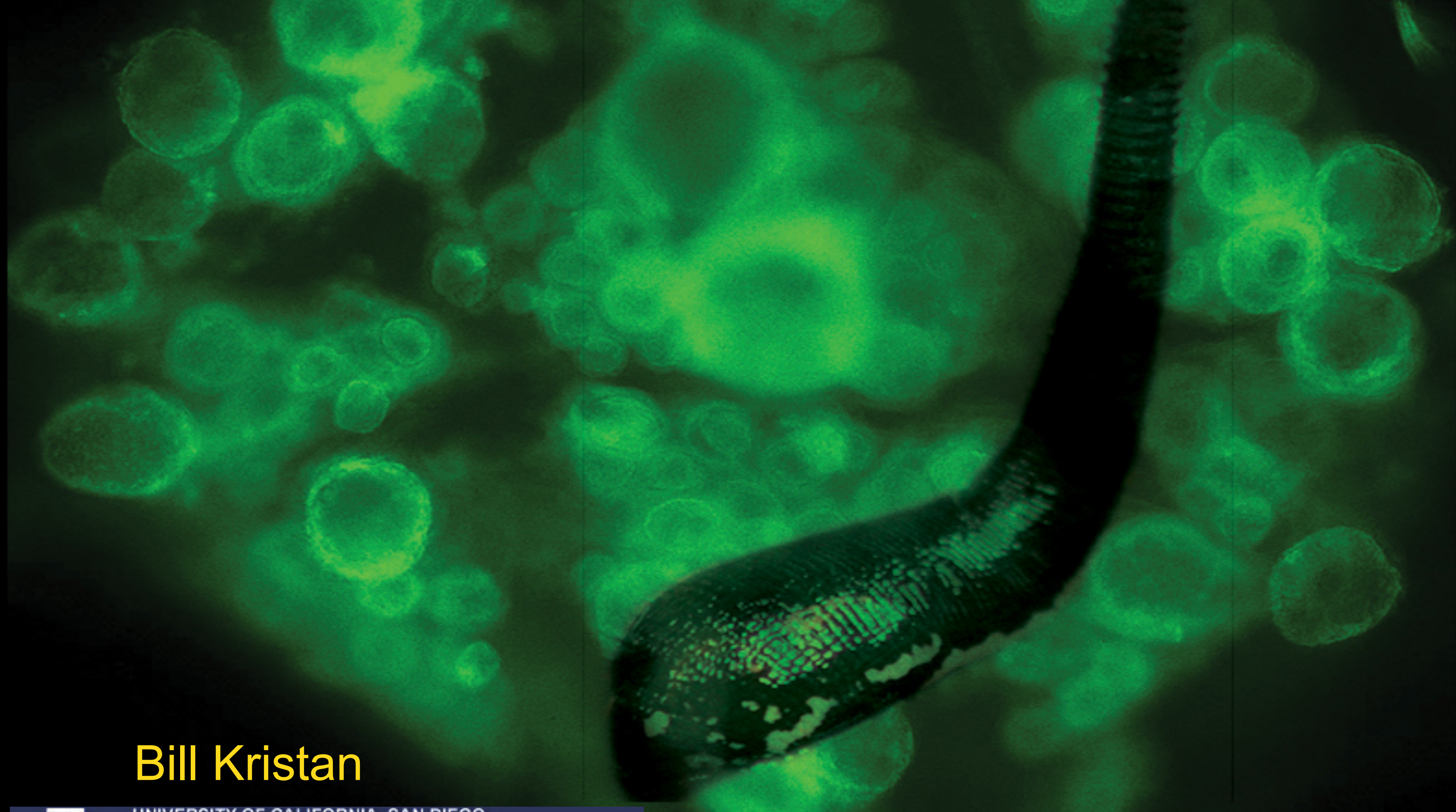
Sensory guidance of locomotion in leeches and flatworms

KITP qBio Summer School UCSB 6 August 2018



Bill Kristan

UNIVERSITY OF CALIFORNIA, SAN DIEGO
BIOLOGICAL SCIENCES

Neurophysics of sensory navigation

How animals sense and move in a stimulus gradient

Two recurring strategies:

1. Spatial difference: two (or more) receptors at one time.

2. Temporal difference: two (or more) measurements by the same receptor(s) at different times.

- continuous or discontinuous gradient.
- during movements either along or across the body axis.

Three projects, each looking at different gradients in different worms:

Worm	**Gradient**	**Student**

Neurophysics of sensory navigation

Eva-Maria
Schoetz-Collins
Swarthmore

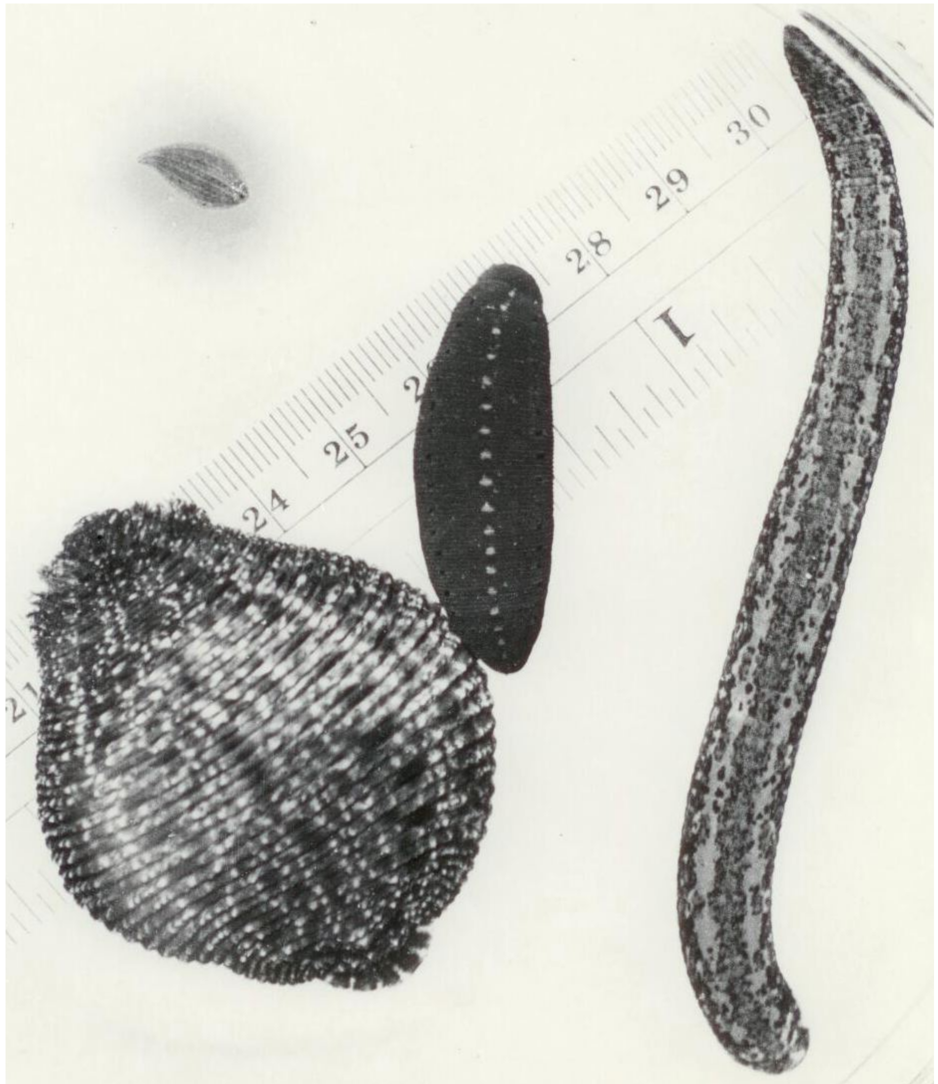
David Weisblat
UC Berkeley

Daniel Wagenaar
Caltech

Three projects, each looking at different gradients in different worms:

Worm	Gradient	Student
Planarian	Stationary light	Akihiro Yamaguchi
Small leech	Stationary mechanical (roughness)	Jiayin Hong
Big leech	Moving light and water waves	Jess Kanwal

Leeches come in a variety of shapes and sizes



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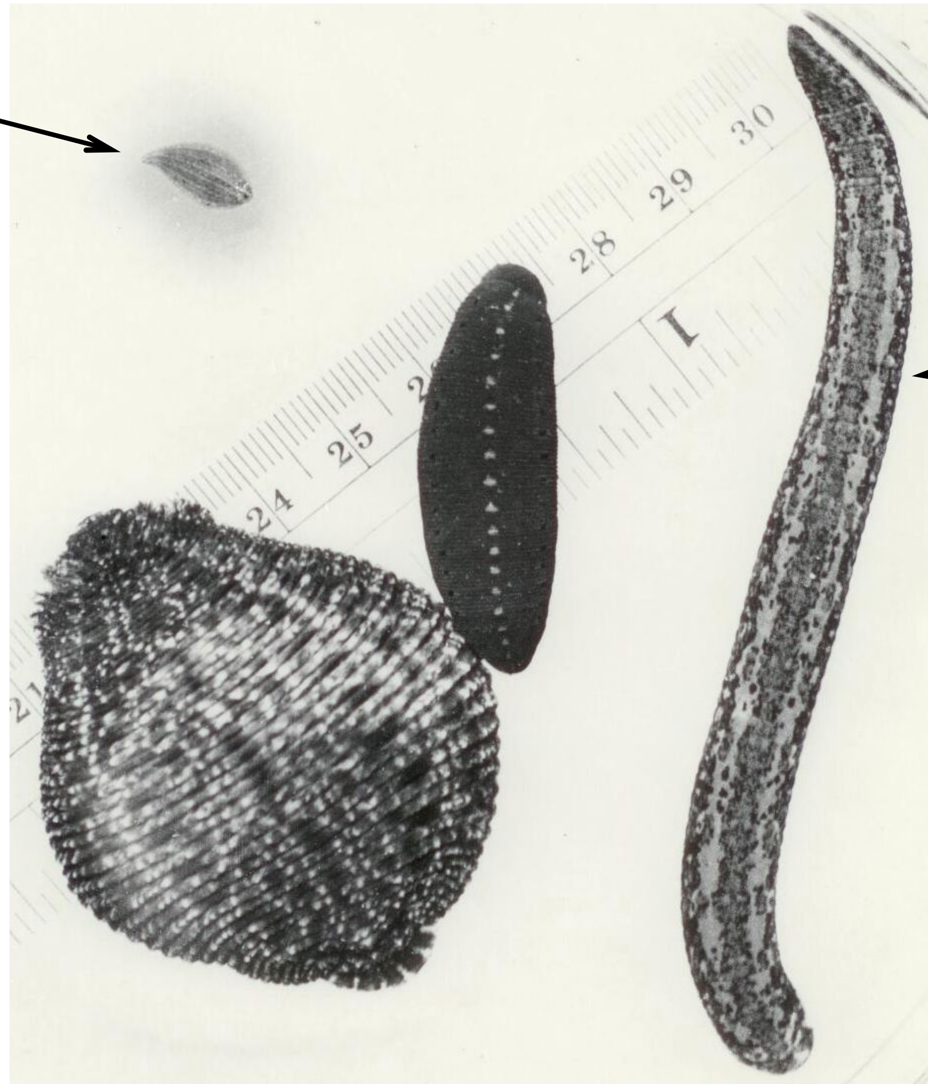
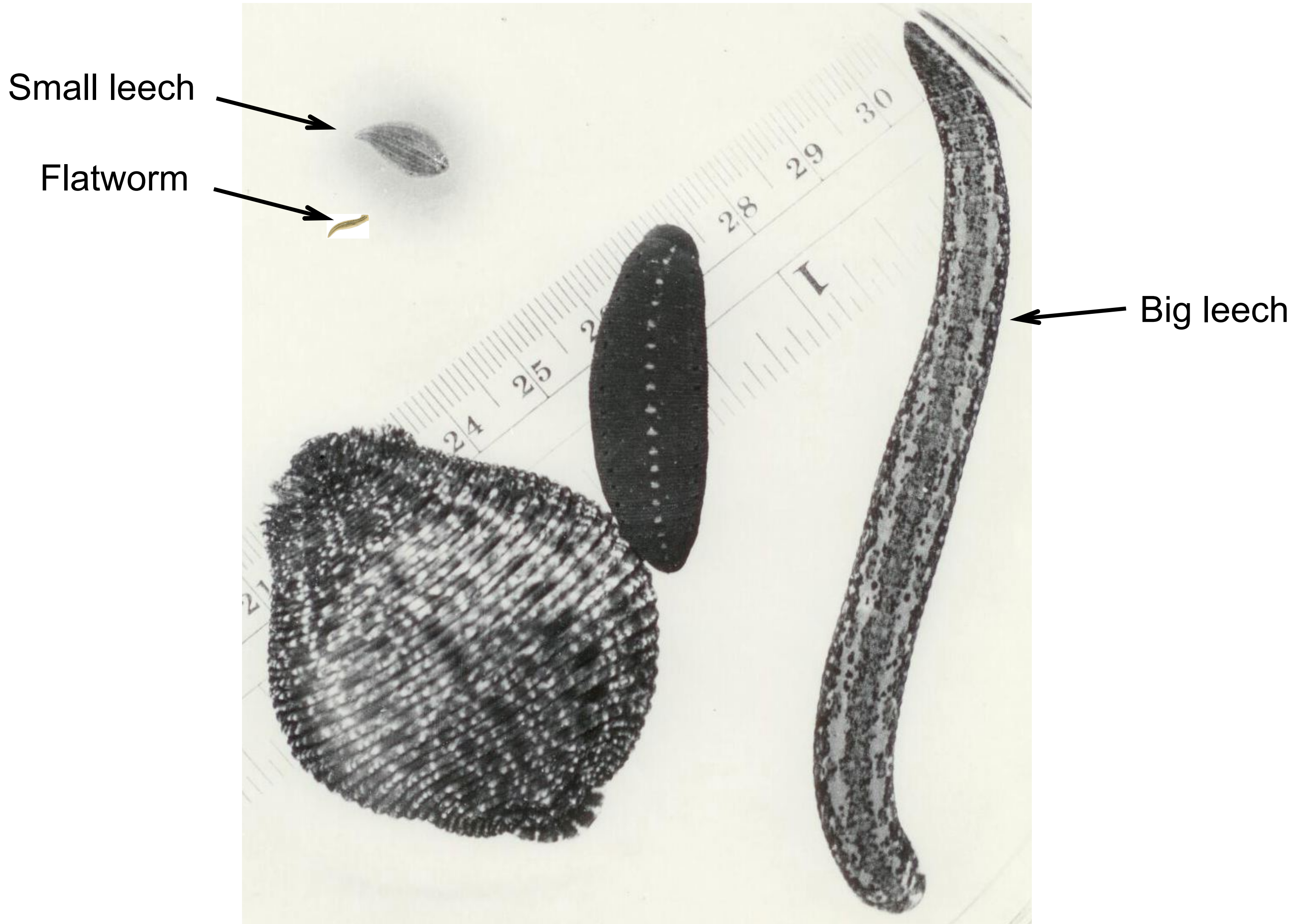


Dugesia japonica (flatworm)

Dylan Le
Eva-Maria Schoetz-Collins

The flatworms are actually quite small:



Flatworms move away from light

Move forward (“glide”): beat cilia on ventral surface

Turn by contracting longitudinal muscles in body wall

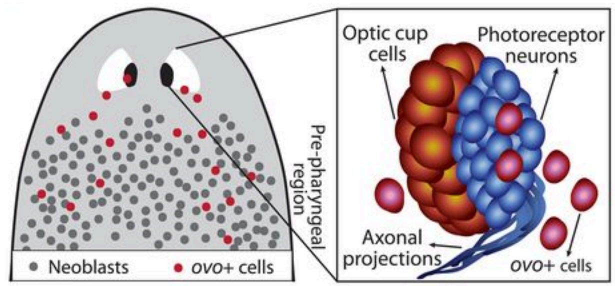
Flatworm negative phototaxis

Initial distribution of ~100 flatworms

1 minute after turning on a light

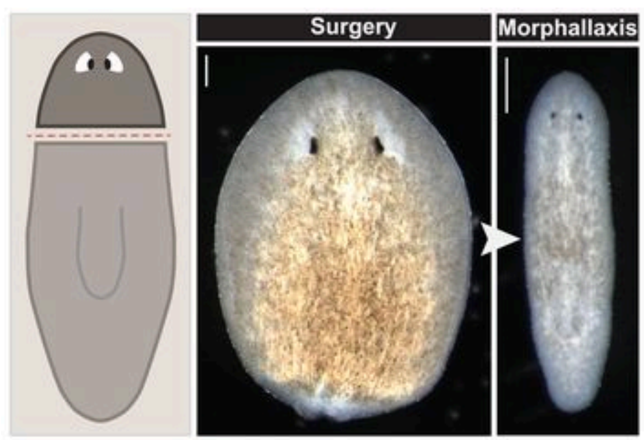
Flatworm neuroanatomy

eyes

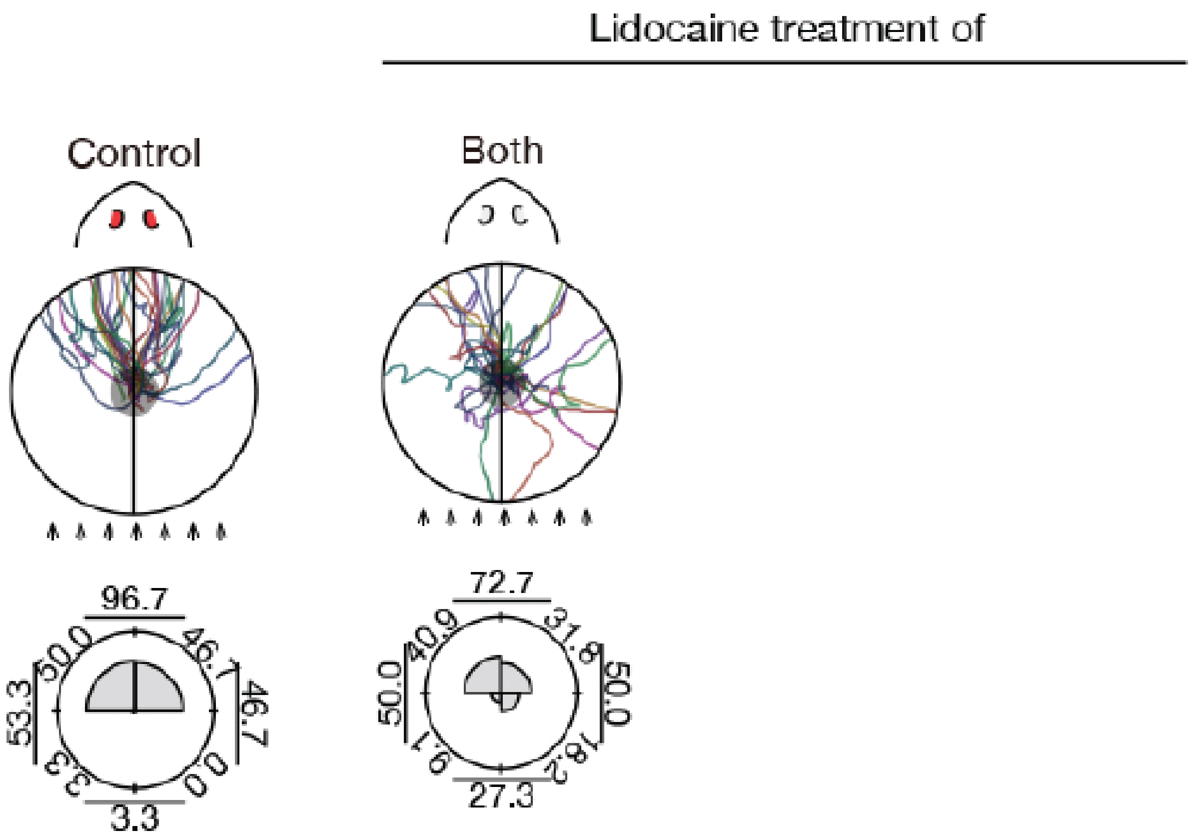


CNS

Regeneration



Responses of individual planaria:

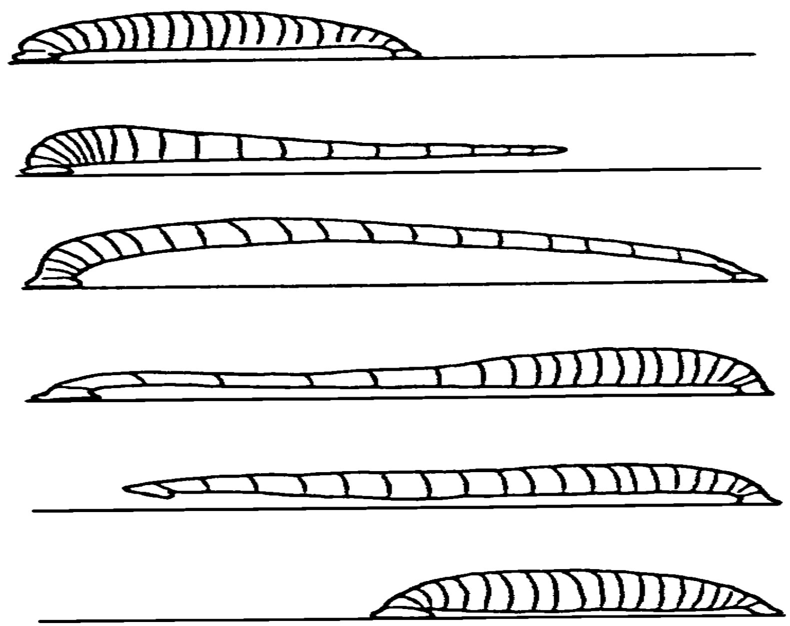


Provisional conclusion: planaria use an intensity comparison between the two eyes to avoid bright light.

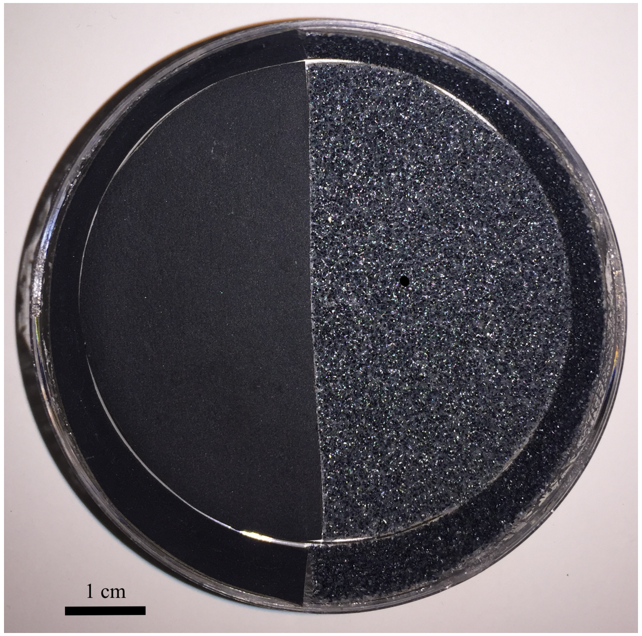
Akihiro Yamaguchi will test this idea in the next 3 weeks.

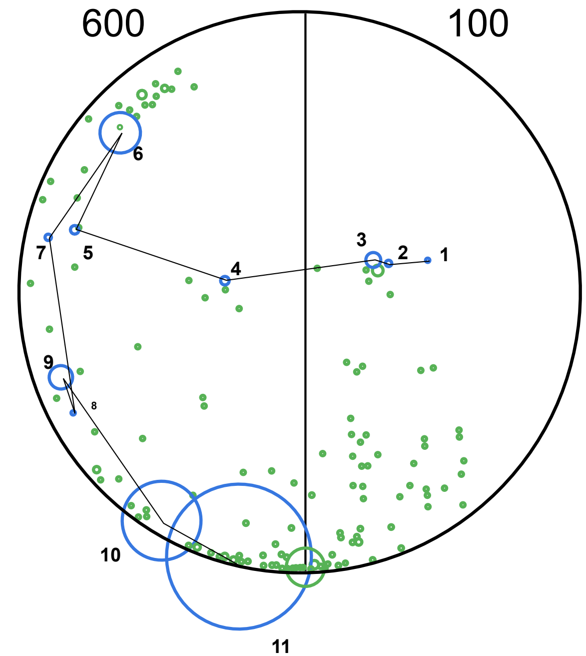
Inoue, Hoshino, Yamashita, Shimoyama, Agata (2015) Zool Lett

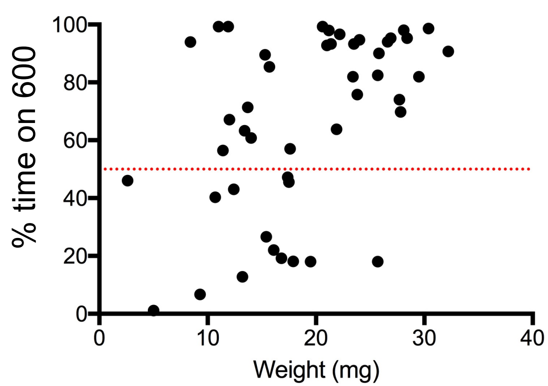
Small leech moves to smooth surfaces, food

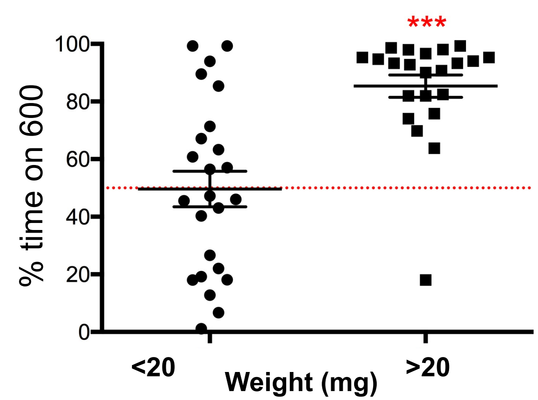


Small leeches on sandpaper of differing roughness



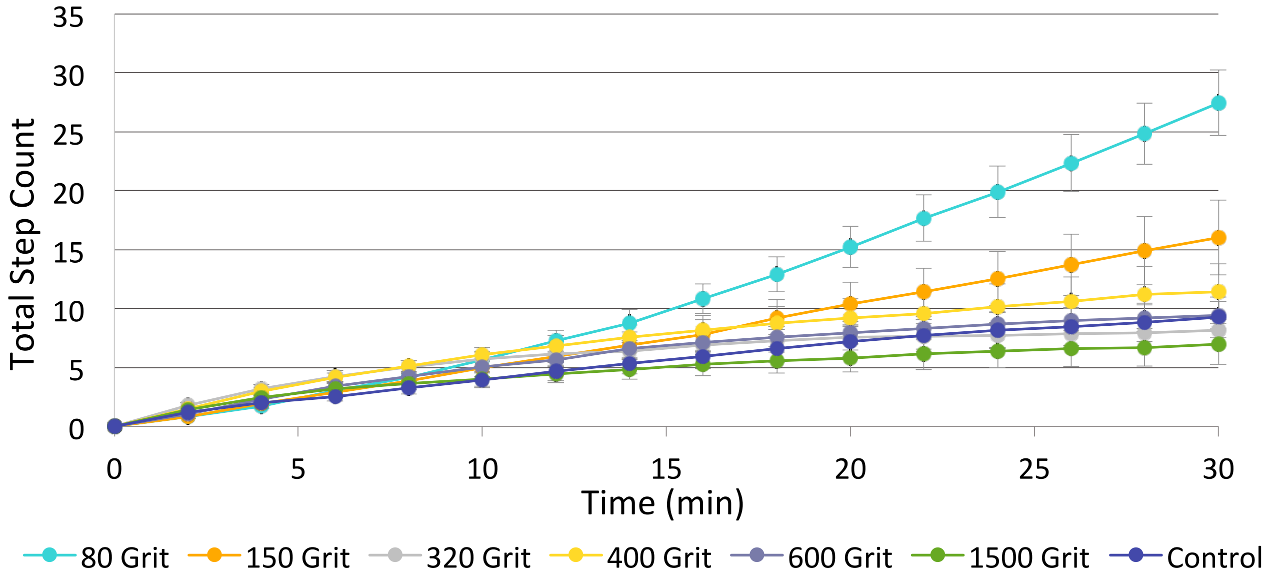






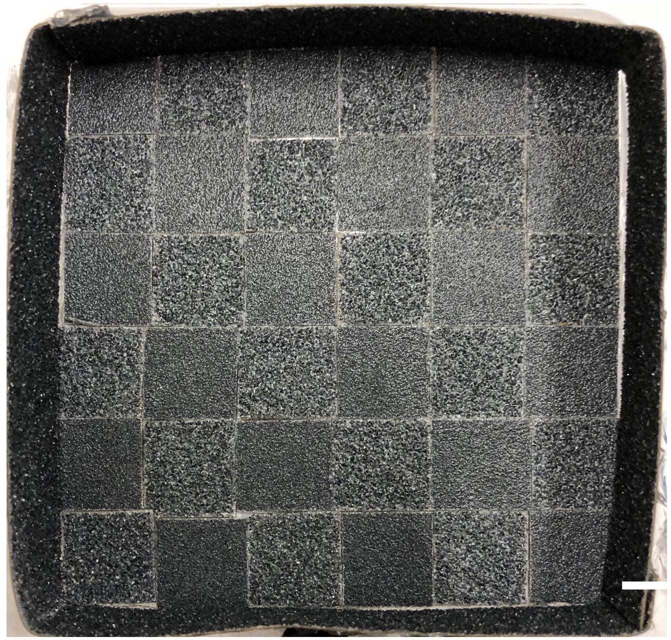
Kim, Le, Ma, Heath-Heckman, Whitehorn, Kristan, Weisblat (2018)

Number of steps on a uniform substrate (small leech)



Kim, Le, Ma, Heath-Heckman, Whitehorn, Kristan, Weisblat (2018)

Small leeches choose smoother surfaces

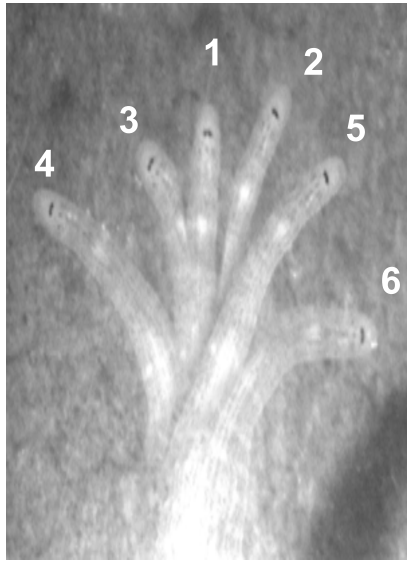


Grit: 80 150 600 1500

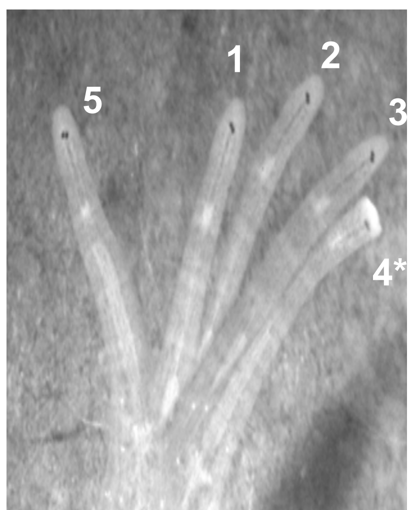
Avg. part. diam. (μm): (190) (92) (26) (13)

Kim, Le, Ma, Heath-Heckman, Whitehorn, Kristan, Weisblat (2018)

Small leeches make L/R scanning movements before stepping:



Sometimes they also lift their heads during scanning:

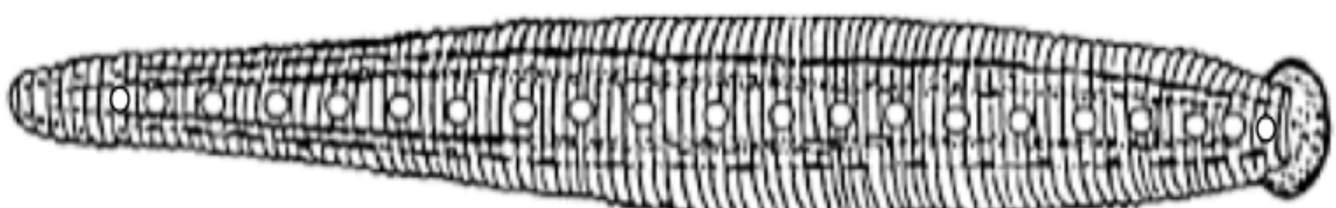


….and make more head-lifts
on coarser surfaces.

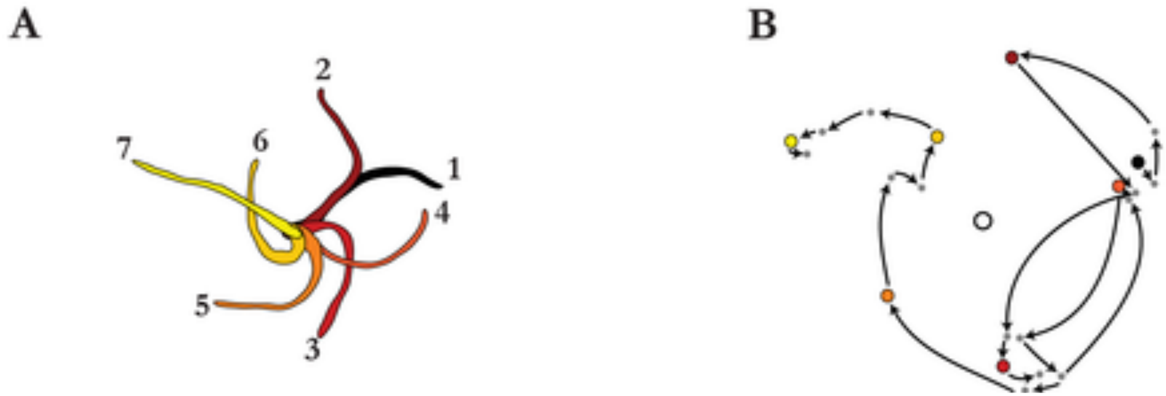
Jiayin Hong will tell you more
about this at the end of the course

Kim, Le, Ma, Heath-Heckman, Whitehorn, Kristan, Weisblat (2018)

Large leech moves into water waves, moving shadows



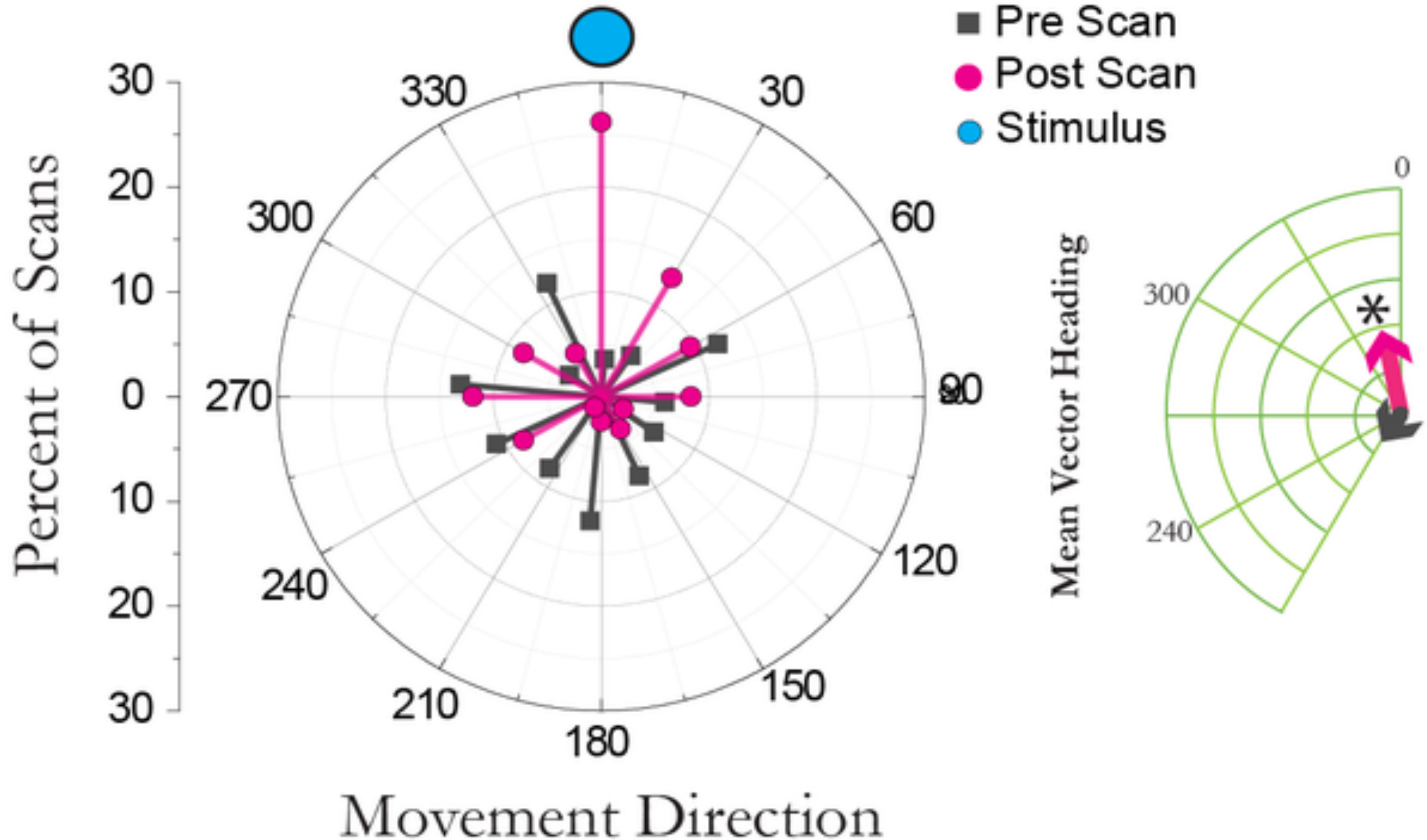
Qualitative description of scan behavior in the big leech



Harley CM, Wagenaar DA (2014) Scanning Behavior in the Medicinal Leech Hirudo verbana. PLOS ONE 9(1): e86120. https://doi.org/10.1371/journal.pone.0086120

http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0086120

Heading changes after scanning behavior in the big leech



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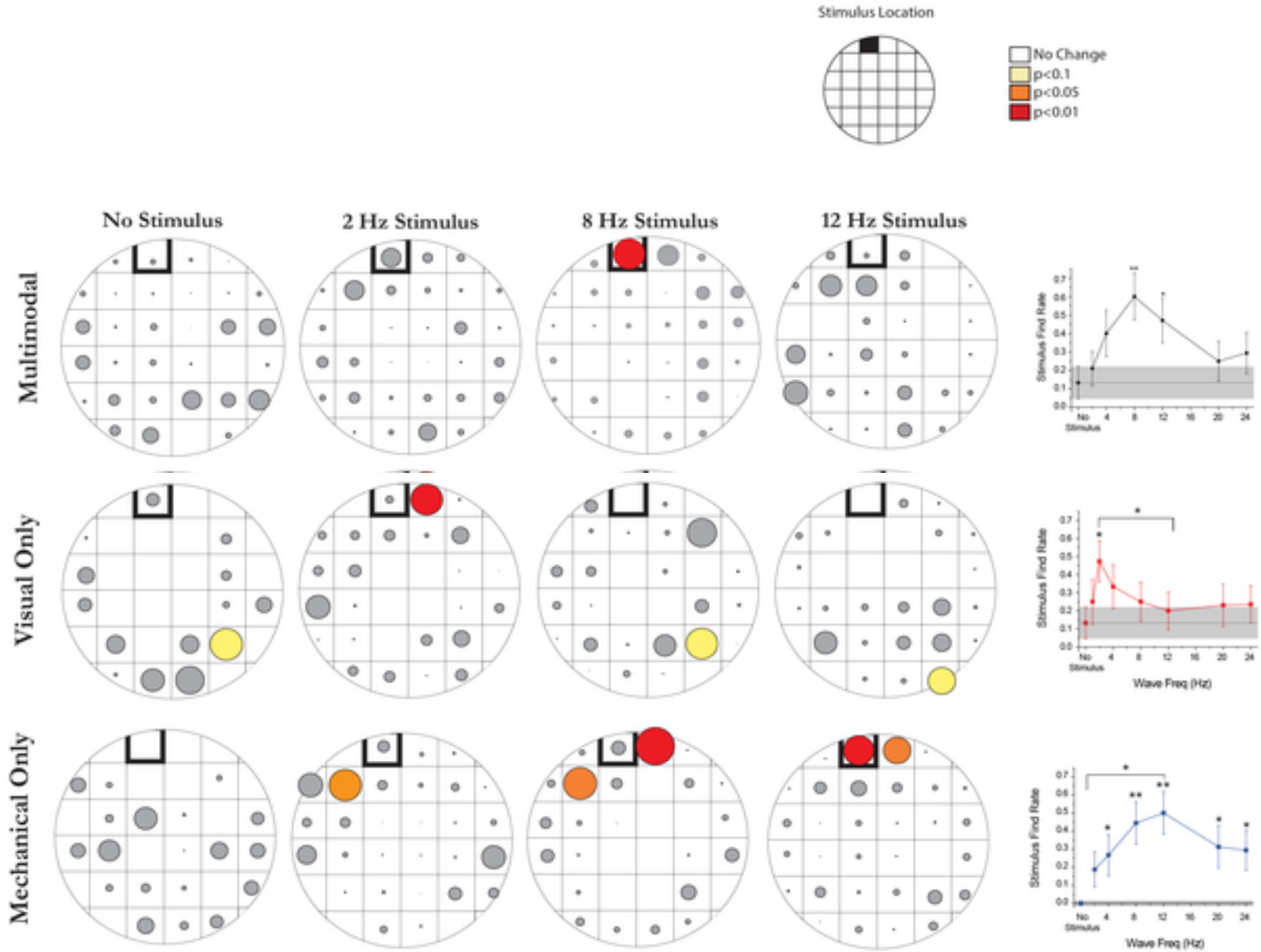
PLOS | ONE

Scanning behavior becomes localized to a given stimulus (big leech)



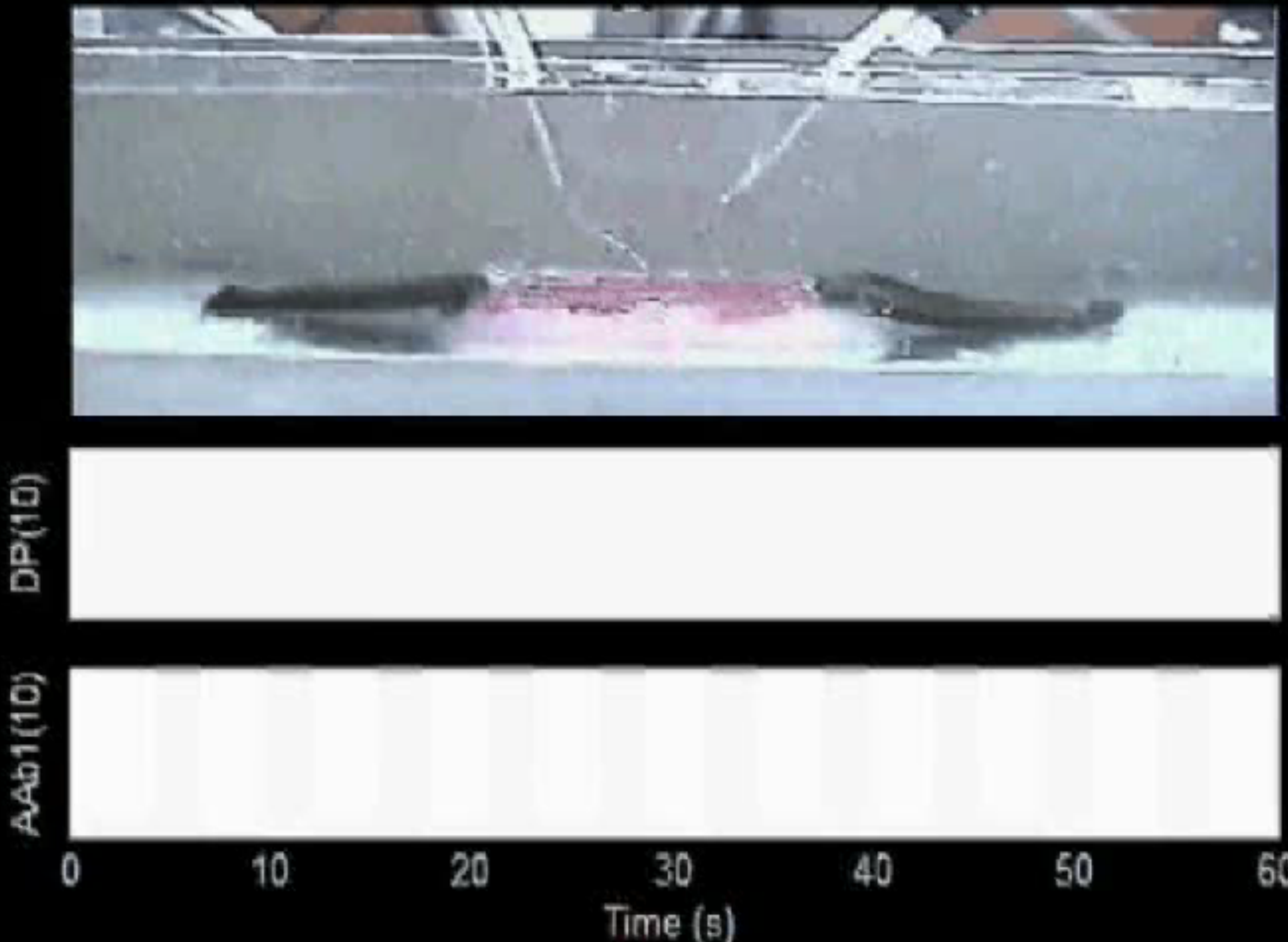
In a tank above the leech tank

In the dark

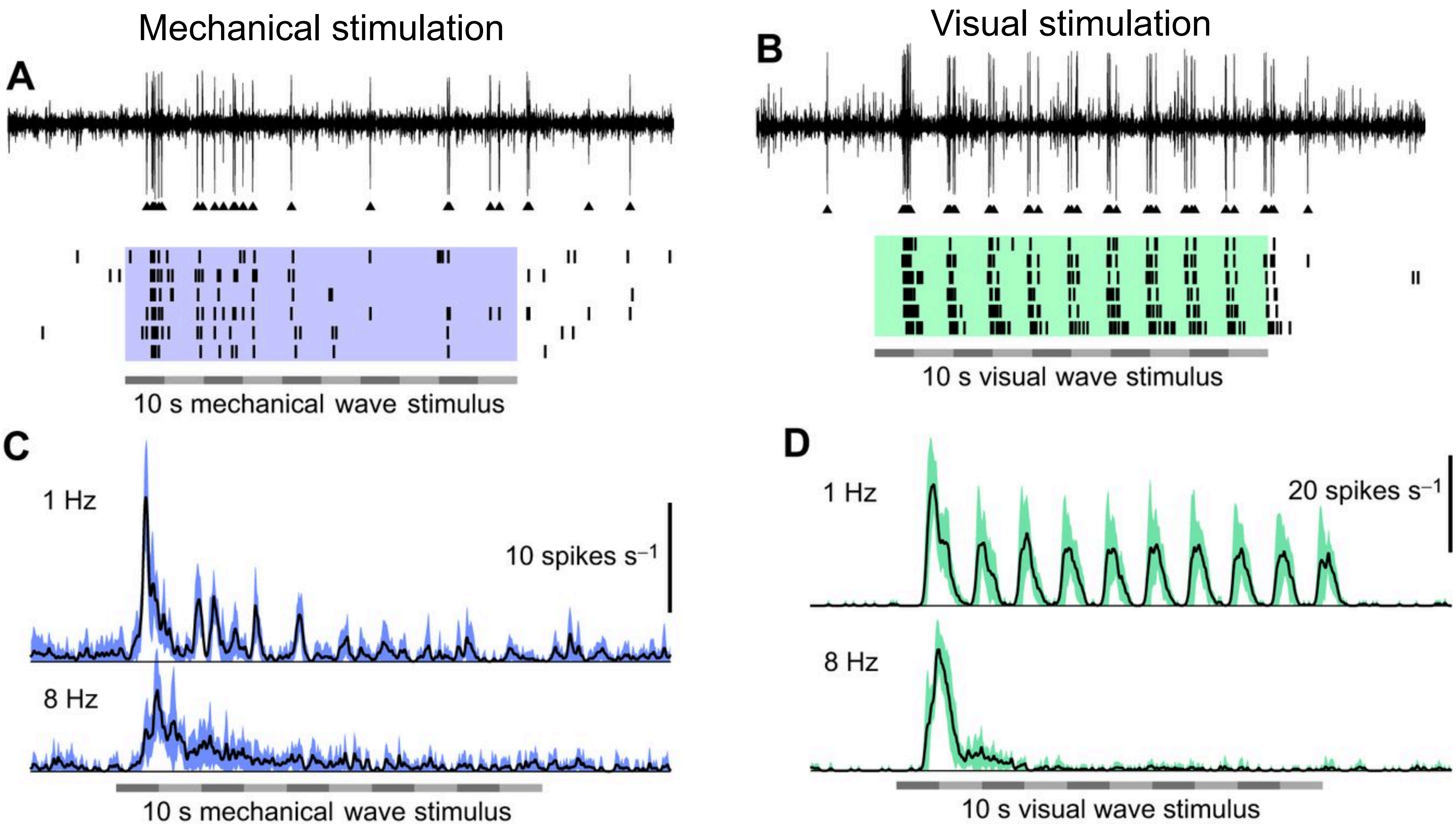
Harley CM, Wagenaar DA (2014) Scanning Behavior in the Medicinal Leech Hirudo verbana. PLOS ONE 9(1): e86120. https://doi.org/10.1371/journal.pone.0086120

http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0086120

PLOS | ONE


DP(1D)
AAb1(1D)
0
10
20
30
40
50
60
Time (s)

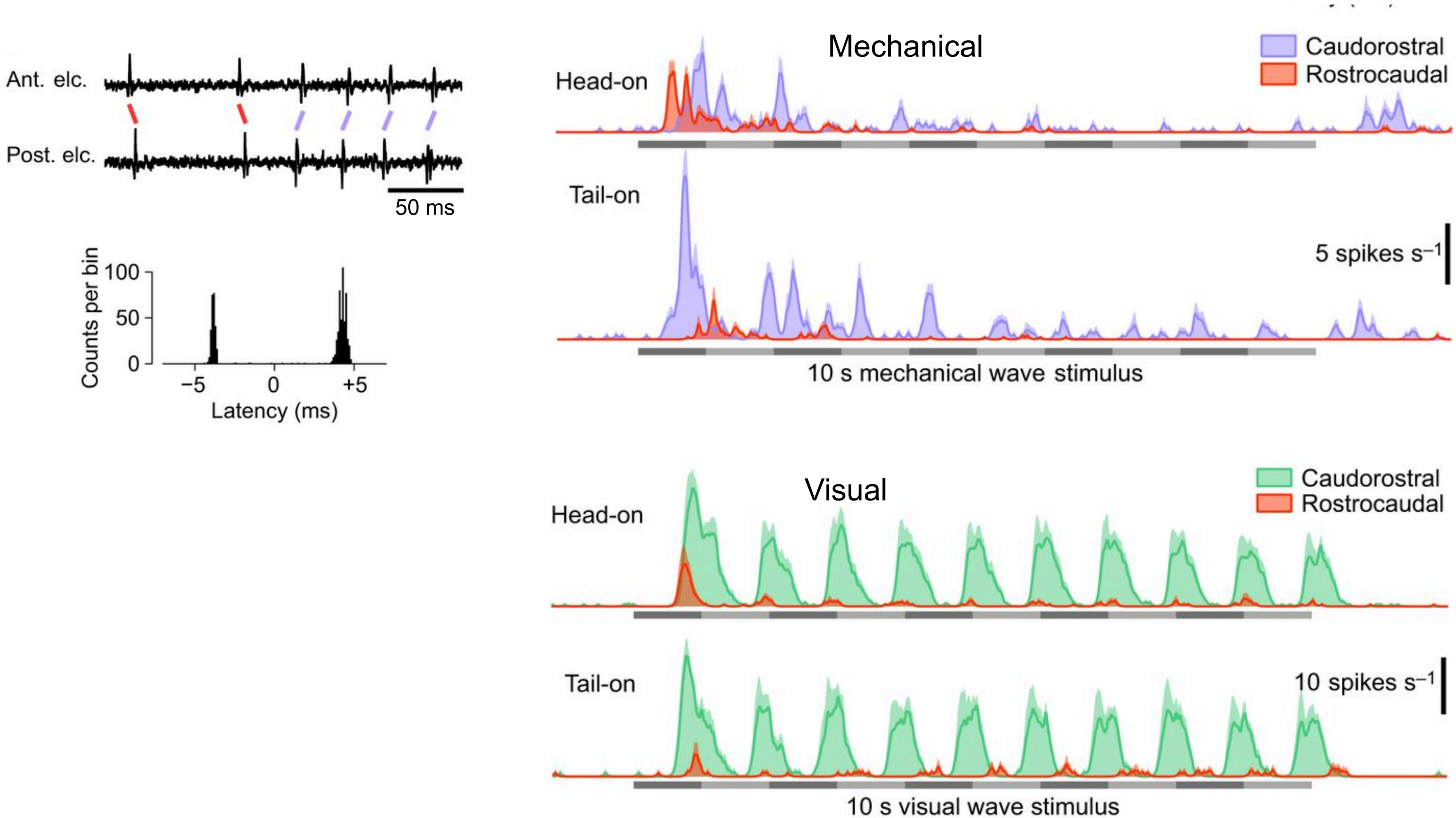
S cell responses to mechanical and visual wave stimuli (big leech)



Andrew M. Lehmkuhl et al. J Exp Biol 2018;221:jeb171728

Journal of Experimental Biology

Dependence of S cell responses on wave direction (big leech)



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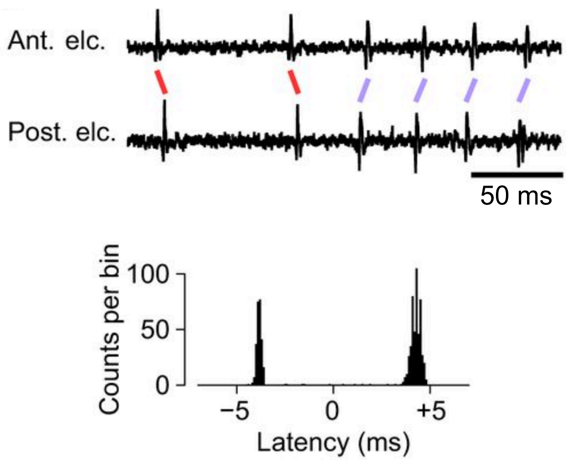
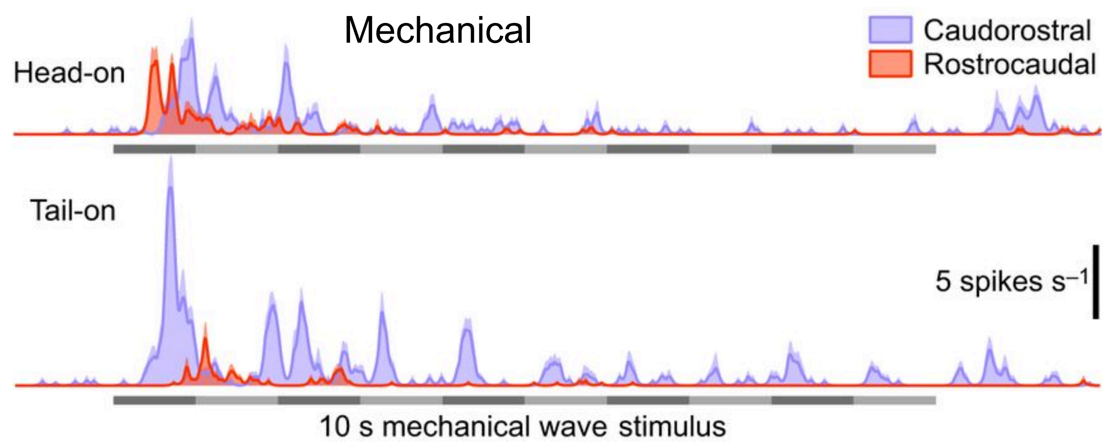
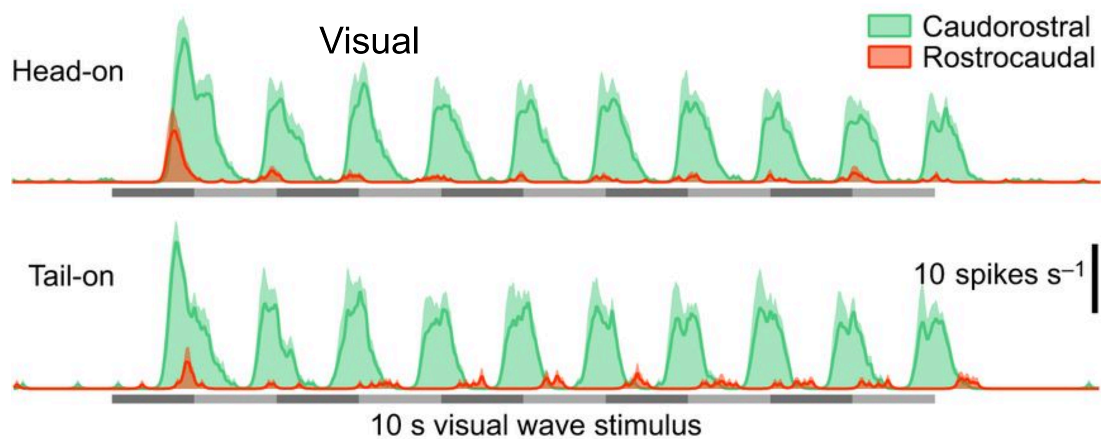
Dependence of S cell responses on wave direction (big leech)

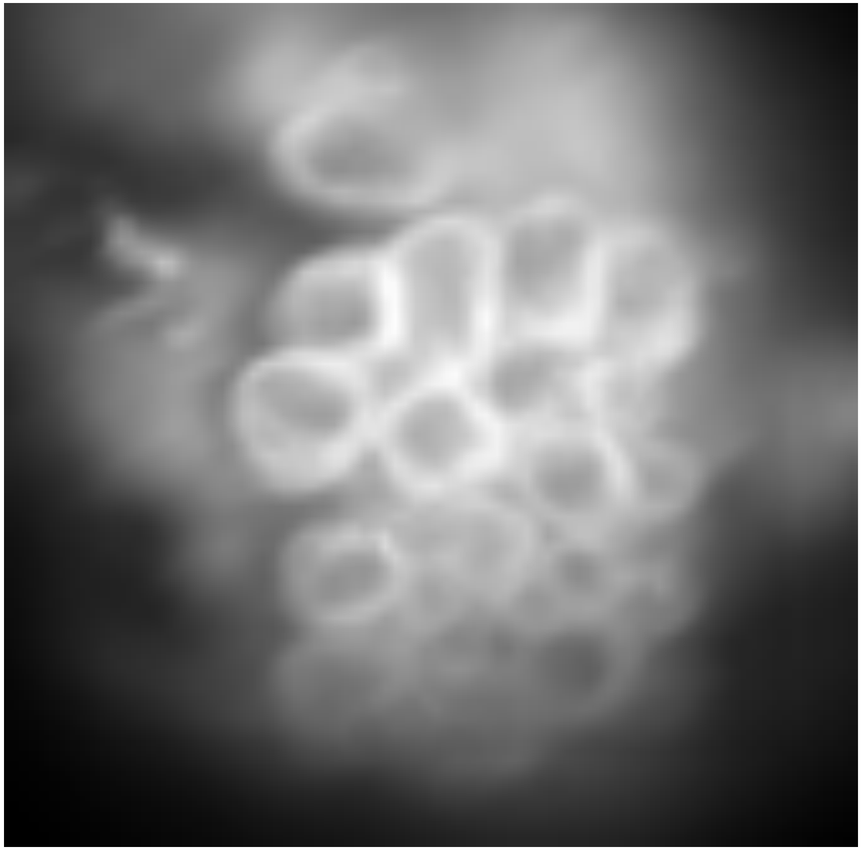


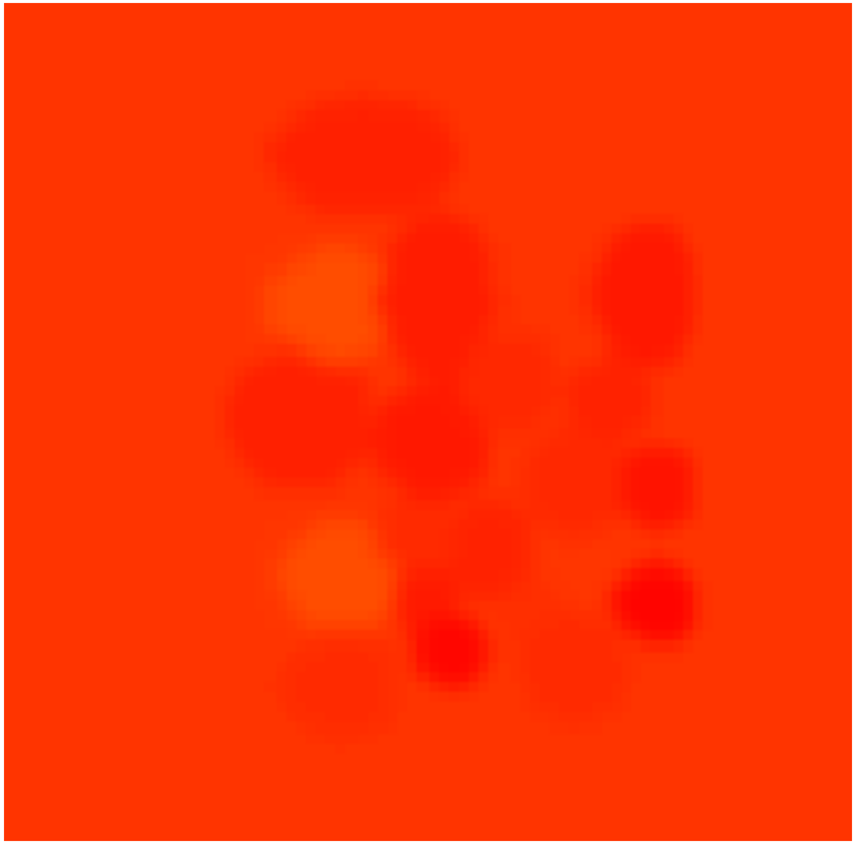




Next steps: Jess Kanwal

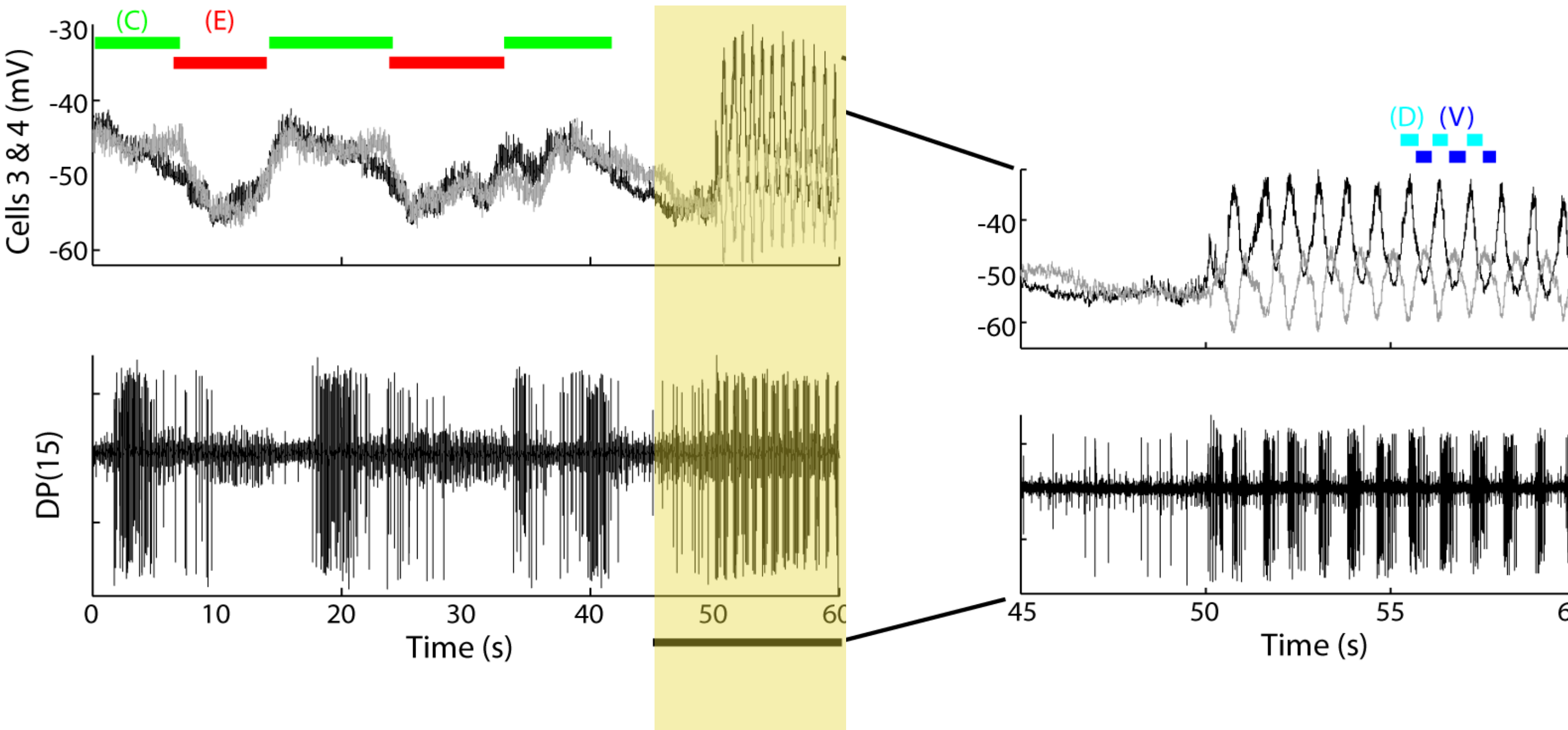
Optical activity in motor neurons during swimming





Data of Adam Taylor

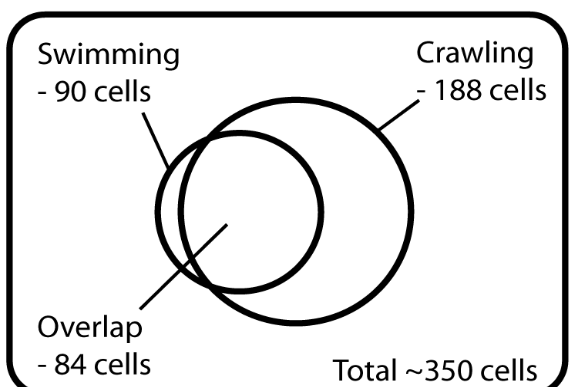
Some neurons are active during both crawling & swimming



Neurons in phase with swim: 90

Neurons in phase with crawl: 188

Total neurons recorded: 350

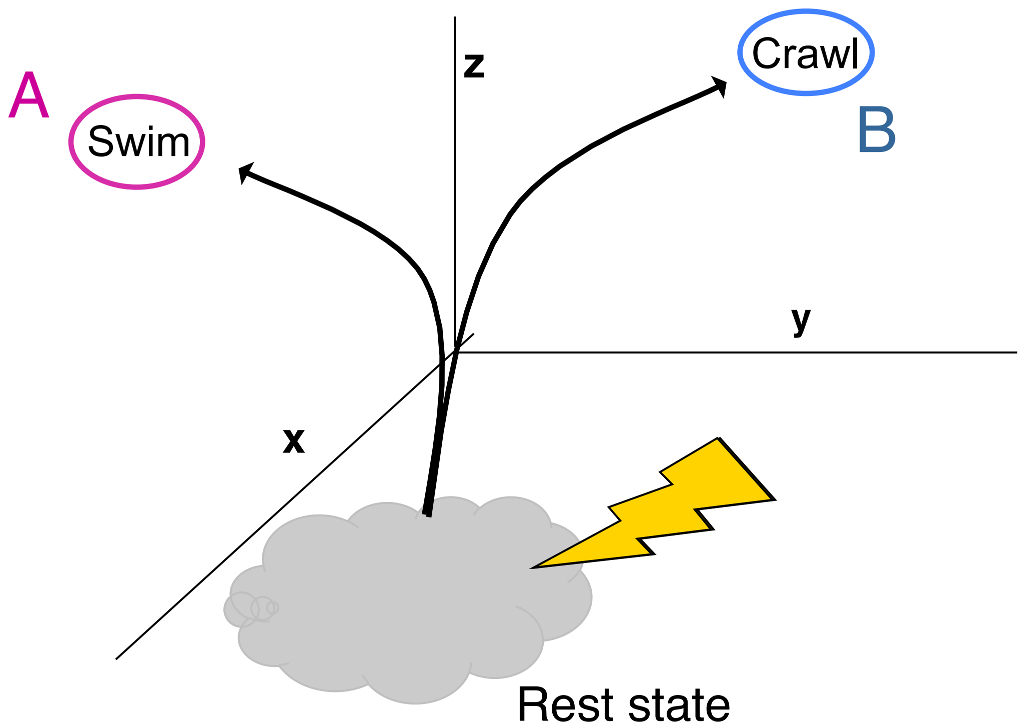


Kevin Briggman

Briggman, Kristan (2006) J Neurosci.

How swimming and crawling interact

Swimming and crawling seem to be different dynamic states
of the same neuronal network



Kevin Briggman

Neurophysics of sensory navigation

How animals sense and move in a stimulus gradient

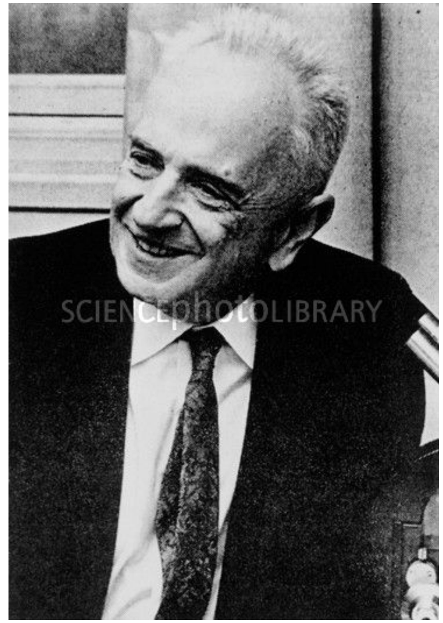
Two recurring strategies:

1. Spatial difference: two (or more) receptors at one time.
2. Temporal difference: two (or more) measurements of the same receptor(s) at different times.

- could be continuous or discontinuous gradient.
- during movements either along or across the body axis.

Three projects, each looking at different gradients in different worms:

Worm	**Gradient**	**PIs**	**Students**
Planarian	Stationary light	Collins/Kristan	Akihiro Yamaguchi
Small leech	Stationary mechanical (roughness)	Weisblat/Kristan	Jiayin Hong
Big leech	Moving light and water waves	Wagenaar	Jess Kanwal



Theodosius Dobzhansky*, "Nothing in Biology Makes Sense Except in the Light of Evolution" (1973)*

Kristan dictum (2018): Nothing in neuroscience make sense except in the light of behavior
……and even then, not always!

Janis Weeks


Shawn Lockery


John Lewis


Kevin Briggman


Mike Baca


Jason Pipkin


Joyce Murphy


Kathy French


Eric Thomson


Mike Baltzley


Paxon Frady


Krista Todd


Daniel Wagenaar

Behavioral choice group

KRISTAN LAB

* Kevin Briggman
Tim Cacciatore
Teresa Esch
Paxon Frady
Kathy French
* Quentin Gaudry
* Chris Palmer
Brian Shaw
Adam Taylor
Krista Todd
Daniel Wagenaar

COLLABORATORS

UCSD:
David Kleinfeld
Roger Tsien
Tito Gonzalez
Evan Miller
Gary Cottrell
Henry Abarbanel

Karen Mesce-U Minn
Eric Horvitz-Microsoft Research
Peter Brodfuehrer-Bryn Mawr

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- Richard Geckler

Some hard-won wisdom:

- If you can think of a possible mechanism, it will be found somewhere
  ….along with several others you never imagined.

- There are few clear dichotomies in biological systems…
  reality will always be "both", "in between", or "other".

- "Model system" is a slippery concept, depending on the definition*:
  1. A substitute for the real system (e.g., human)
  2. The best system for approaching a given problem

- There is no such thing as a "simple system"!

- New tools (e.g., molecular, imaging, computational) are extremely effective
  —be prepared to use them all!

*See: Katz PS (2016) "Model organisms" in the light of evolution. Curr Biol 26:R1-R2.

SUMMARY AND SPECULATIONS

Decision-making can use a number of mechanisms:

- inhibition of sensory input (feeding inhibits everything else) ….sledge hammer
- inhibition of command neurons (feeding inhibits withdrawal in *Pleurobranchaea*)
- alternative states of shared decision-makers (swimming/crawling) ….velvet glove

Decisions may be made in stages:

- take some action (“do something”)
- broad decisions (“get out of here”)
- more specific decisions (“swim” or “crawl”)

Some neurons have multiple functions (cell 208 is a decision-maker and a swim CPG neuron).

Pure speculation: most neurons in complex brains are multifunctional, because new behaviors arise in evolution by using neurons that already have a function.

A consequence of multifuntional neurons: quick transitions between behaviors:

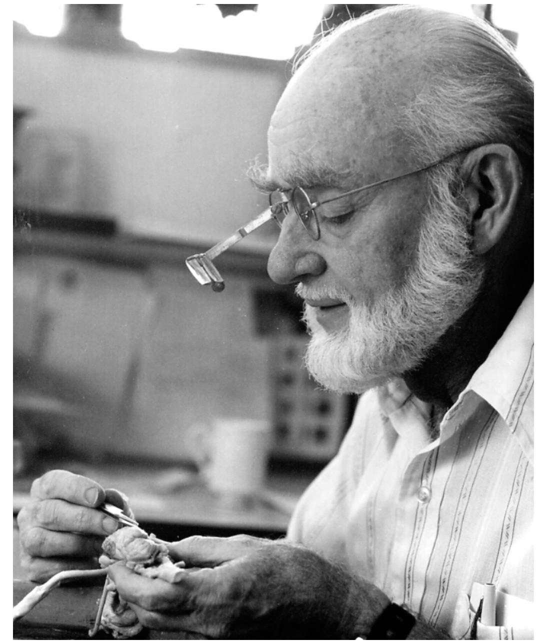
Why a leech?

August Krogh
(1874-1949)

Danish comparative physiologist

“For such a large number of problems there will be some animal of choice, or a few such animals, on which it can be most conveniently studied."

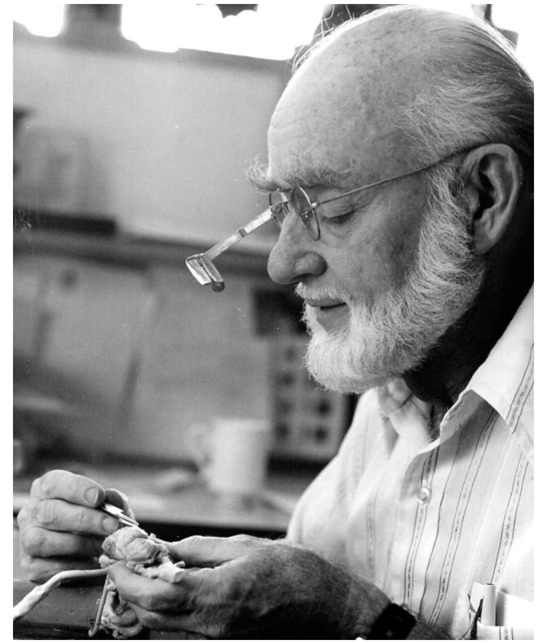
“Krogh’s Principle”



Ted Bullock
(1915-2005)
“Use the best animal to answer any particular question”

Why a leech?

Walter Heiligenberg
(1938-94)
“Use the champion animal”



Ted Bullock
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“Use the best animal to answer any particular question”

Why a leech?

1. Can study a neuronal circuit from sensory input to motor output.

   Can drive each circuit into the ground.

   Totally.

2. Its behaviors are distinct and robust.

3. Its neurons are readily recordable,
   with both electrodes and voltage-sensitive dyes.

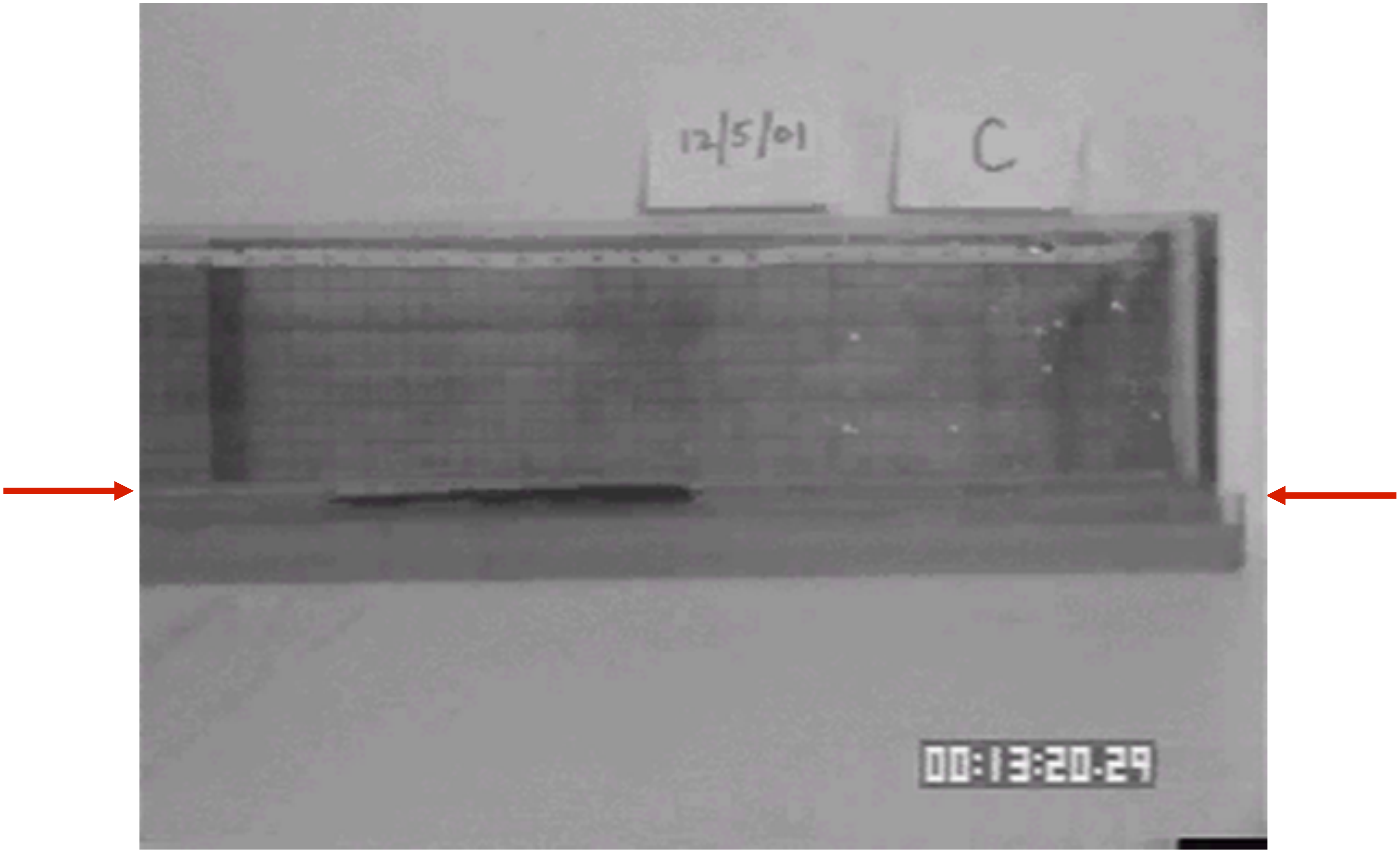
4. Its neurons are identifiable from animal to animal.

5. It has just the right number of neurons:

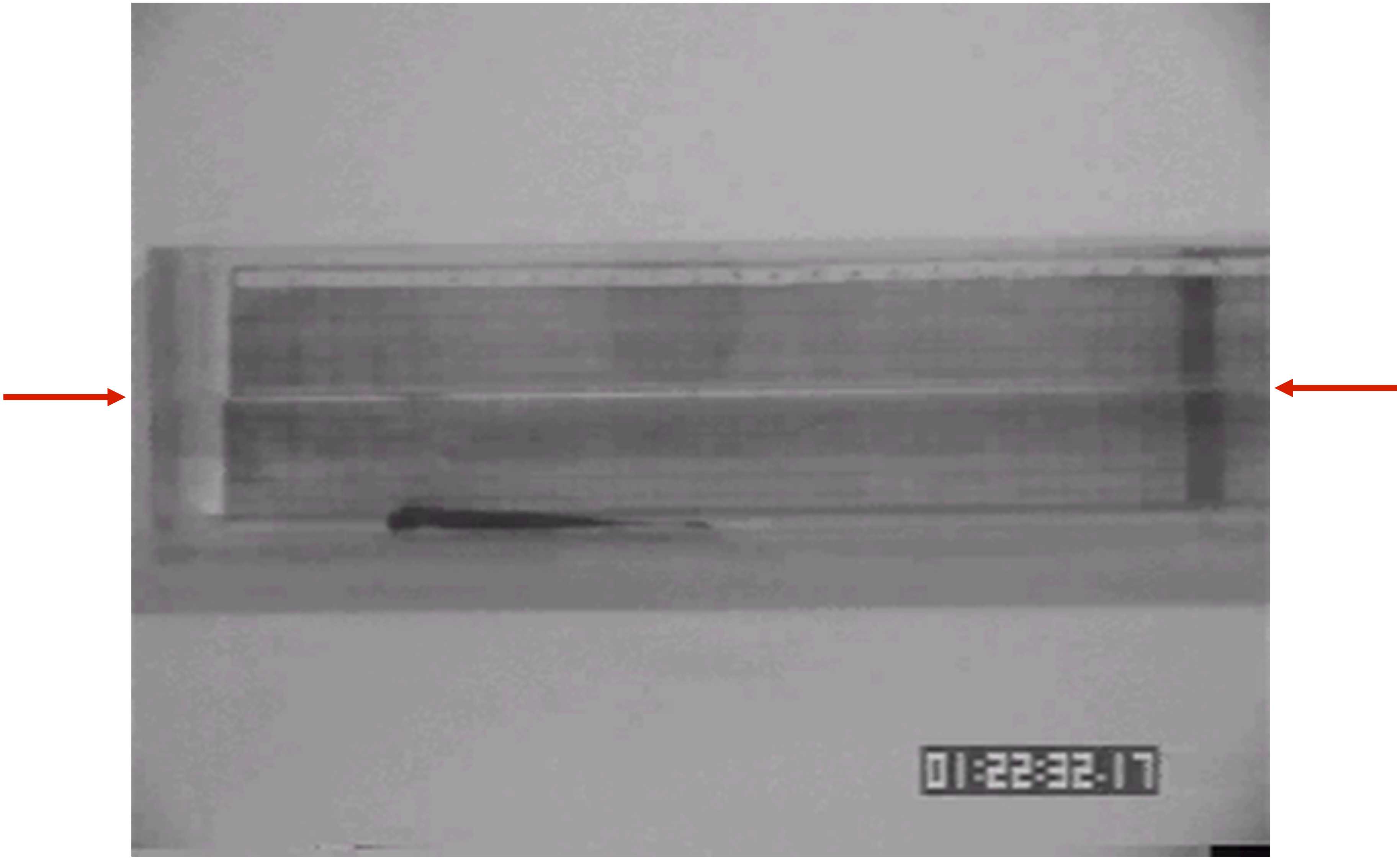
   - circuits are similar to those in more complicated animals.
   - because there is little or no redundancy,
     can test for necessity and sufficiency at the cellular level;

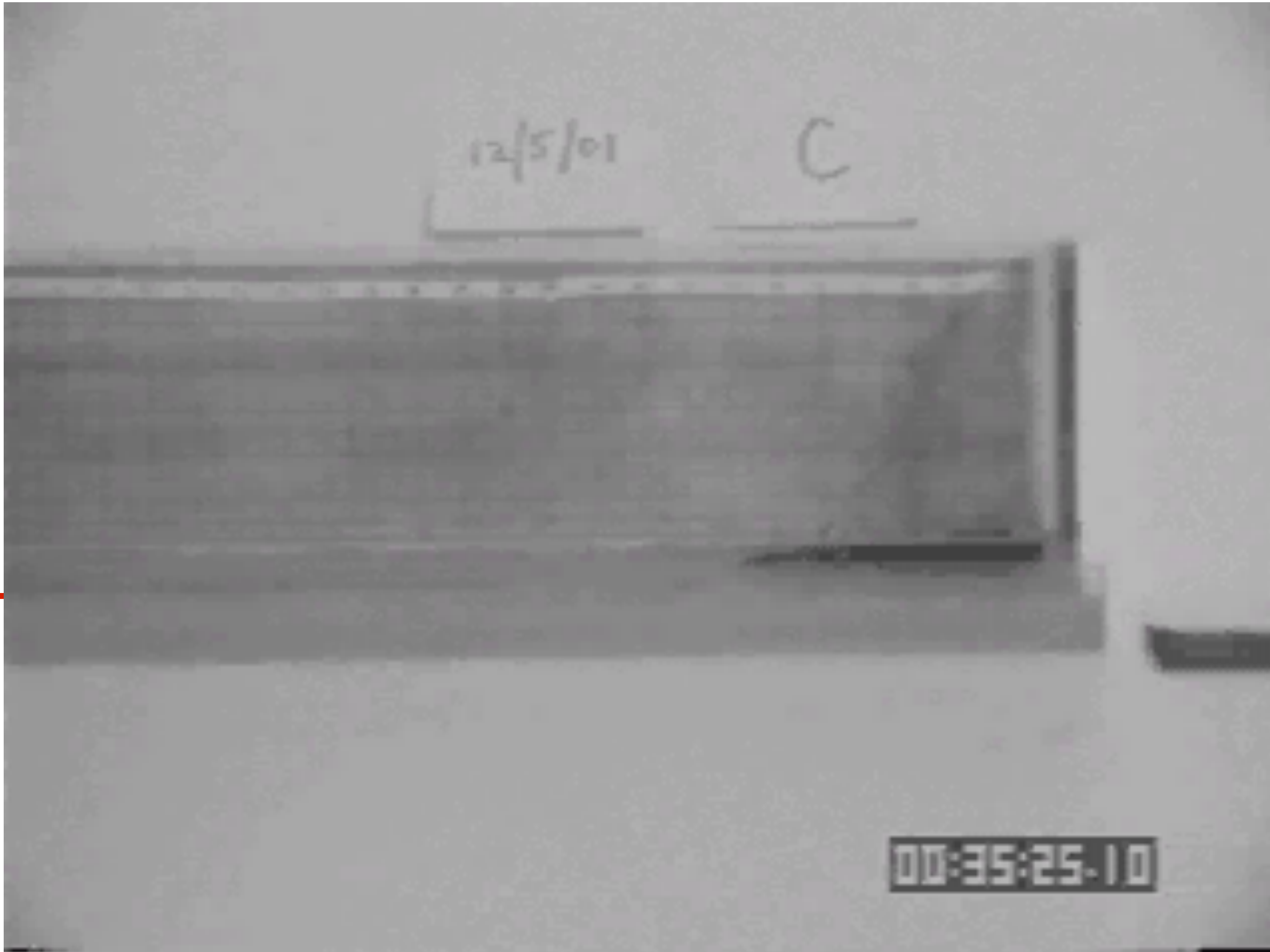
     i.e., a single neuron affects behavior.

Leeches make decisions to crawl……



…..or to swim

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