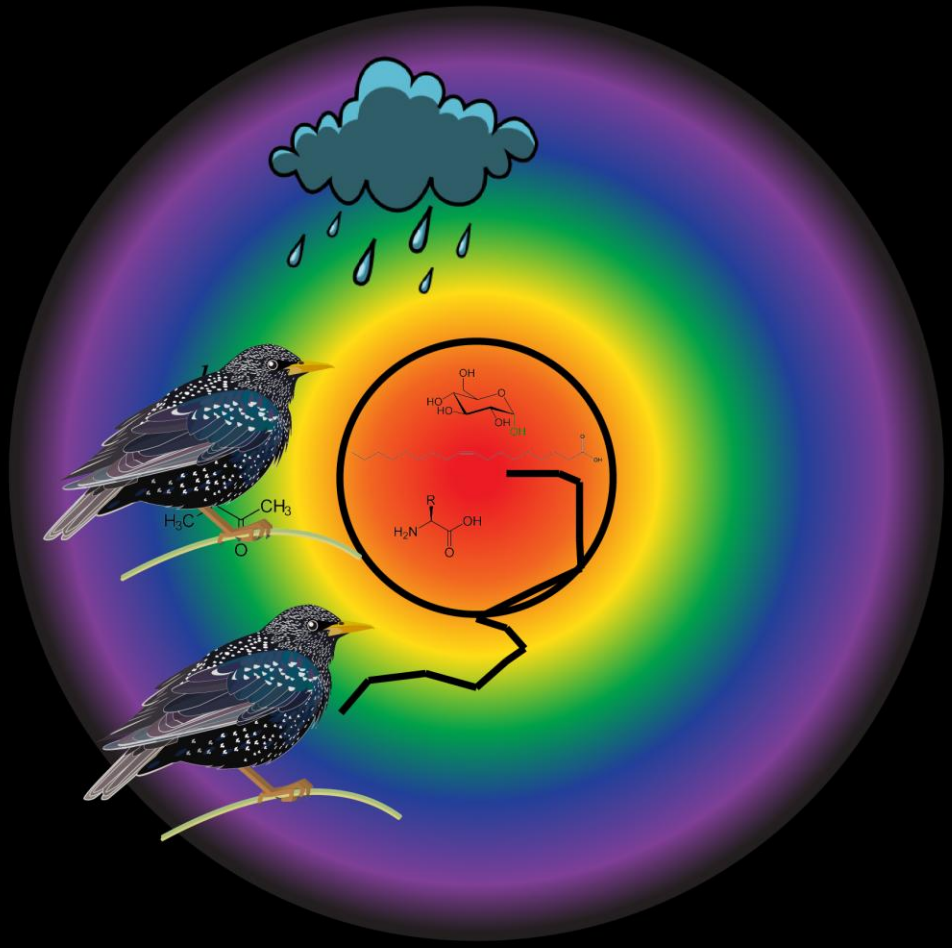

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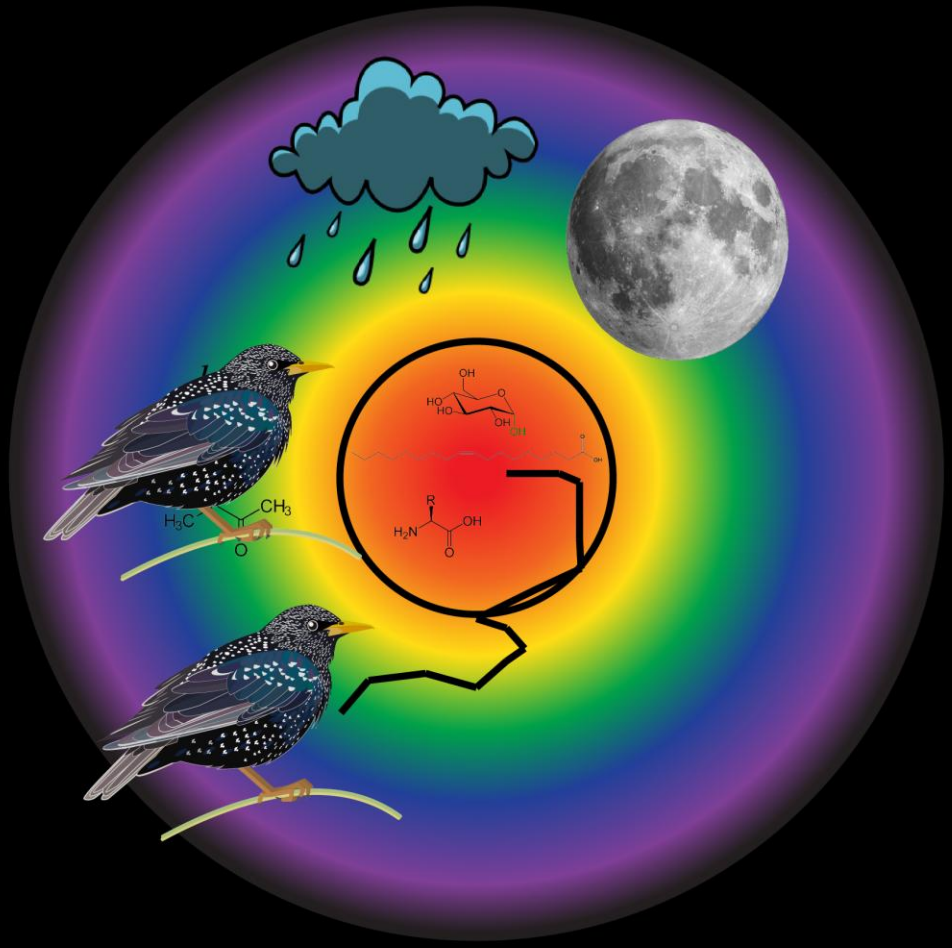

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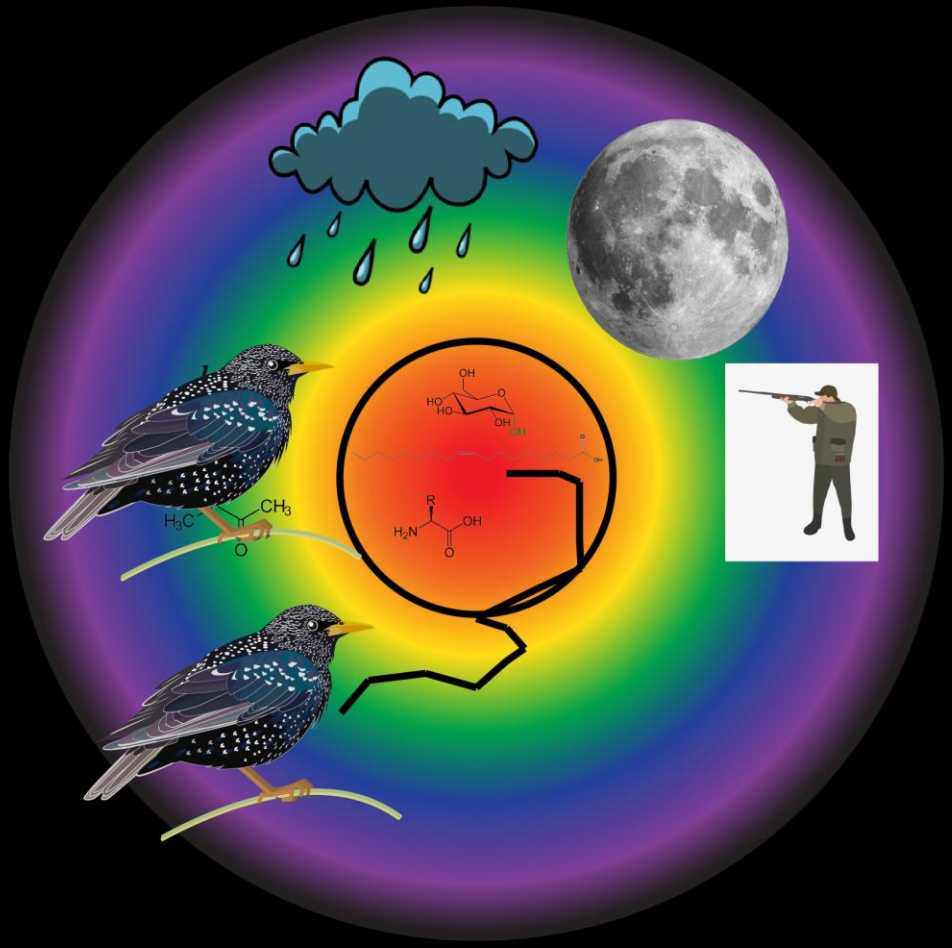

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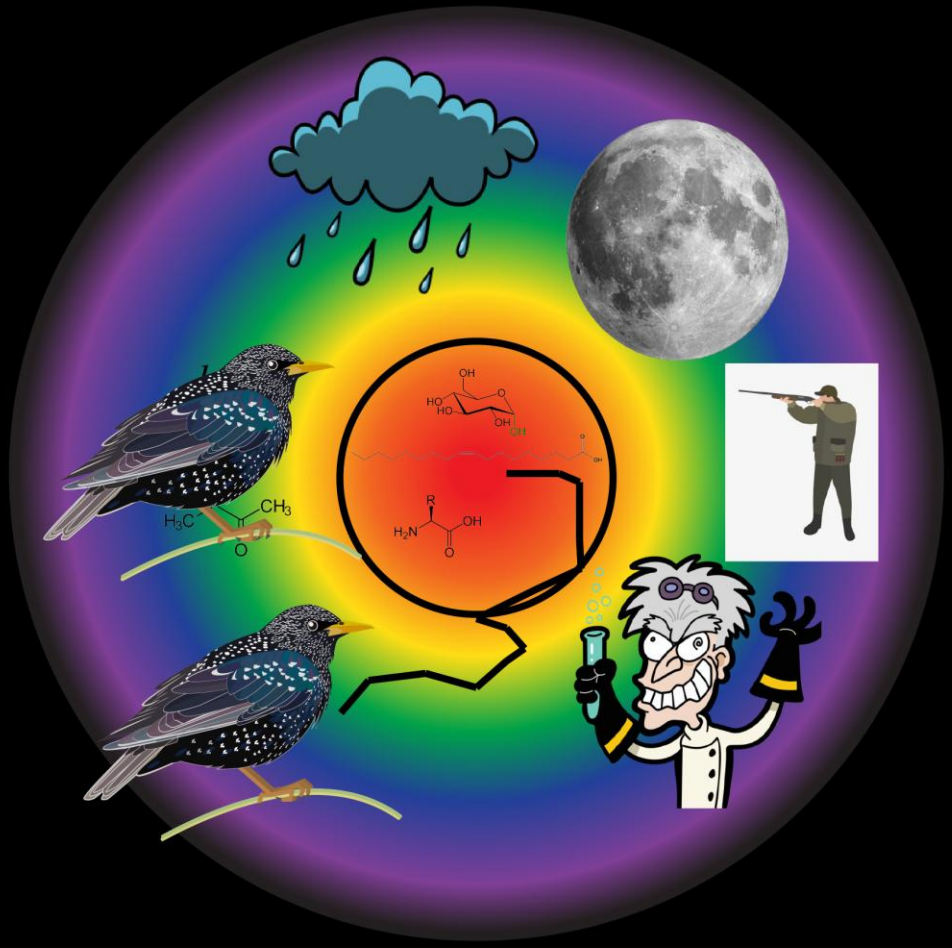

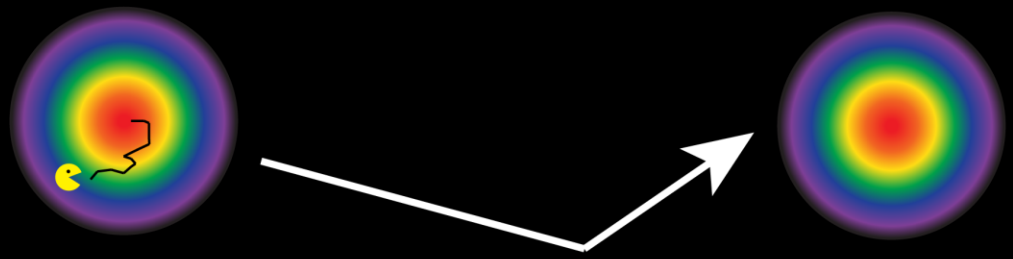

Foraging Strategies of *Drosophila melanogaster*: A Chromosomal Analysis

Marla B. Sokolowski[1]

Behavior Genetics, Vol. 10, No. 3, 1980

Natural Behavior Polymorphism Due to a cGMP-Dependent Protein Kinase of *Drosophila*

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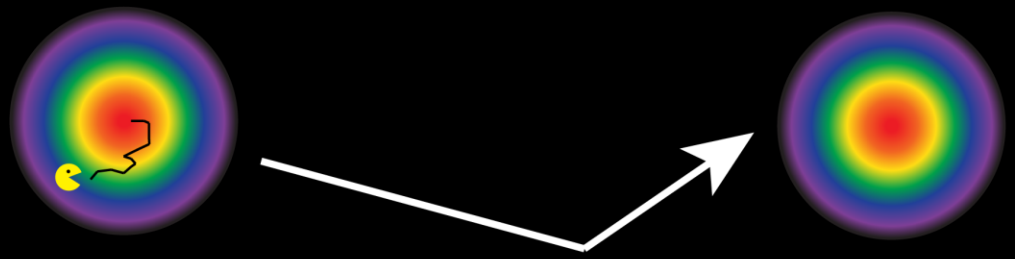
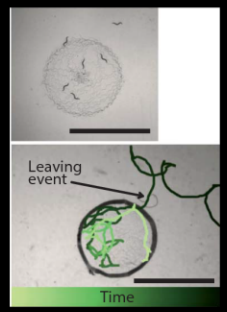
SCIENCE • VOL. 277 • 8 AUGUST 1997





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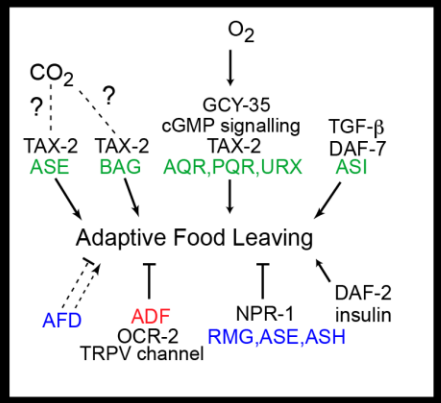
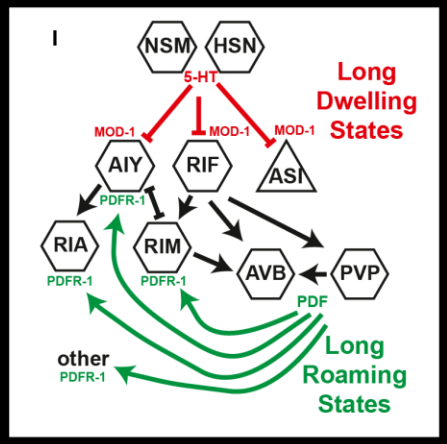
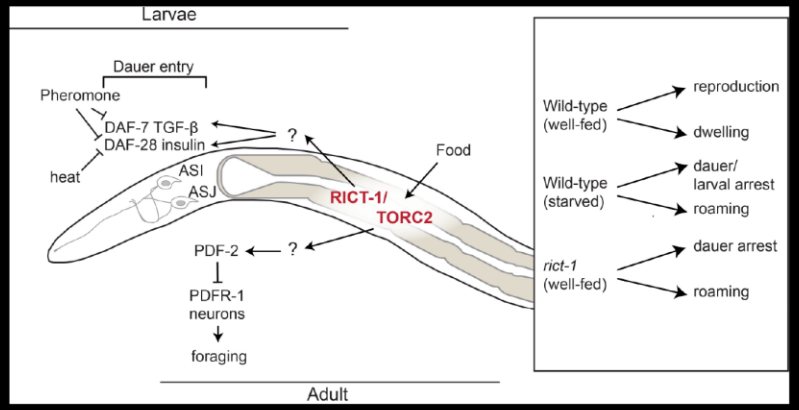


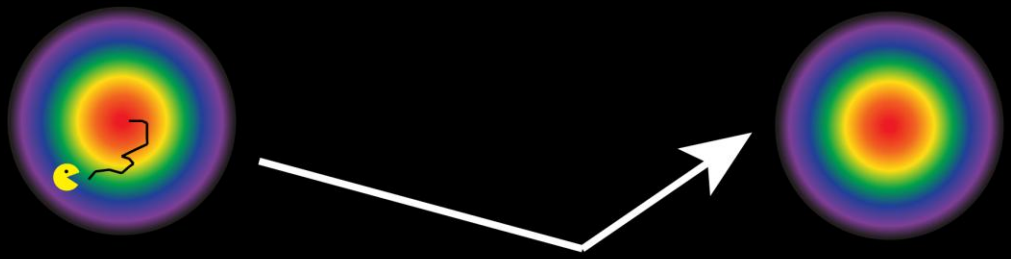
Milward et. al., PNAS, 2011

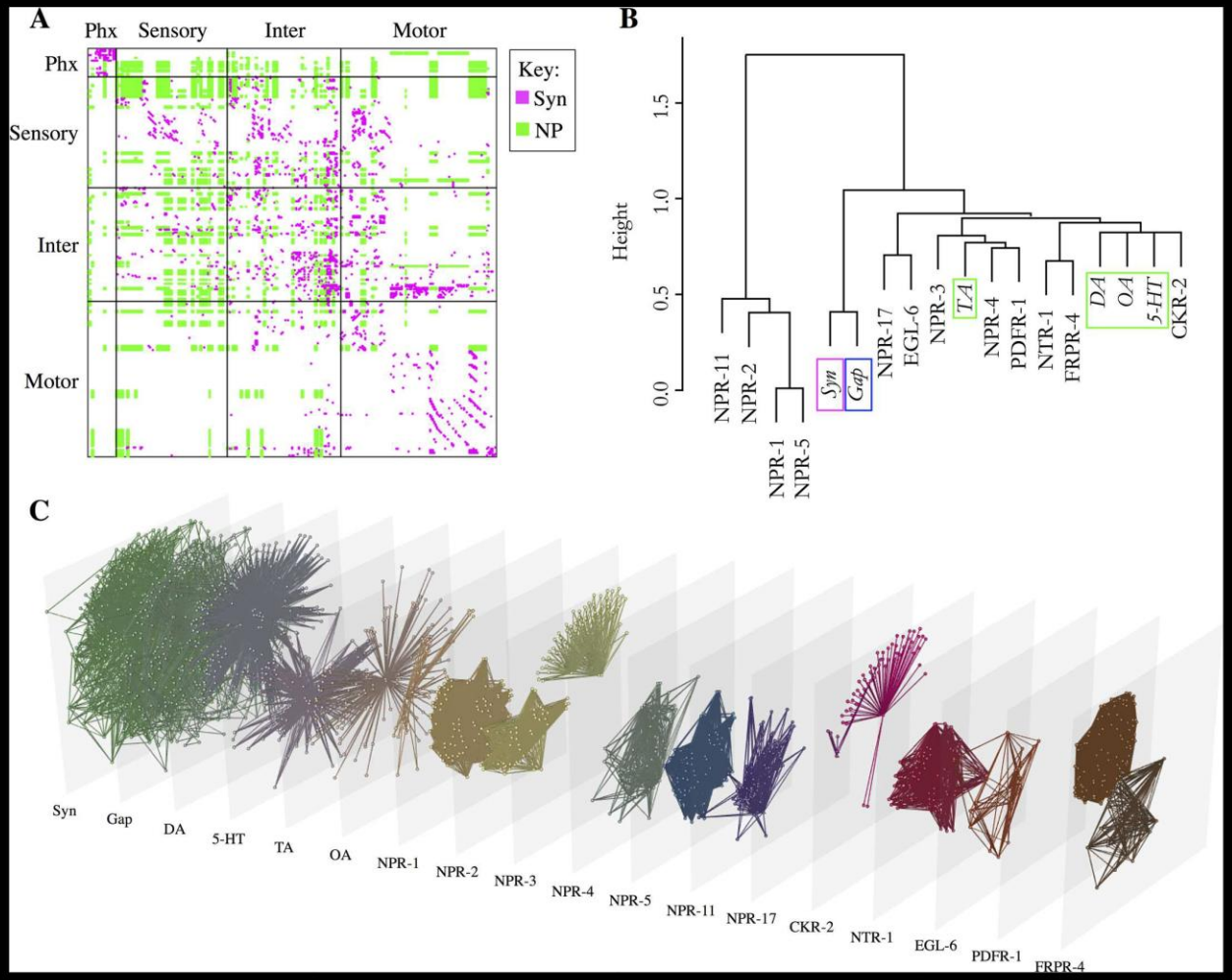


Flavell et. al., Cell, 2013



O'Donnell et. al., PLOS Gen., 2018





Bentley et. al., PLOS Comp. Bio., 2016

Questions

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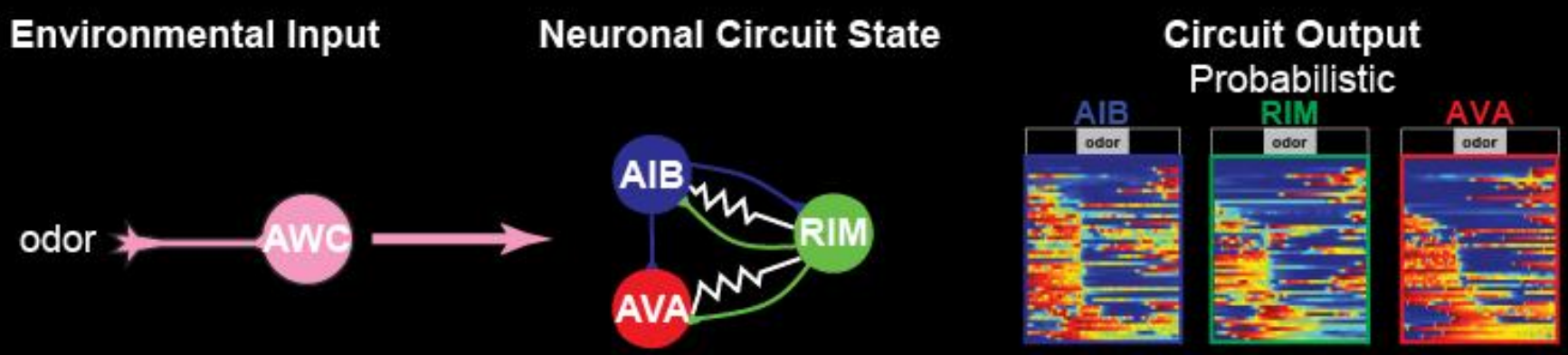
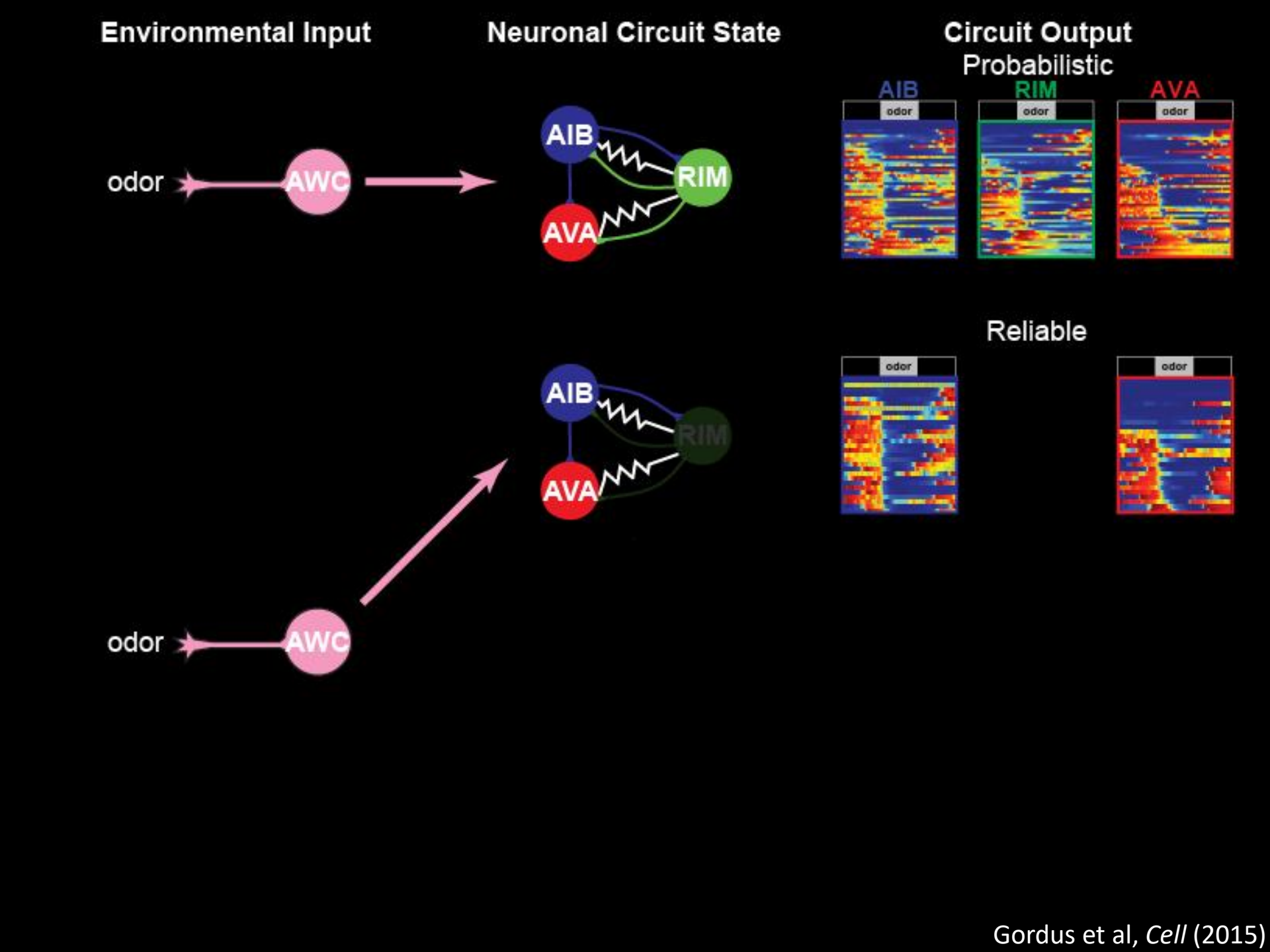


Gordus et al, *Cell* (2015)



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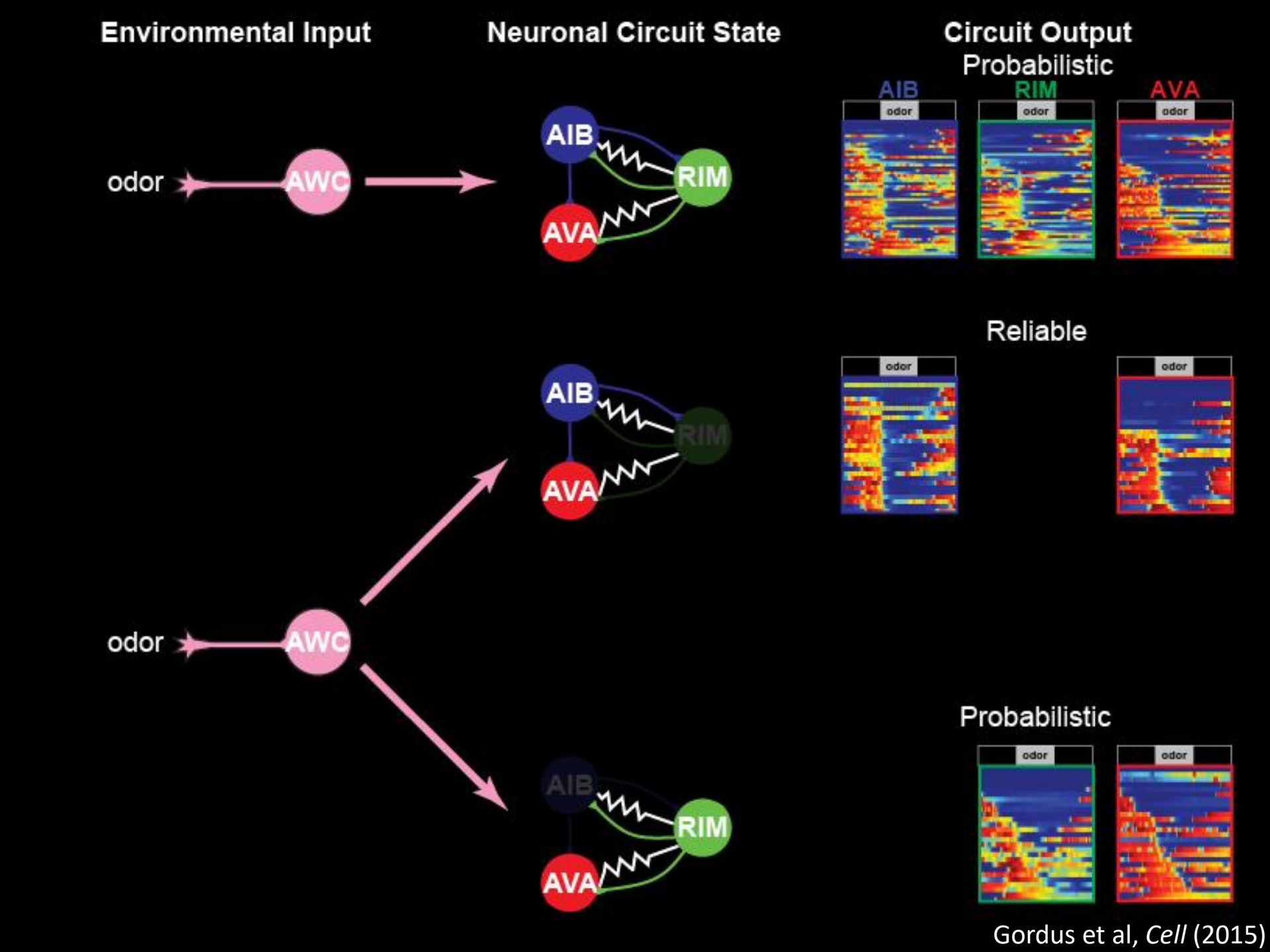

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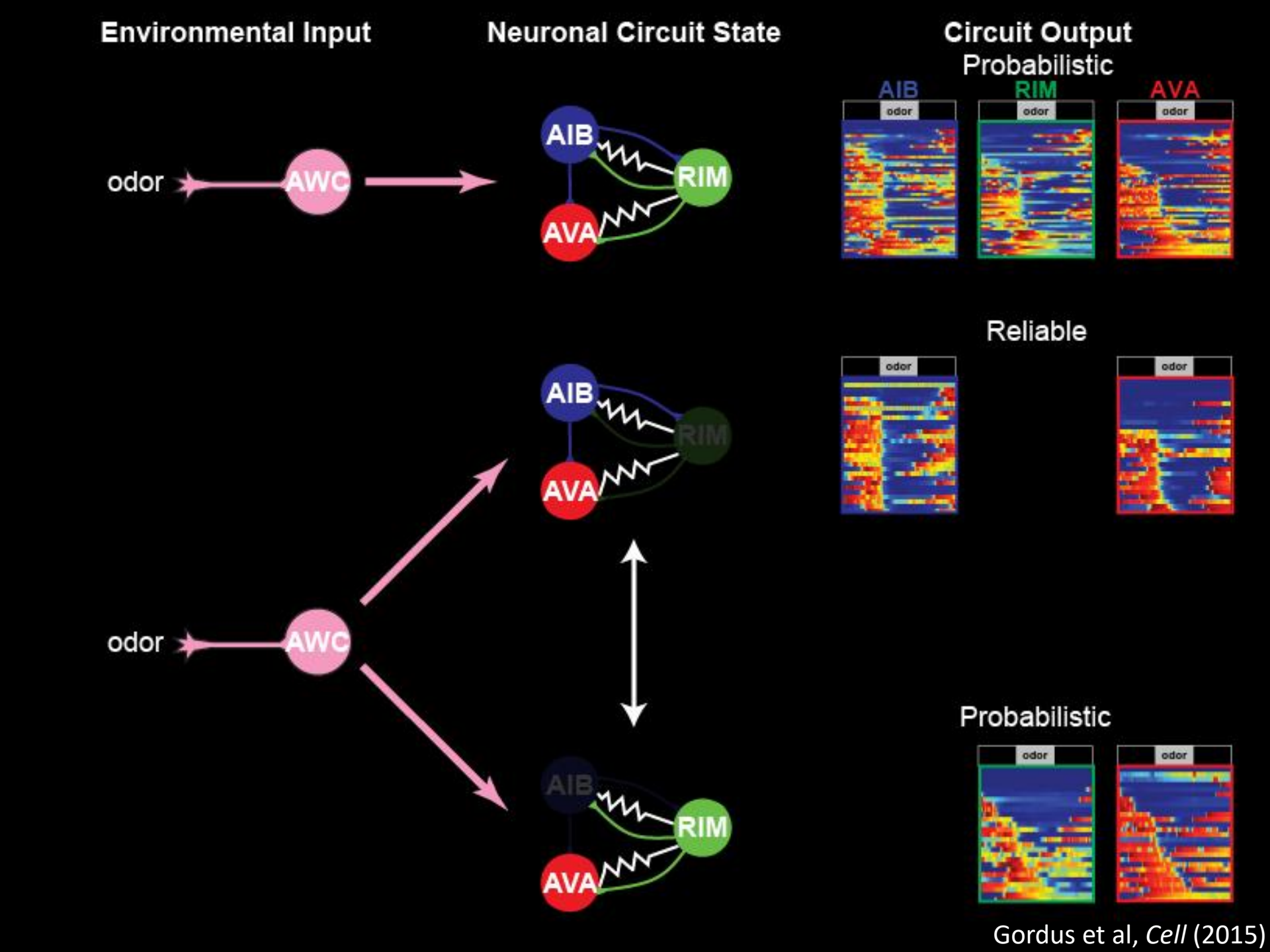

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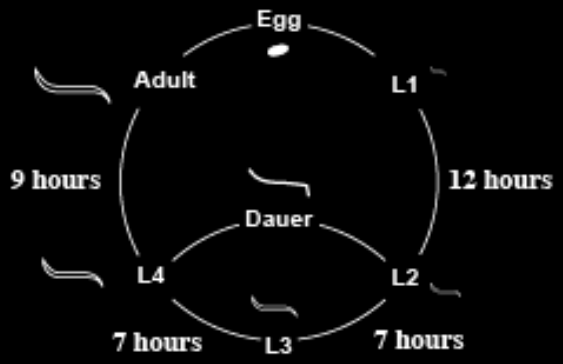
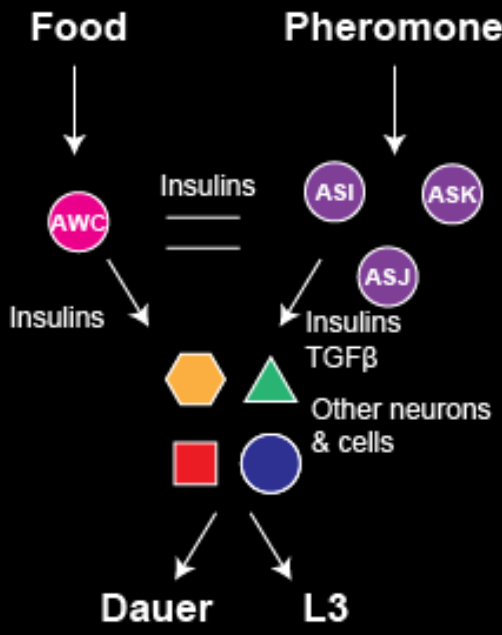
Confidence in Dauer Decision





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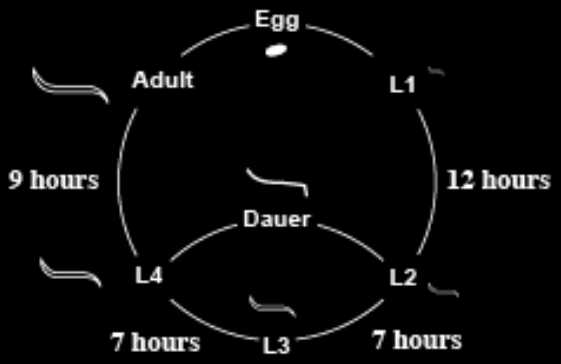
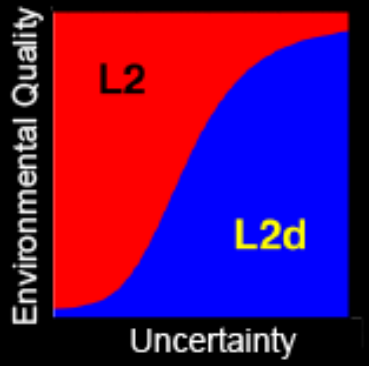
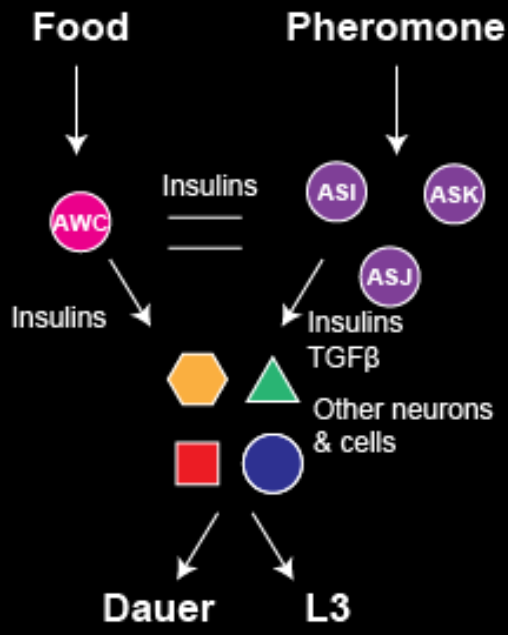




L. Avery, *PLOS One*, (2014)



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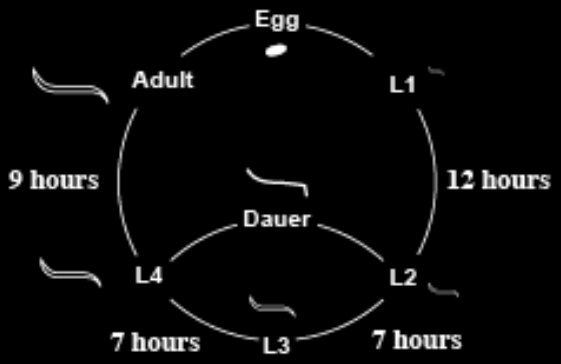

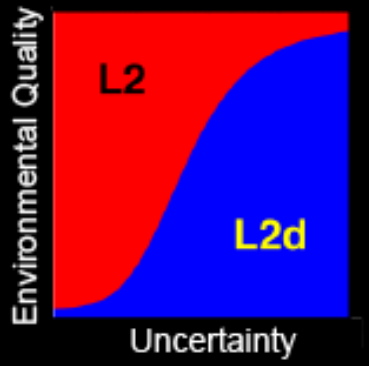

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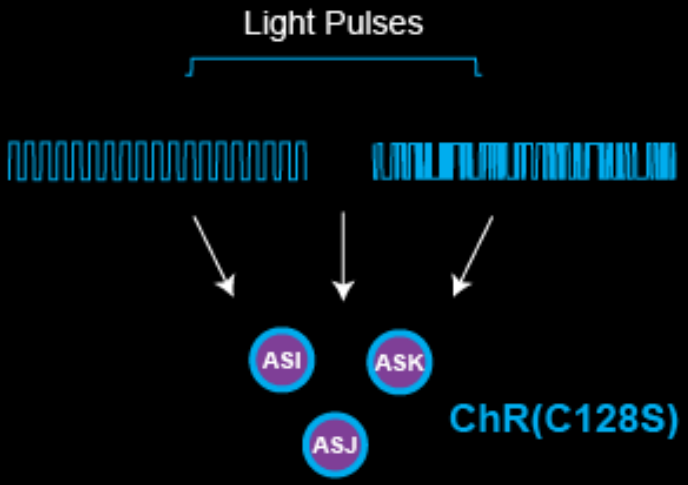

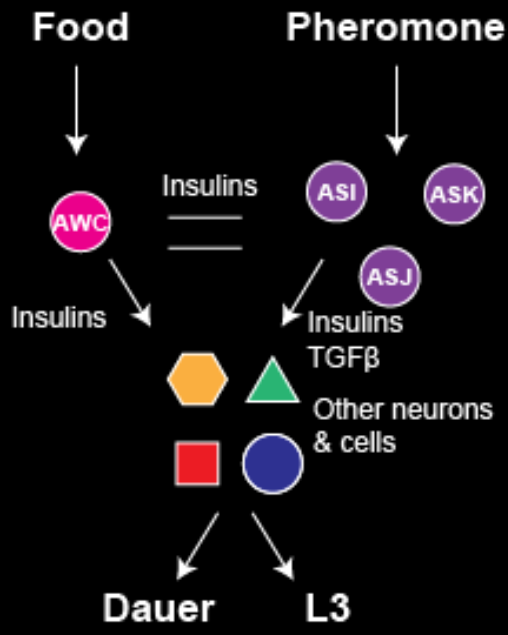

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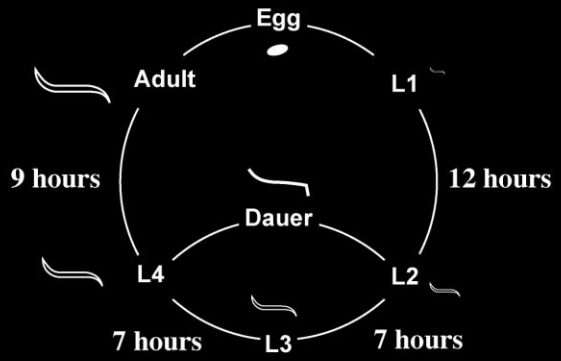

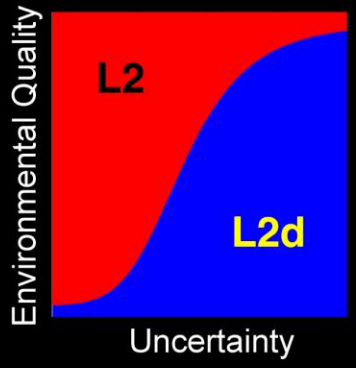

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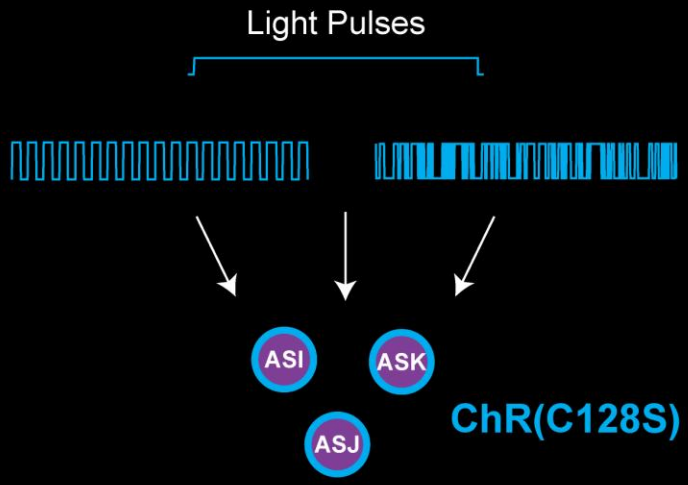
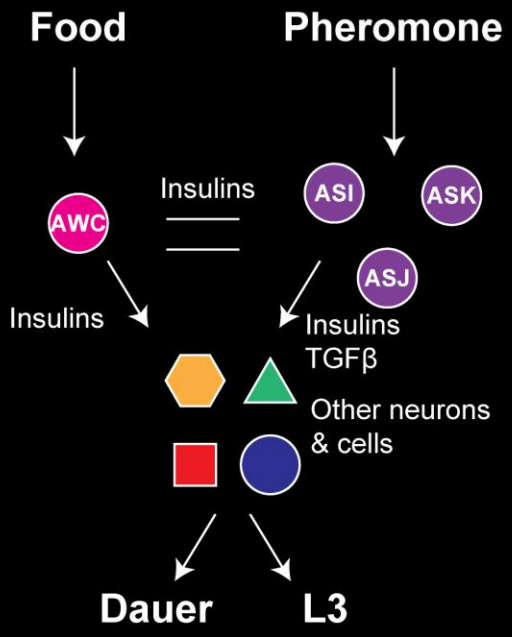
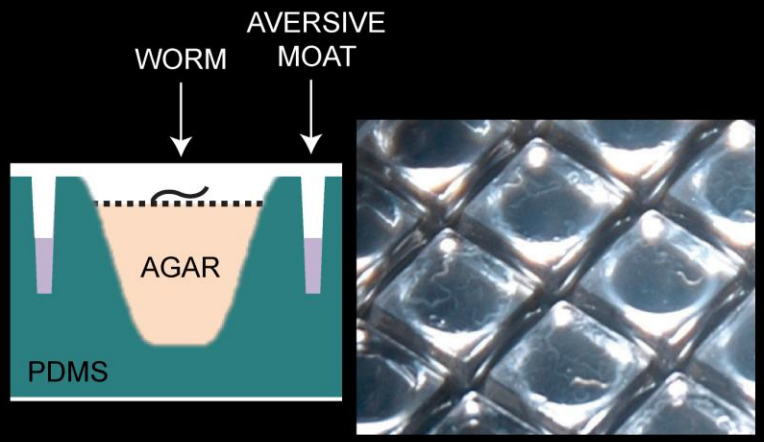
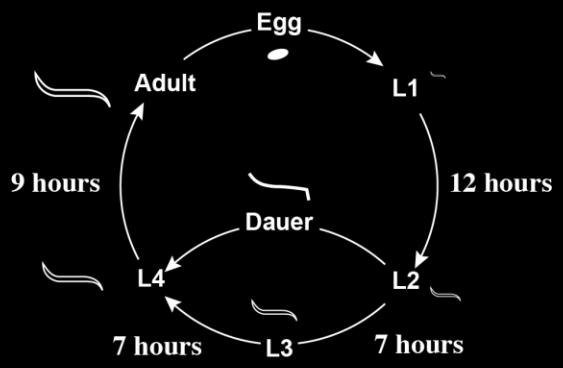


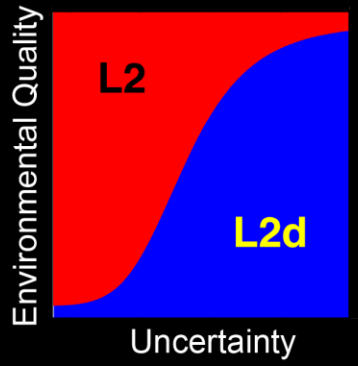


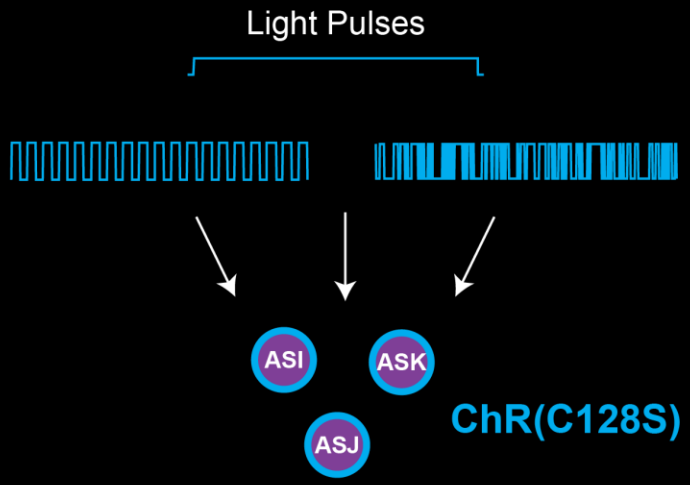


"WorMotel": Churgin *et. al. eLife* 2017;6:e26652

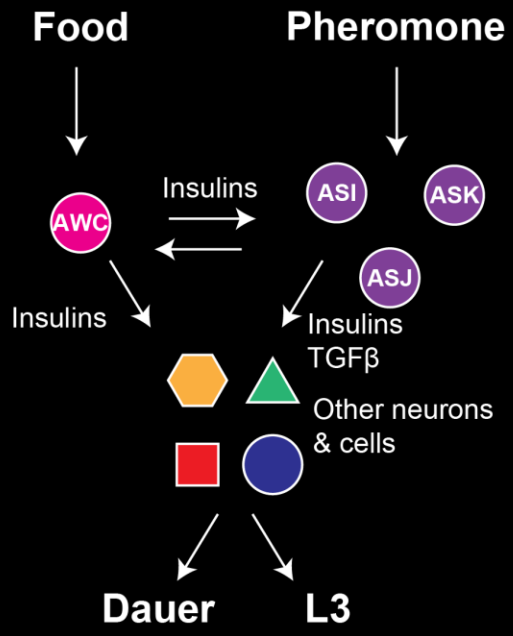
Confidence in Dauer Decision

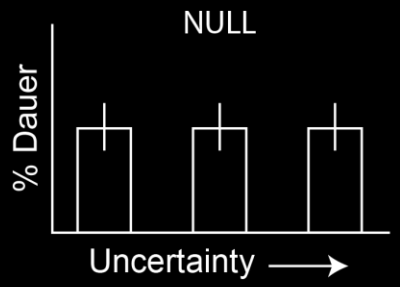


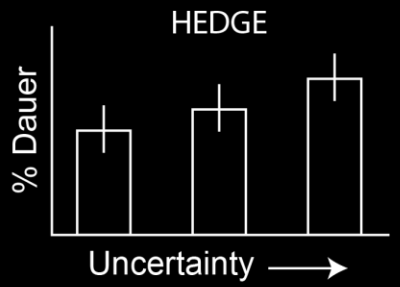




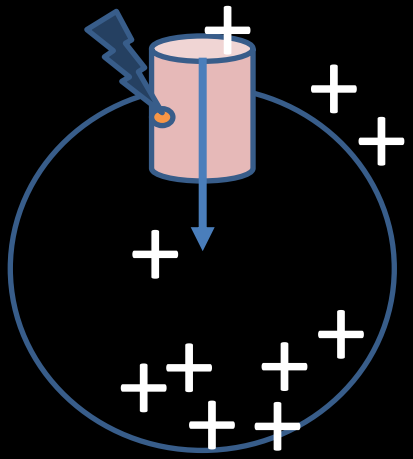
L. Avery, *PLOS One*, (2014)



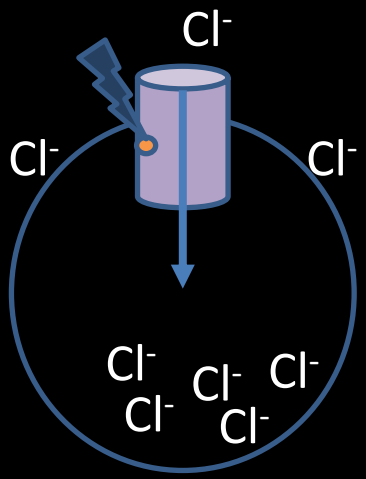




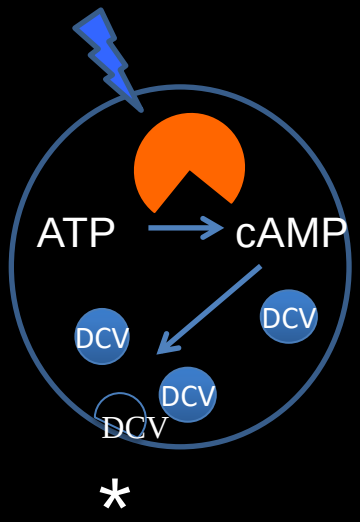
Optogenetics for different signaling modalities



Cation Channelrhodopsin

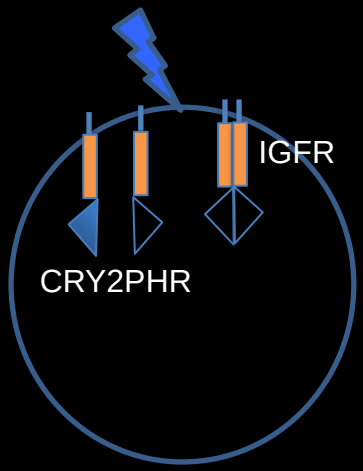


Anion Channelrhodopsin

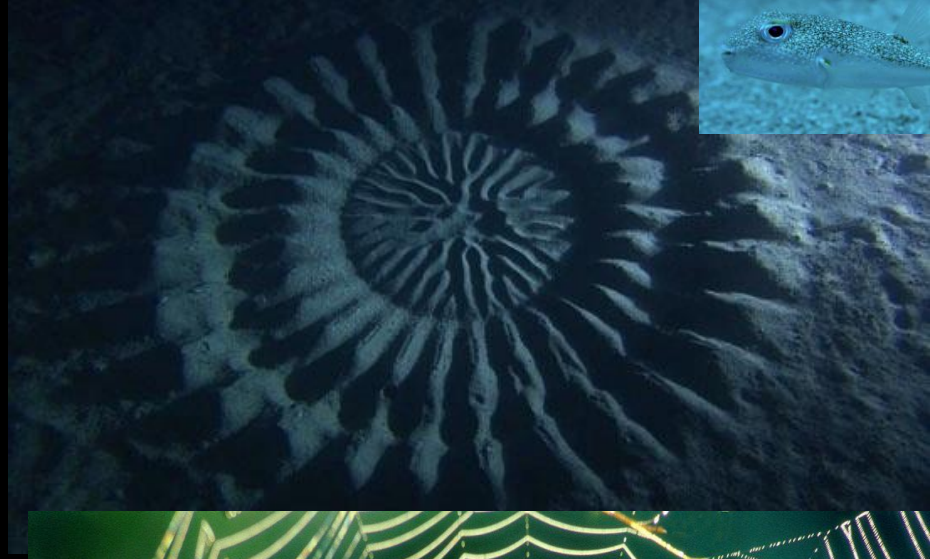


*

BlaC (Dense core vesicle release)



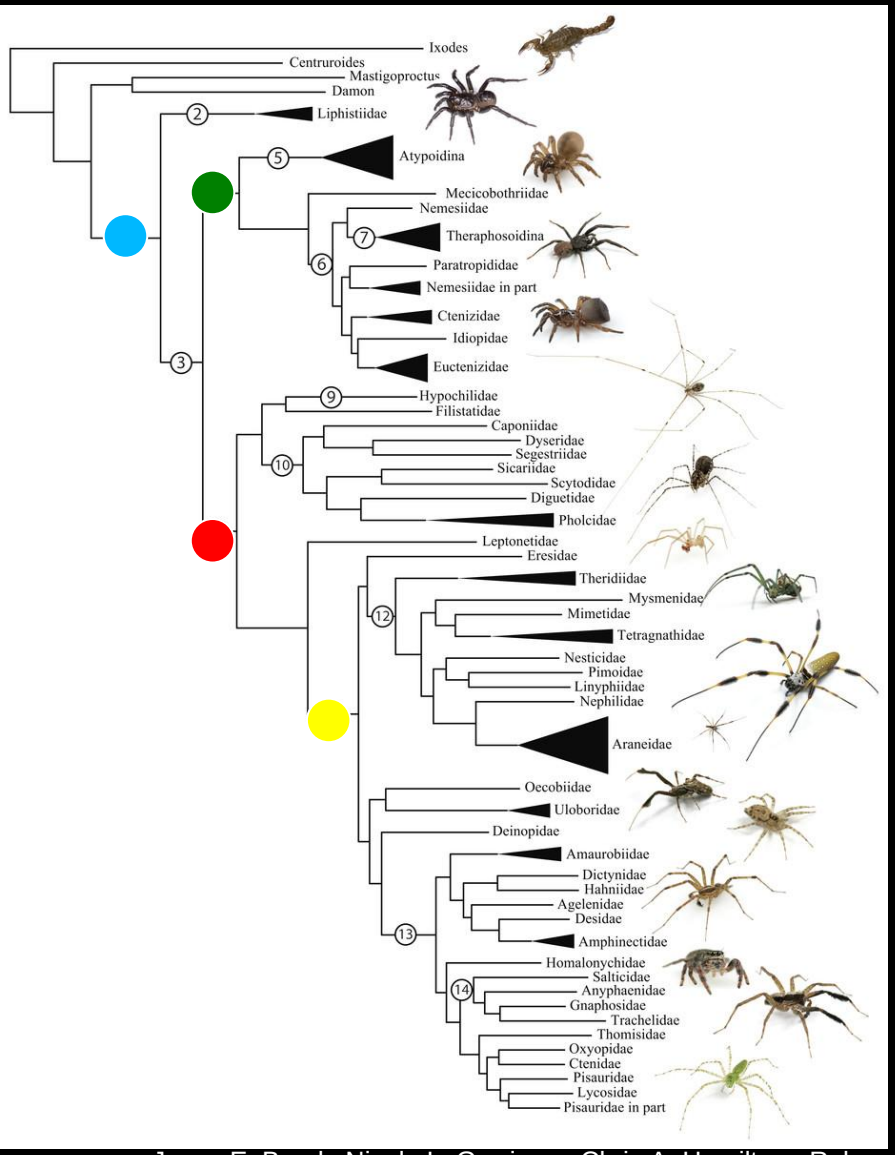
optoIGFR & optoTGFR (RTK activation)



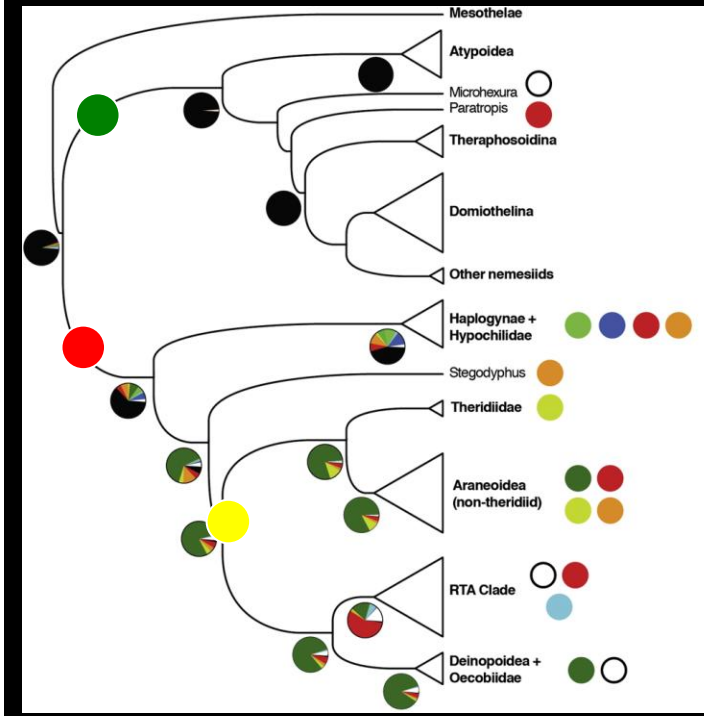
Web Architecture Reflects Behavioral Architecture

- Geometric Structure.
- Genetically Encoded Behavior.
- Requires path integration.
- Performs error correction during construction
- Behavior that is performed multiple times in the lifetime of the organism

Orb-Weaving Evolved Once



- Aranae
- Mygalamorphae
- Aranaeomorphae
- Orb-weaving



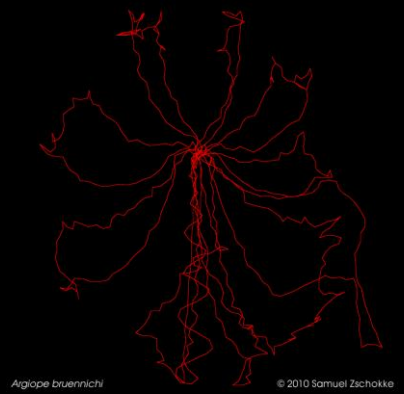
Jason E. Bond, Nicole L. Garrison, Chris A. Hamilton, Rebecca L. Godwin, Marshal Hedin, Ingi Agnarsson
Phylogenomics Resolves a Spider Backbone Phylogeny and Rejects a Prevailing Paradigm for Orb Web Evolution
Current Biology, Volume 24, Issue 15, 2014, 1765–1771

Common Behavioral Strategy

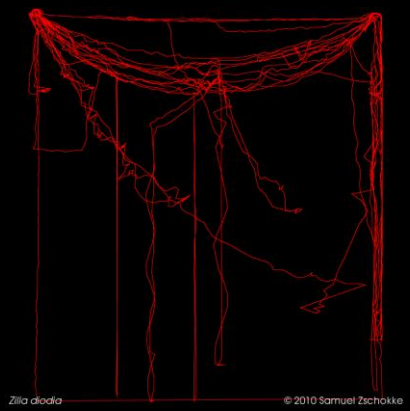
1. Proto-web (red)
2. Radii (yellow)
3. Auxiliary Spiral (white)
4. Sticky Spiral (blue)
5. Eat hub and wait

Cyclosa insulana

Araneus diadematus



Argiope bruennichi

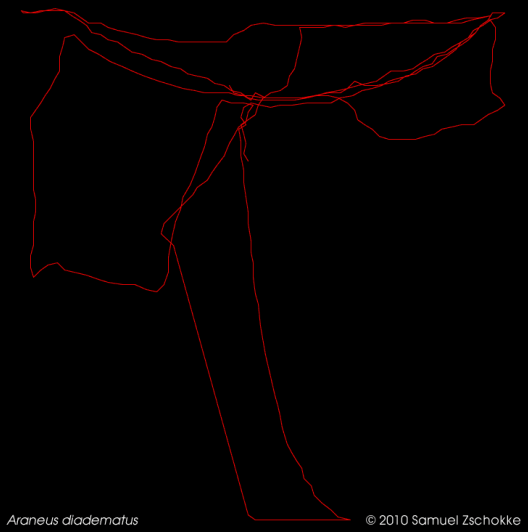


Zilla diodia

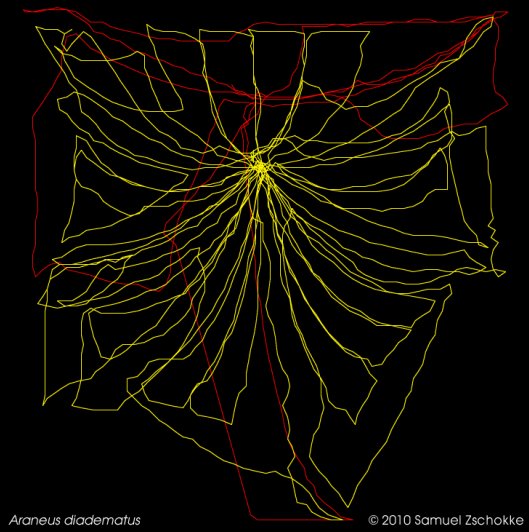
Samuel Zschokke
U. Basel, Switzerland

Common Behavioral Strategy

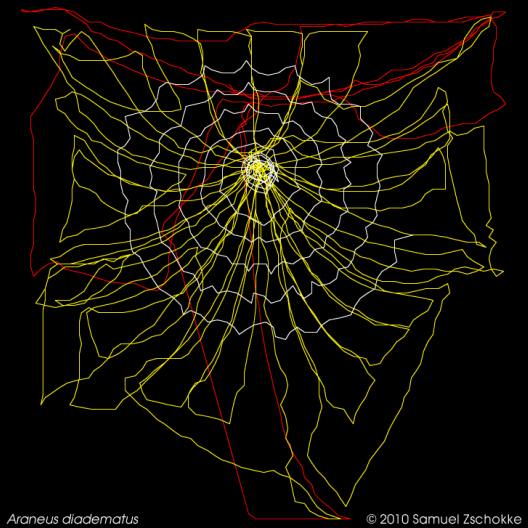
Proto-web (red)



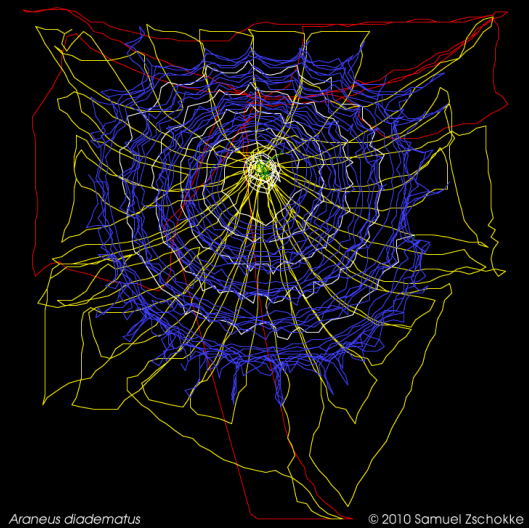
Radii (yellow)



Auxiliary web (white)

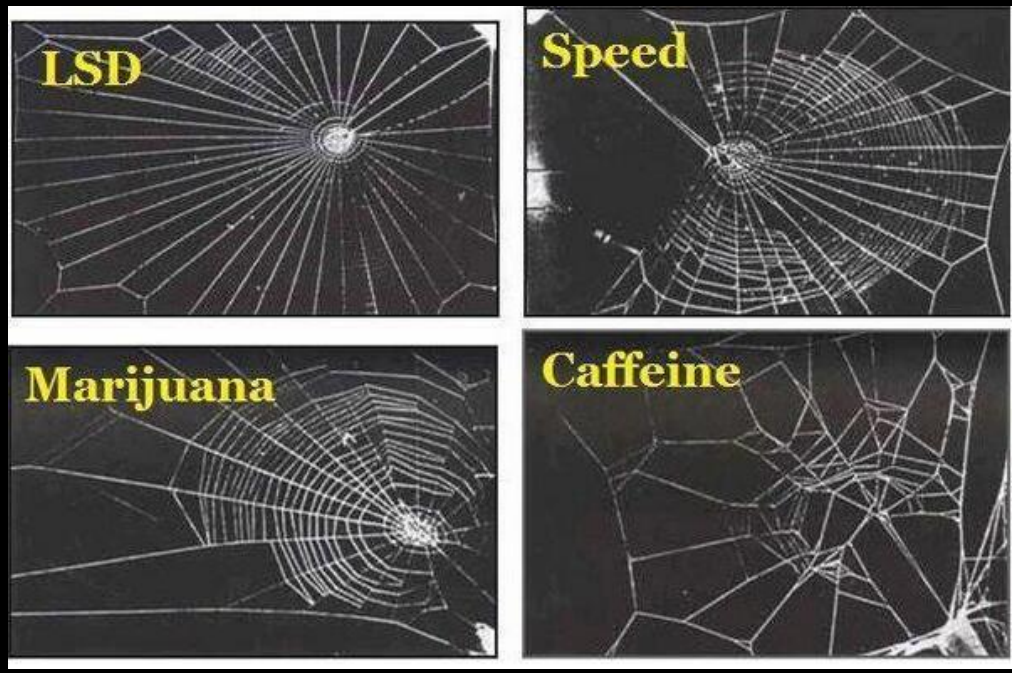


Sticky spiral (blue)

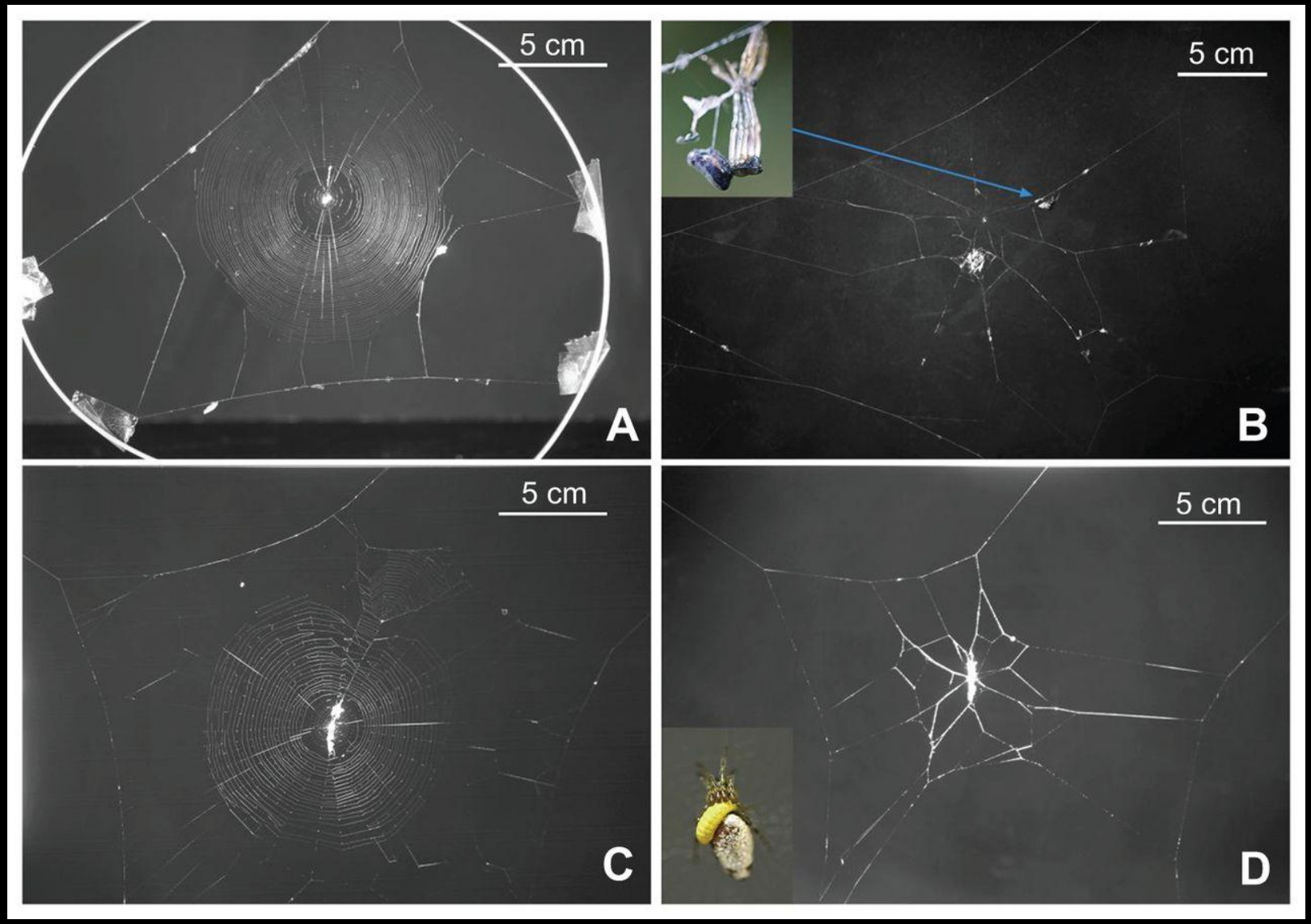


Pharmacological Perturbation

- Effect of drugs on web design investigated. (P.N. Witt, 1949)

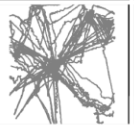
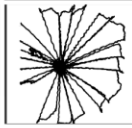
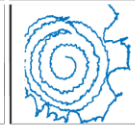
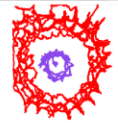


Pharmacological Perturbation (Neuromodulatory)



Keizo Takasuka et al. J Exp Biol 2015;218:2326-2332

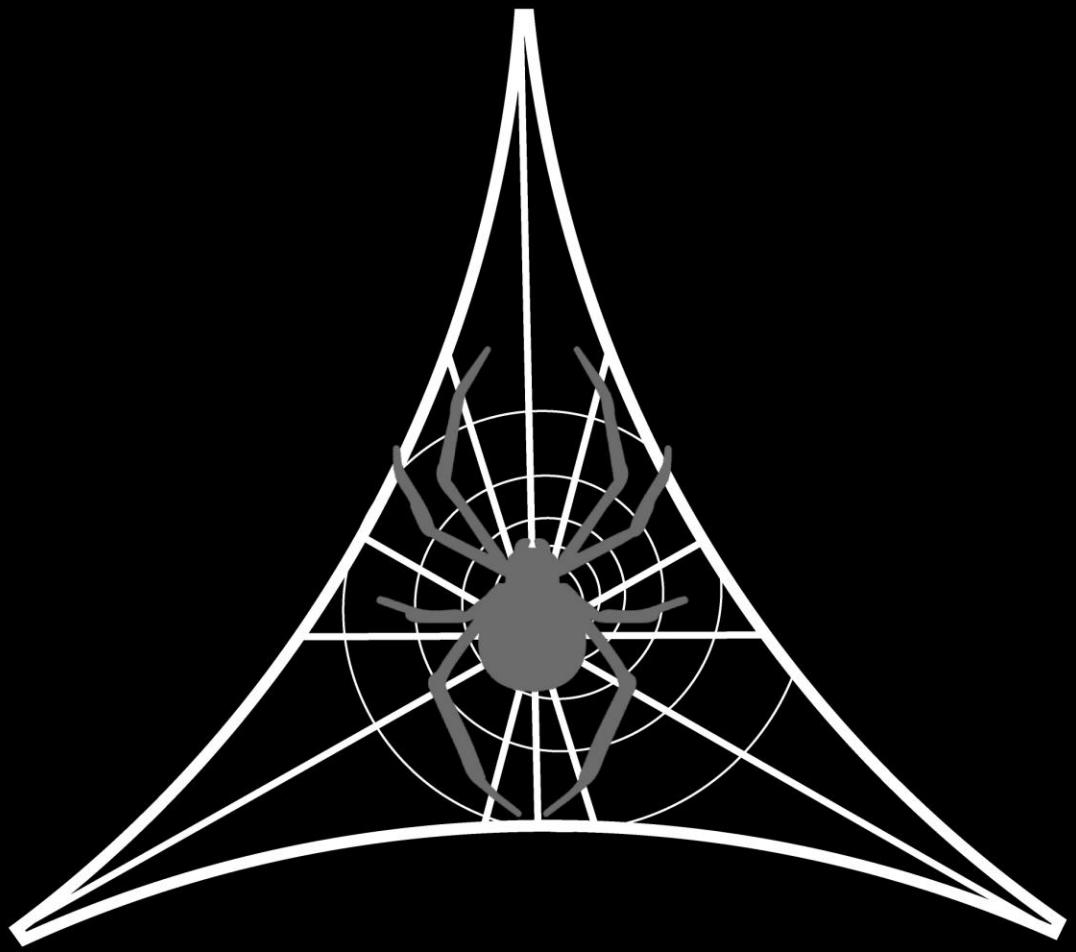
Chemical Perturbation

Reagent	Target	Ref.	Web Feature Affected: Proto	Radii	Auxillary*	Sticky
						
Chloropromazine	Antagonist Dopamine Receptors	[6]				
Diazepam	Agonist GABA Receptors	[6]				
Pentobarbital	Agonist GABA Receptors	[6]				
Phenobarbital	Agonist GABA Receptors	[6]				
Physostigmine	Inhibitor Acetylcholinesterase	[6]				
Scopolamine	Antagonist mAChR	[6,7]				
Polysphincta janzeni venom	Ecdysone Receptor ŧ	[5]				
Caffeine	Antagonist Adenosine Receptors	[7]				
LSD-25	Agonist 5-HT Receptors	[6]				
Psilocybin	Agonist 5-HT Receptors	[6]				
Dexedrine	Agonist trace amine receptors	[6]				
Methamphetamine	Agonist trace amine receptors	[6,7]				

*The effect on the auxillary spiral was inferred in Ref. 6, but directly observed in Ref. 7

ŧ The target of *P. janzeni* venom is purely speculative at this moment.

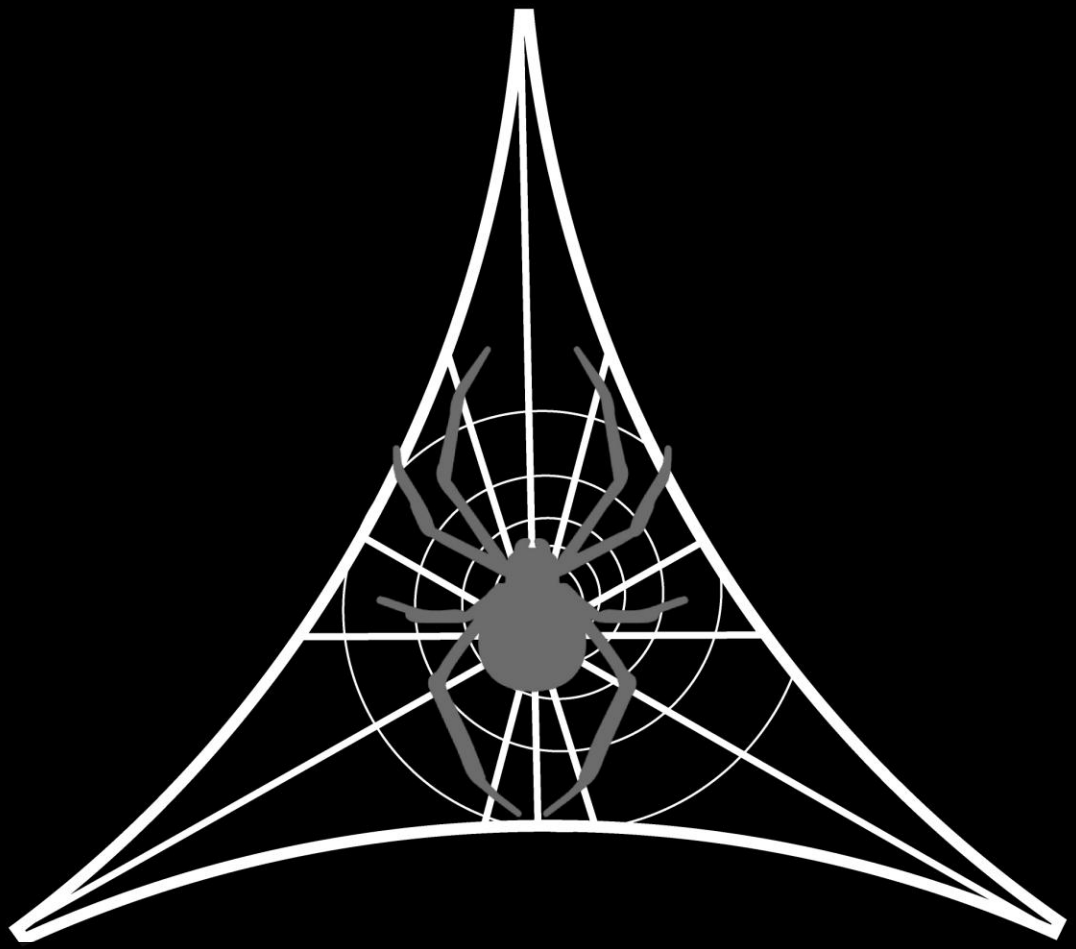
BEHAVIOR



GENETICS

NEURONS

BEHAVIOR



GENETICS

NEURONS

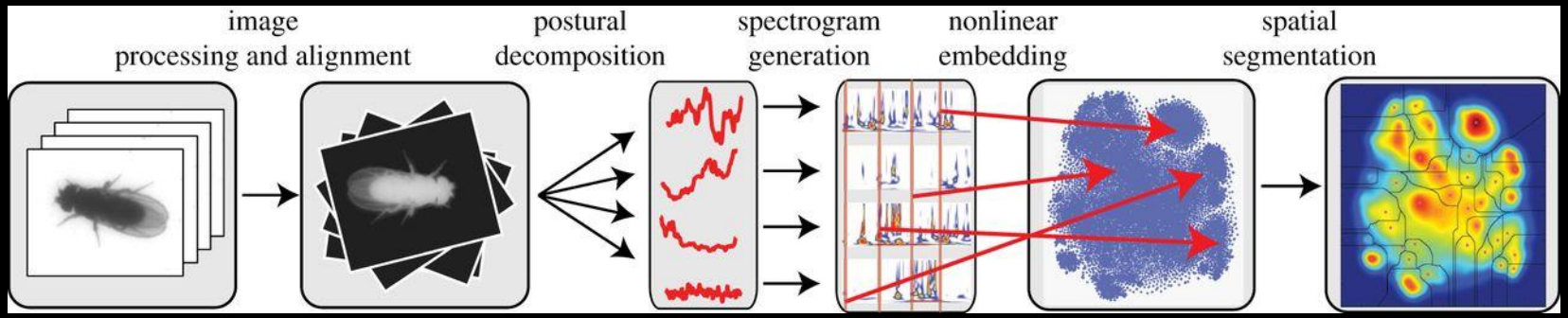
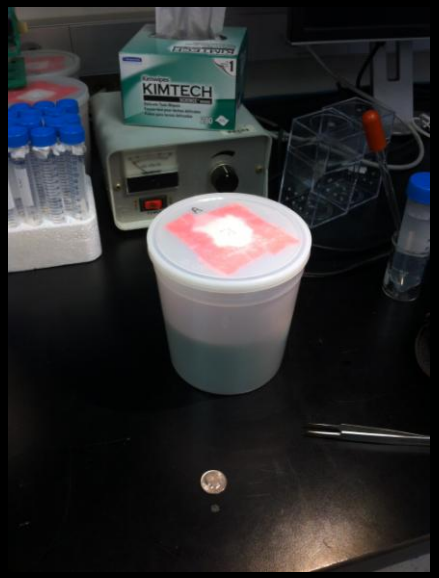
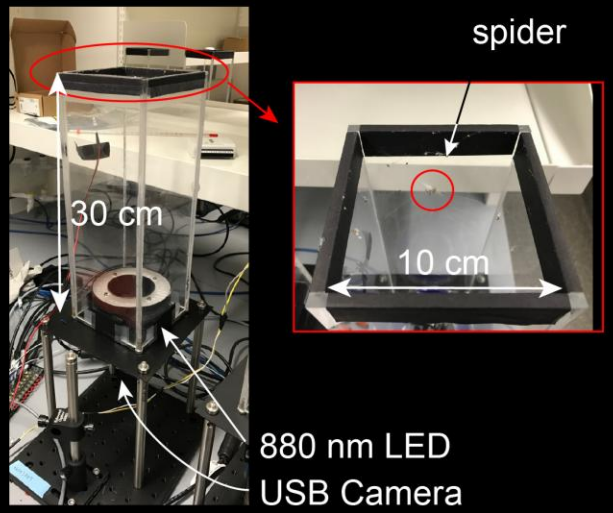


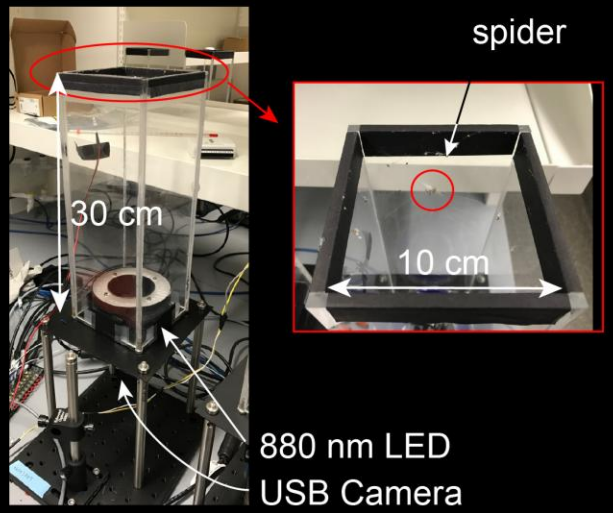
image
processing and alignment
postural
decomposition
spectrogram
generation
nonlinear
embedding
spatial
segmentation

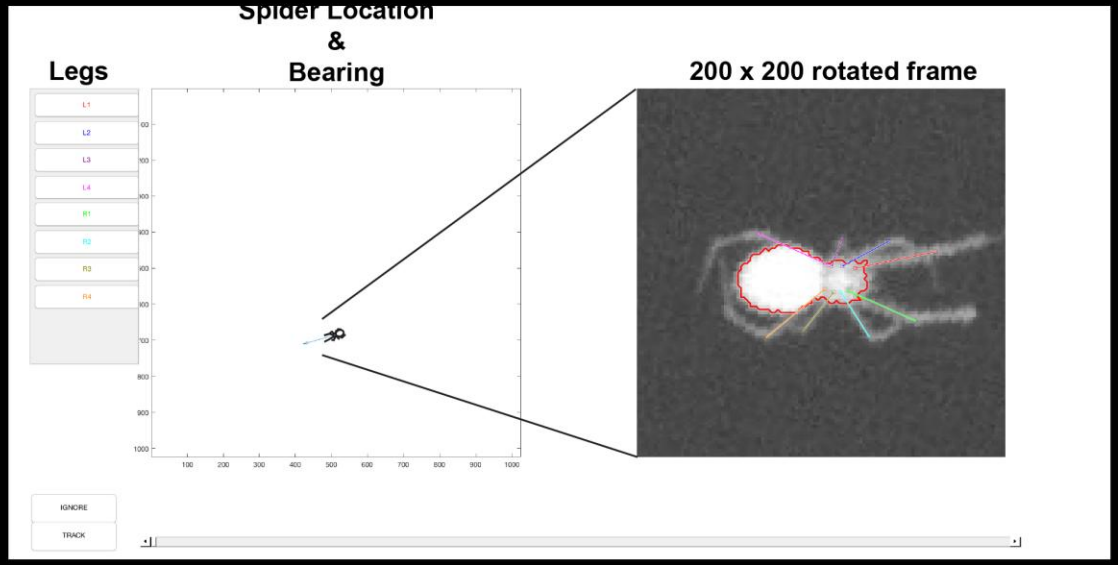
Uloborus diversus

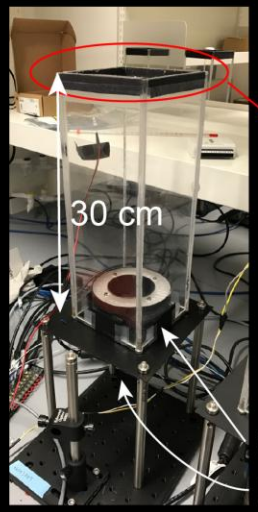
- Small (4-5 mm).
- Short generation time (~1 month).
- Prefers arid, temperate environments.
- Readily builds webs in laboratory conditions.
- Lacks venom glands
  - Neural ganglia are accessible.

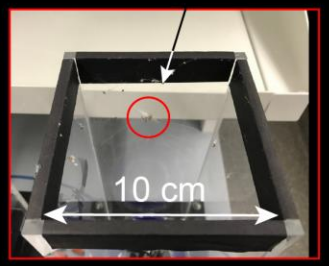


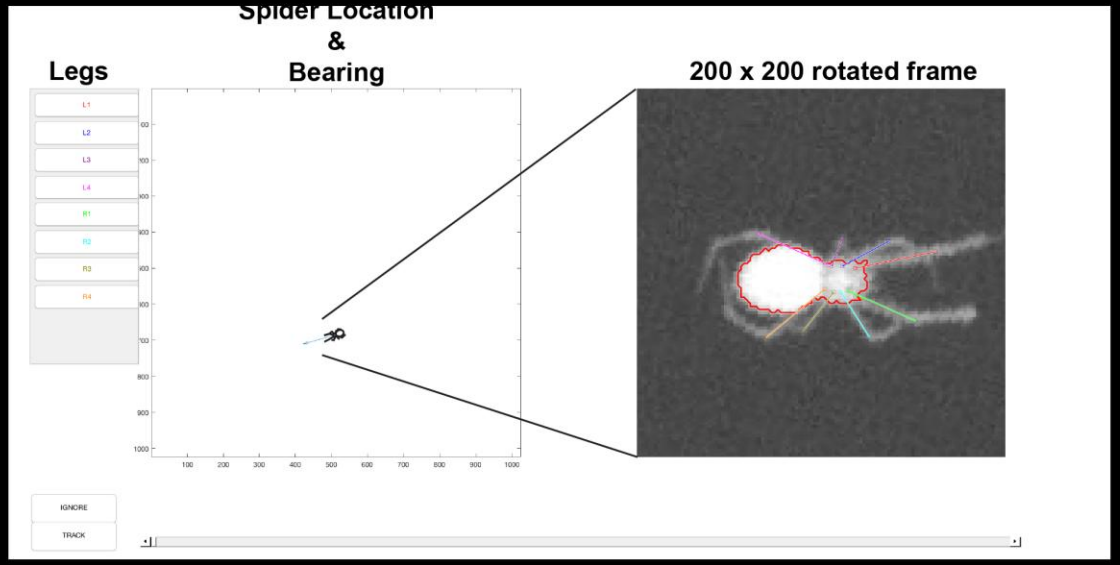

spider
30 cm
10 cm
880 nm LED
USB Camera


spider
30 cm
10 cm
880 nm LED
USB Camera

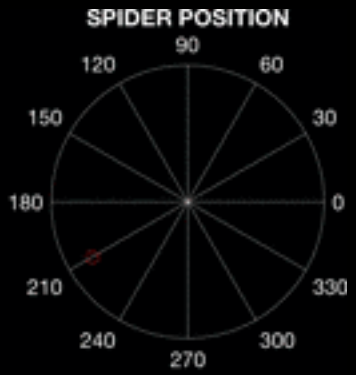

Spider Location
&
Legs
Bearing
200 x 200 rotated frame
L1
L2
L3
L4
R1
R2
R3
R4
IGNORE
TRACK


30 cm
880 nm LED
USB Camera

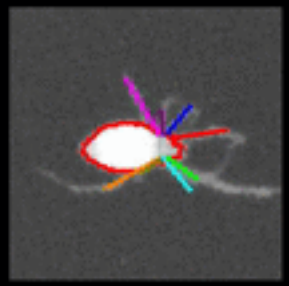

spider
10 cm


Spider Location
&
Bearing
Legs
200 x 200 rotated frame
IGNORE
TRACK

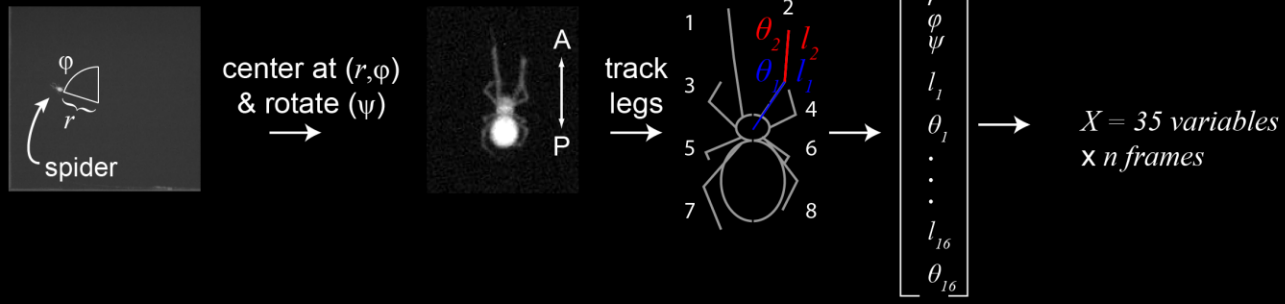

0.02 secs


SPIDER POSITION
90
120
60
150
30
180
0
210
330
240
300
270

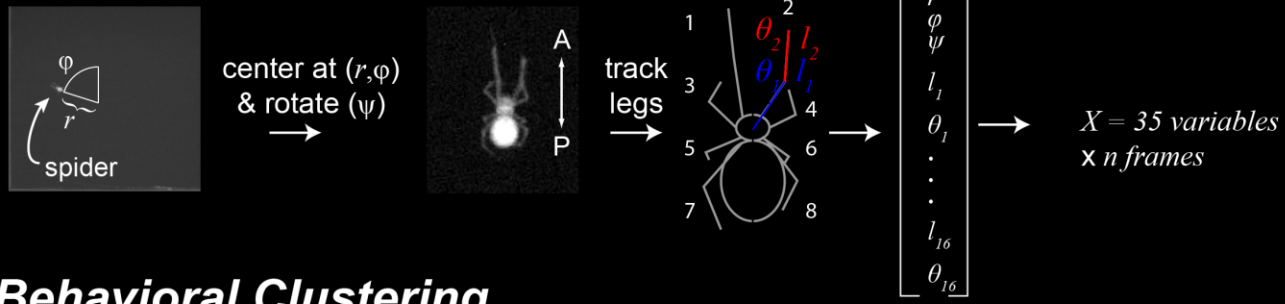

ORIENTATION
90
120
60
150
30
180
0
210
330
240
300
270



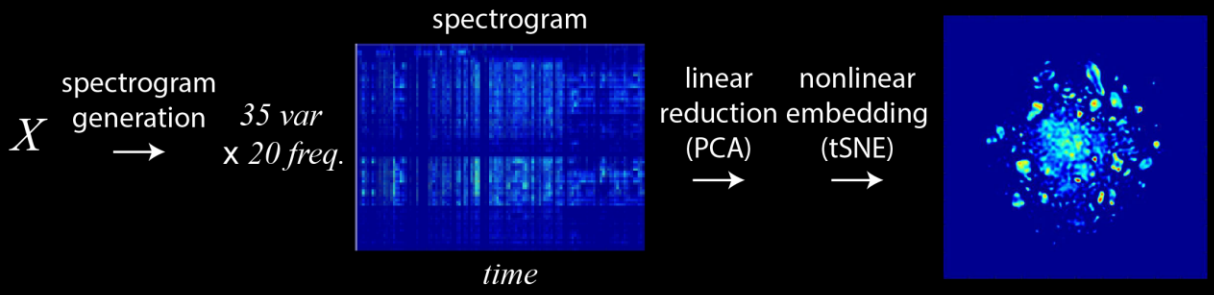
Feature Extraction



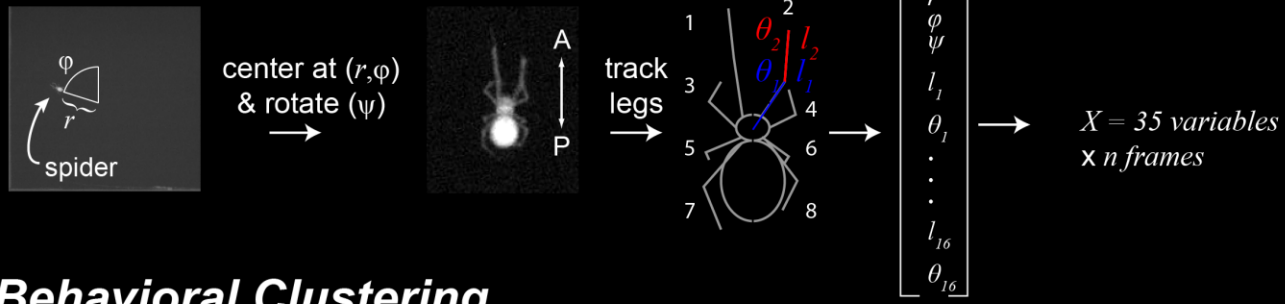
Feature Extraction



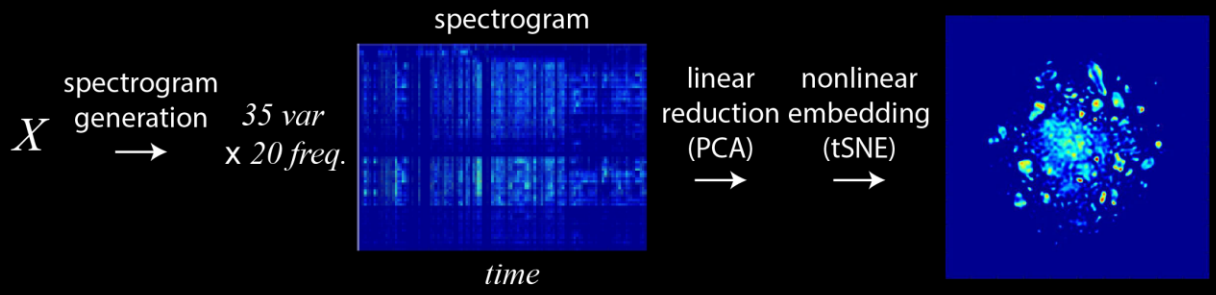
Behavioral Clustering



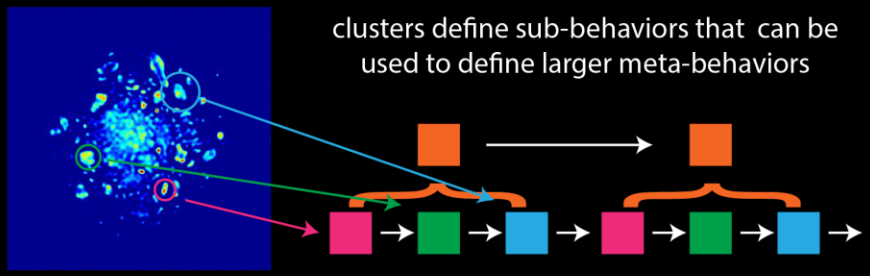
Feature Extraction



Behavioral Clustering



Model Assembly



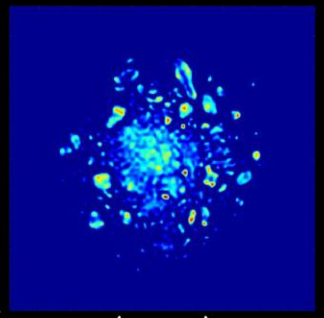
Parameters for inter-web comparisons

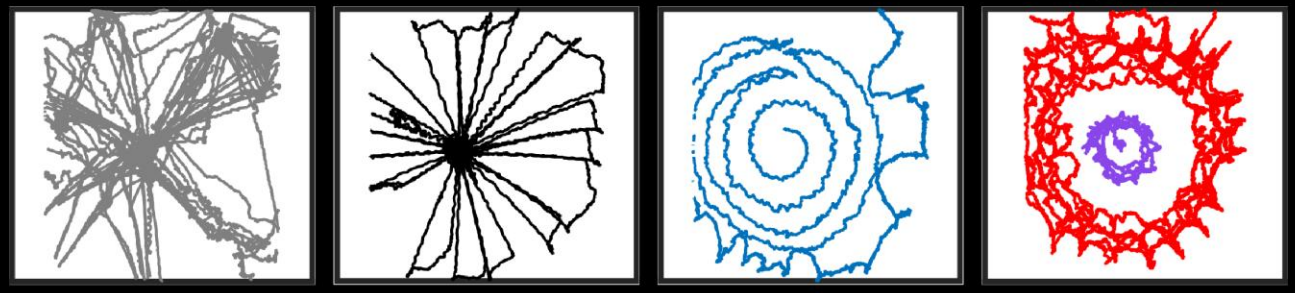
Behavioral Density $P(\ \blacksquare\ )$

Behavioral Dwell Time $P_{\blacksquare}(t),\ P_{\blacksquare}(t),\ \ldots\ P_{\blacksquare}(t)$

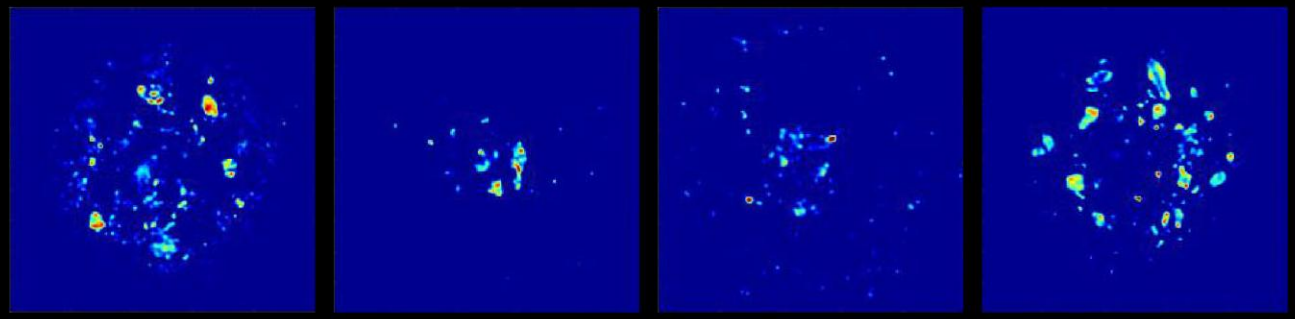
Transitional Probability $P(\blacksquare \mid \blacksquare)$

All tSNE-embedded behaviors

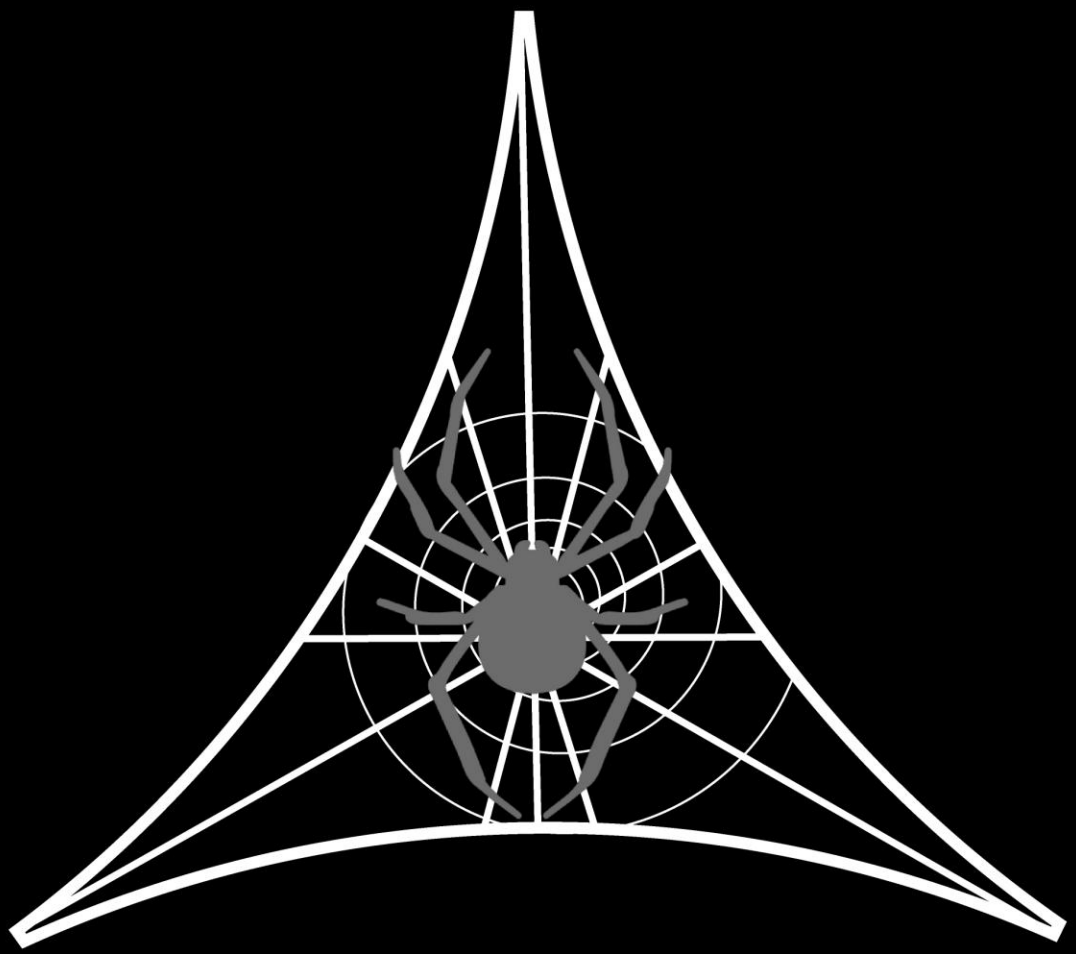




tSNE-embedded behaviors parsed by web stage



BEHAVIOR

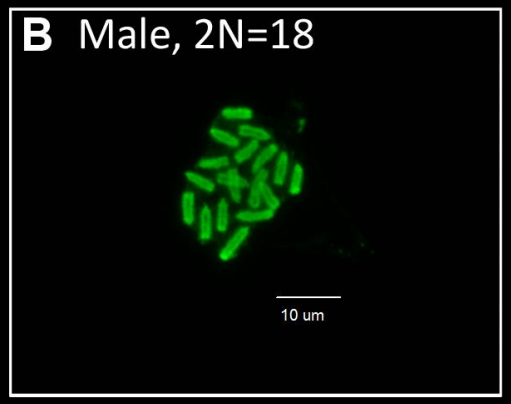


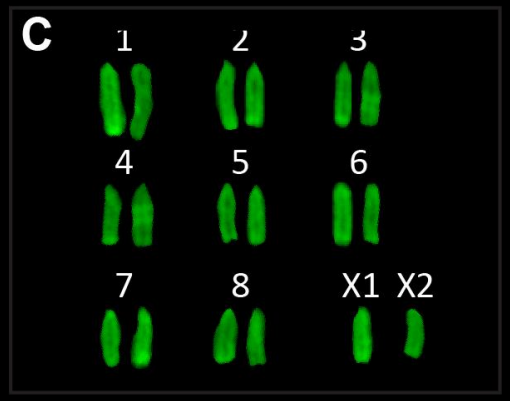
GENETICS

NEURONS

Genetics: So Far

- Illumina library & de novo genome assembly.
  - ~1.7 Gb
- Illumina cDNA sequencing.
  - 121,360 transcripts identified.
  - 30,752 ORFs predicted.

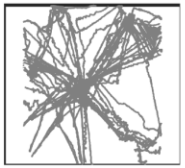
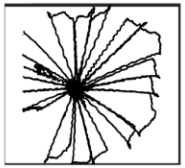
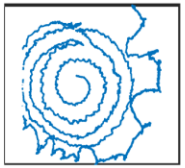
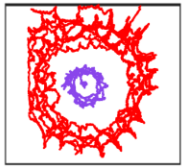




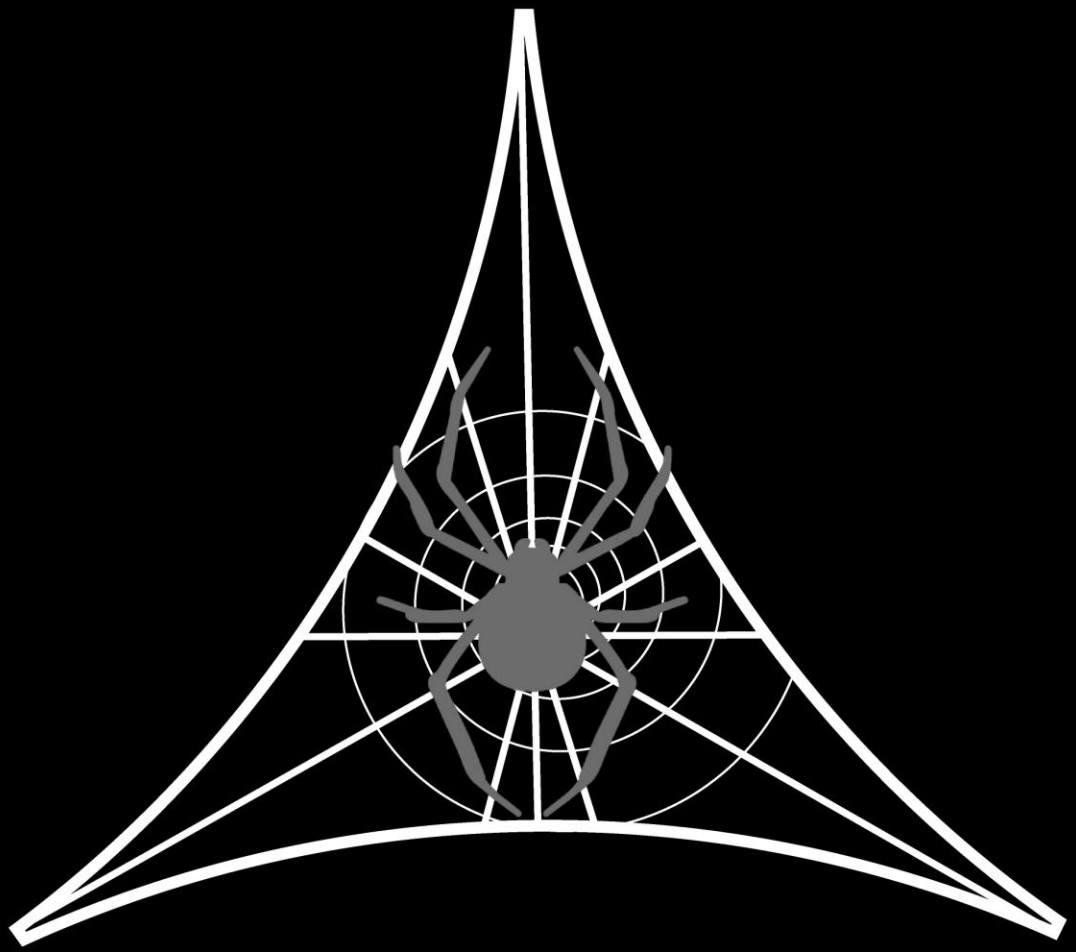
Genetics: Perturbation

- Target neuropeptides and GPCRs for expression knock-down with RNAi and CRISPR-Cas9.
- Introduce transgenics (e.g. GCaMP).

RNAi Targets

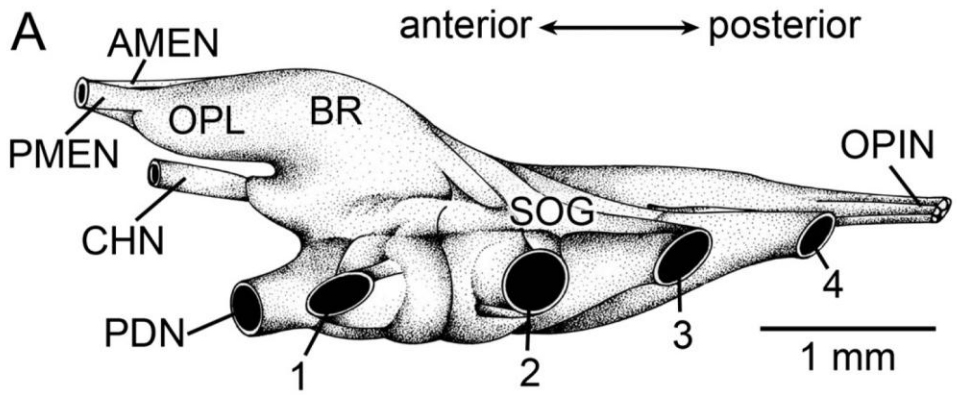
Transcripts	# Identified	Potential Web Feature Affected			
		Proto	Radii	Auxillary	Sticky
					
Receptors					
Dopamine	5				
AMPA-Glutamate	8				
NMDA-Glutamate	7				
nAChR	1				
GABA	10				
mAChR	2				
Ecdysone	1				
Serotonin	7				
Octopamine	1				
Beta-Adrenergic	2	?	?	?	?
Other neuropeptide	20	?	?	?	?
Other hormone	13	?	?	?	?
Other GPCR	22	?	?	?	?
Transporters					
Dopamine	12				
Serotonin	13				

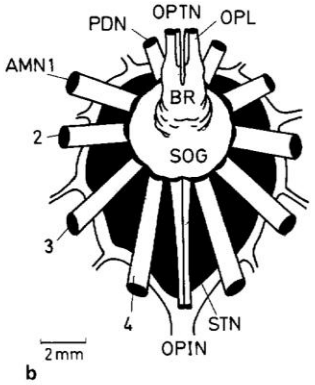
BEHAVIOR

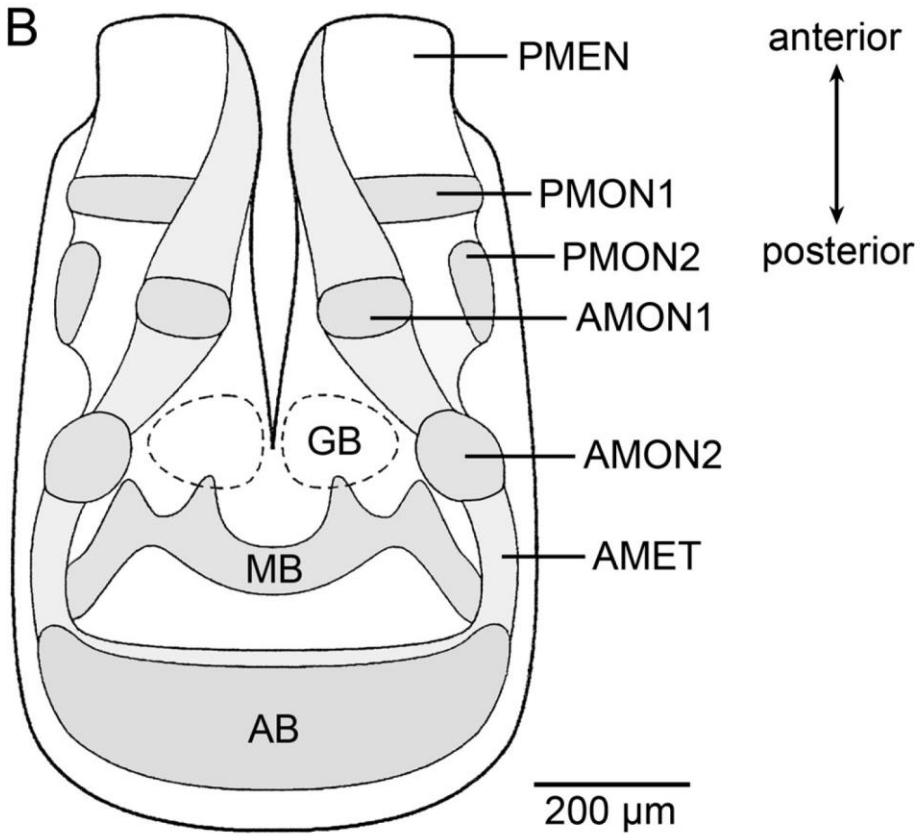


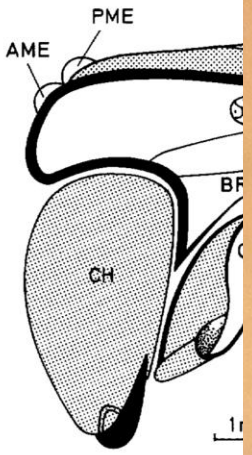
GENETICS

NEURONS









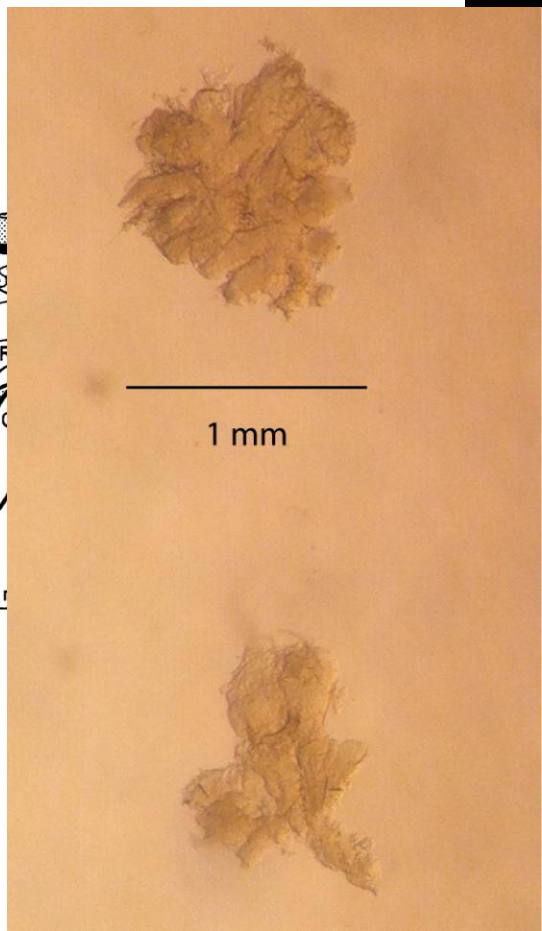
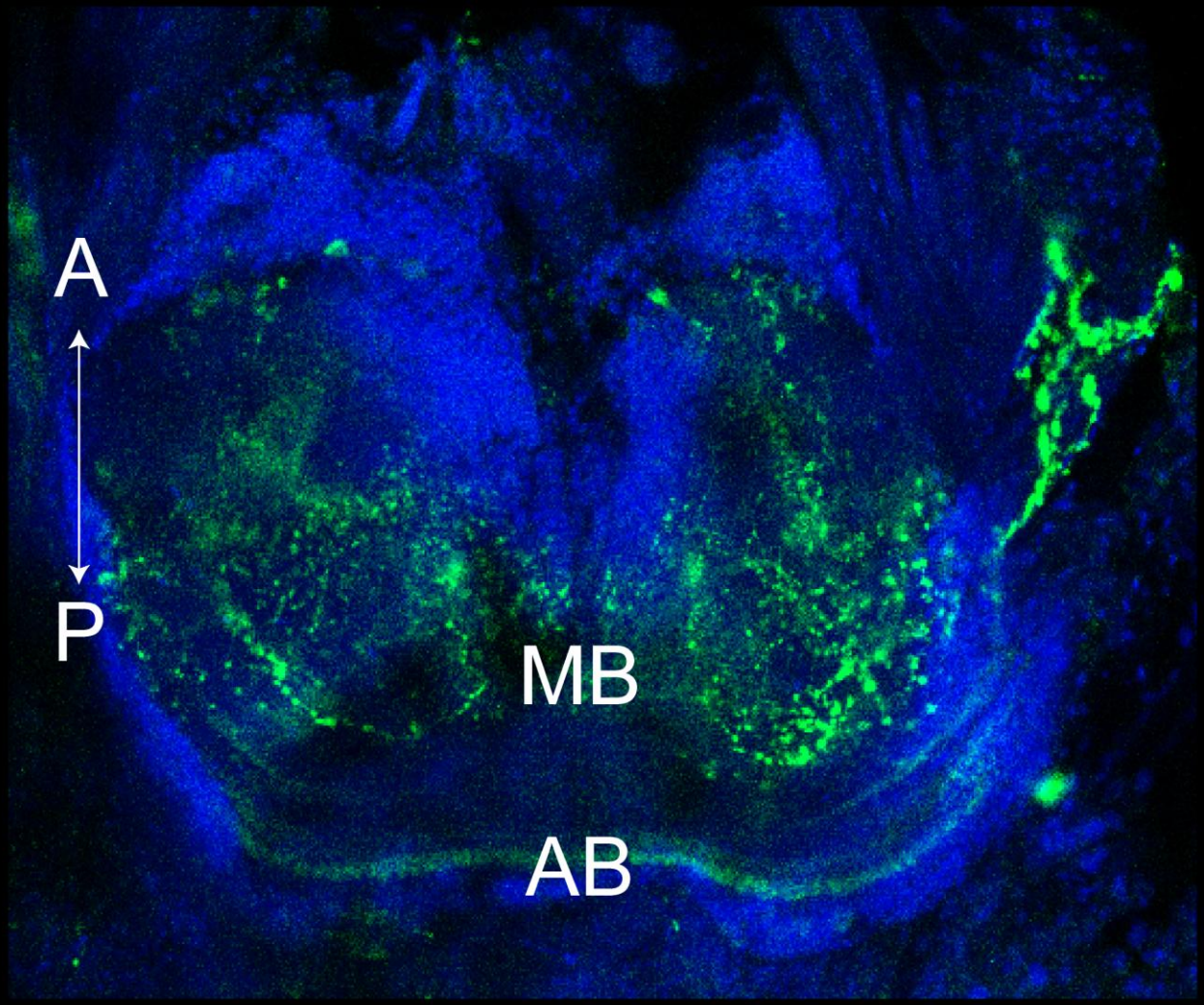


Fig. 1. Gross anatomy of the central nervous system of Cupiennius salei (after Babu and Barth, 1984 , modi fied). (A) External view of the prosomal ganglion complex as seen from lateral. The supraoesophageal ganglion comprises the optic lobes (OPL) and the brain (BR). Major optic nerves entering the optic lobes are the anterior and the posterior median eye nerves (AMEN and PMEN). The fused subesophageal ganglionic mass (SOG) is innervated by the cheliceral nerves (CHN), the pedipalpal nerves (PDN), the leg nerves (1 e 4), and the opisthosomal nerve (OPIN). (B) Schematic drawing of the brain and optic lobes as seen from dorsal (adopted from Duncker, 1992 , unpublished thesis; summarized in Barth, 2002). Prominent neuropils in the brain are the arcuate body (AB) and the mushroom body (MB). GB, region where the perikarya of globuli cells reside, i.e. neurons that innervate the mushroom bodies. Each of the two optic tracts that originate from the anterior and posterior median eye nerves supply two optic neuropils: AMET, anterior median eye tract (extension of the AMEN into the brain); AMON1 and 2, anterior median optic neuropil 1 and 2; PMON1 and 2; posterior median optic neuropil 1 and 2.

Uloborus diversus: Adult Protocerebrum

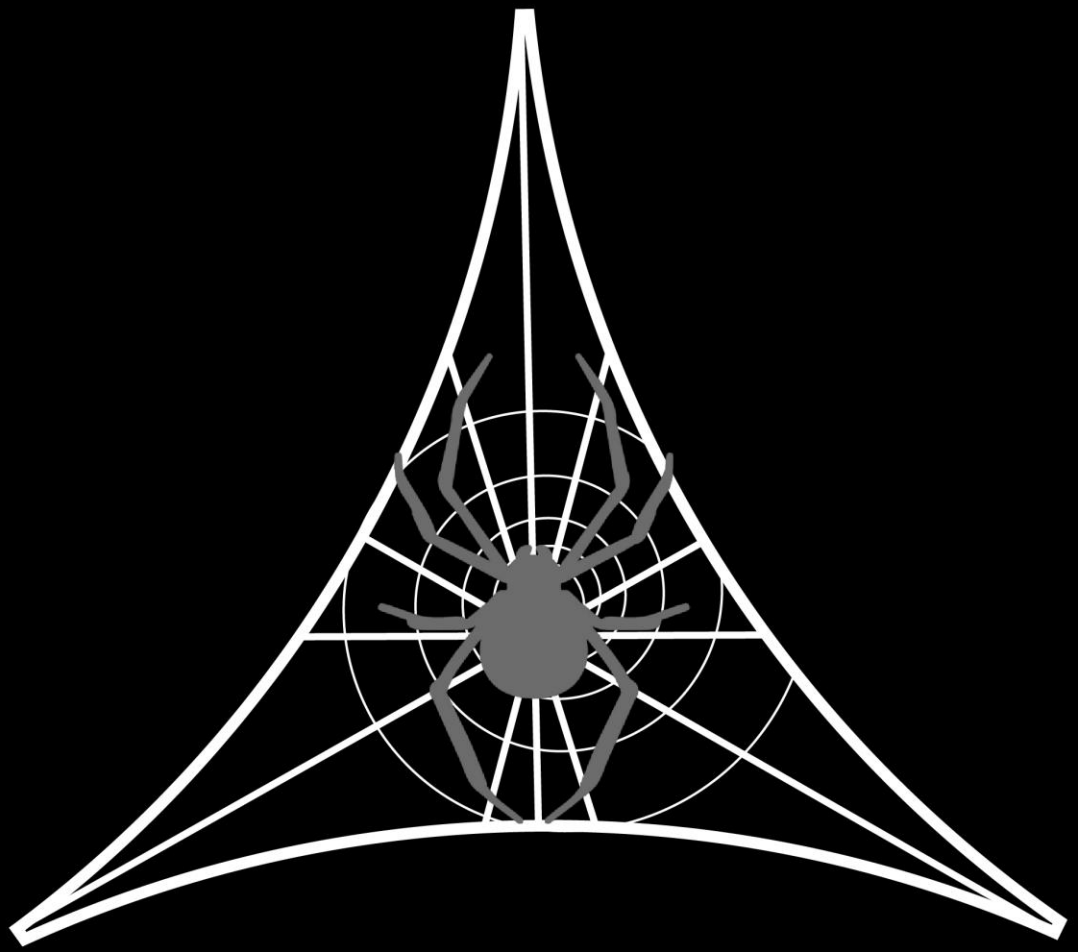


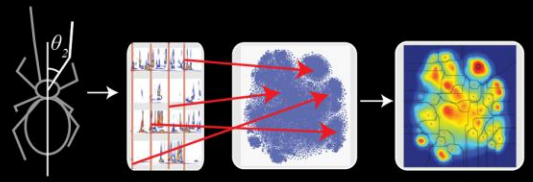
DAPI

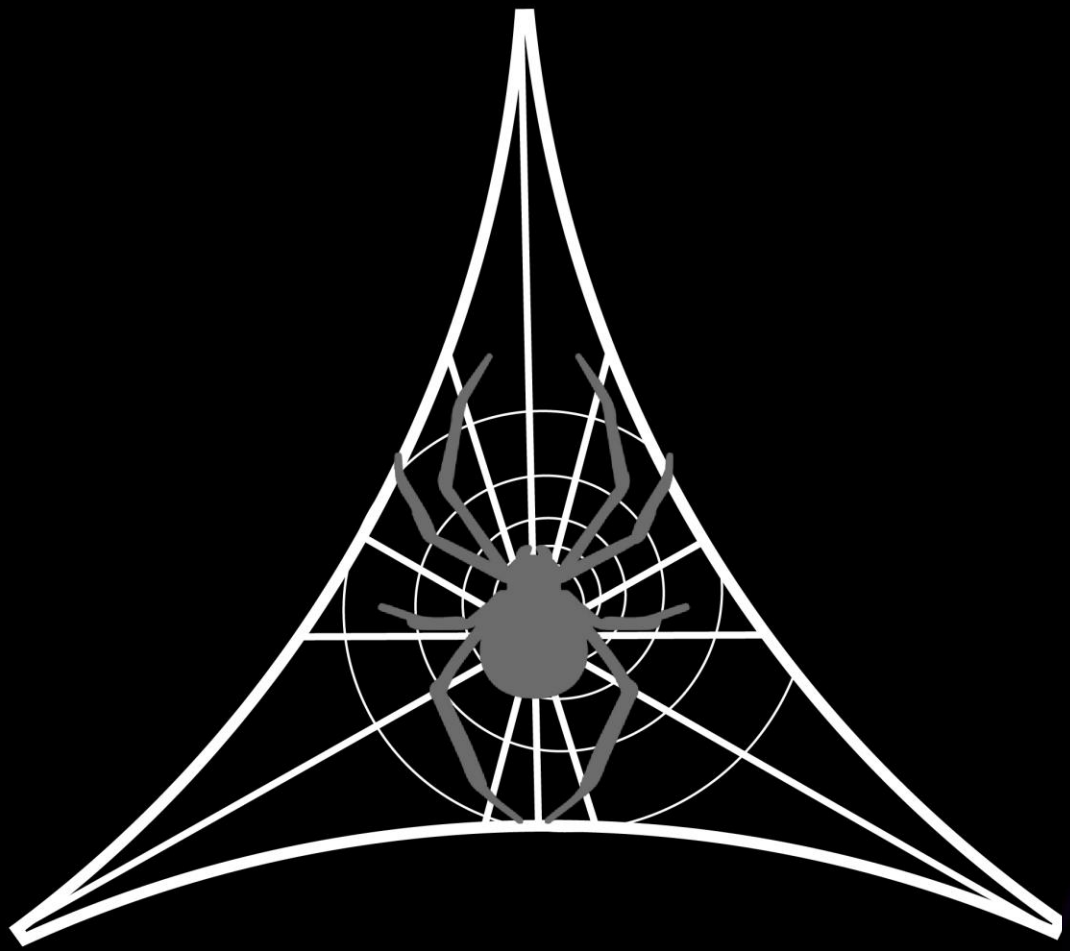
Anti-Inotocin

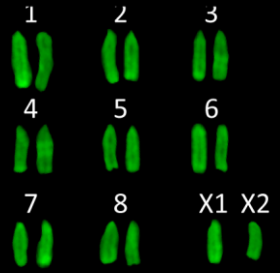
MB: Mushroom Body

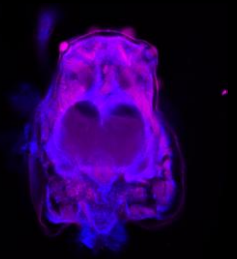
AB: Arcuate Body








1
2
3
4
5
6
7
8
X1
X2



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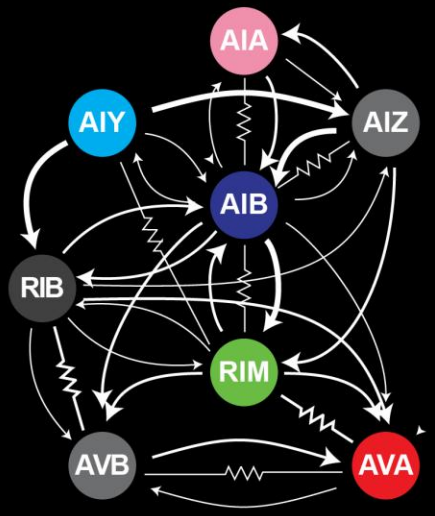

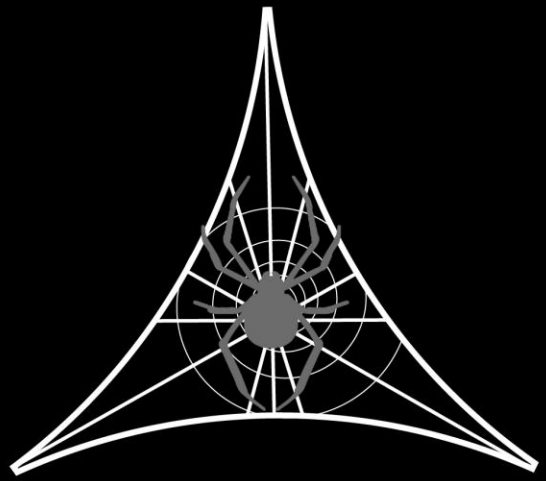

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