Against Mind-Blindness: Recognizing and Communicating With Unconventional Intelligences

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http://thoughtforms.life/

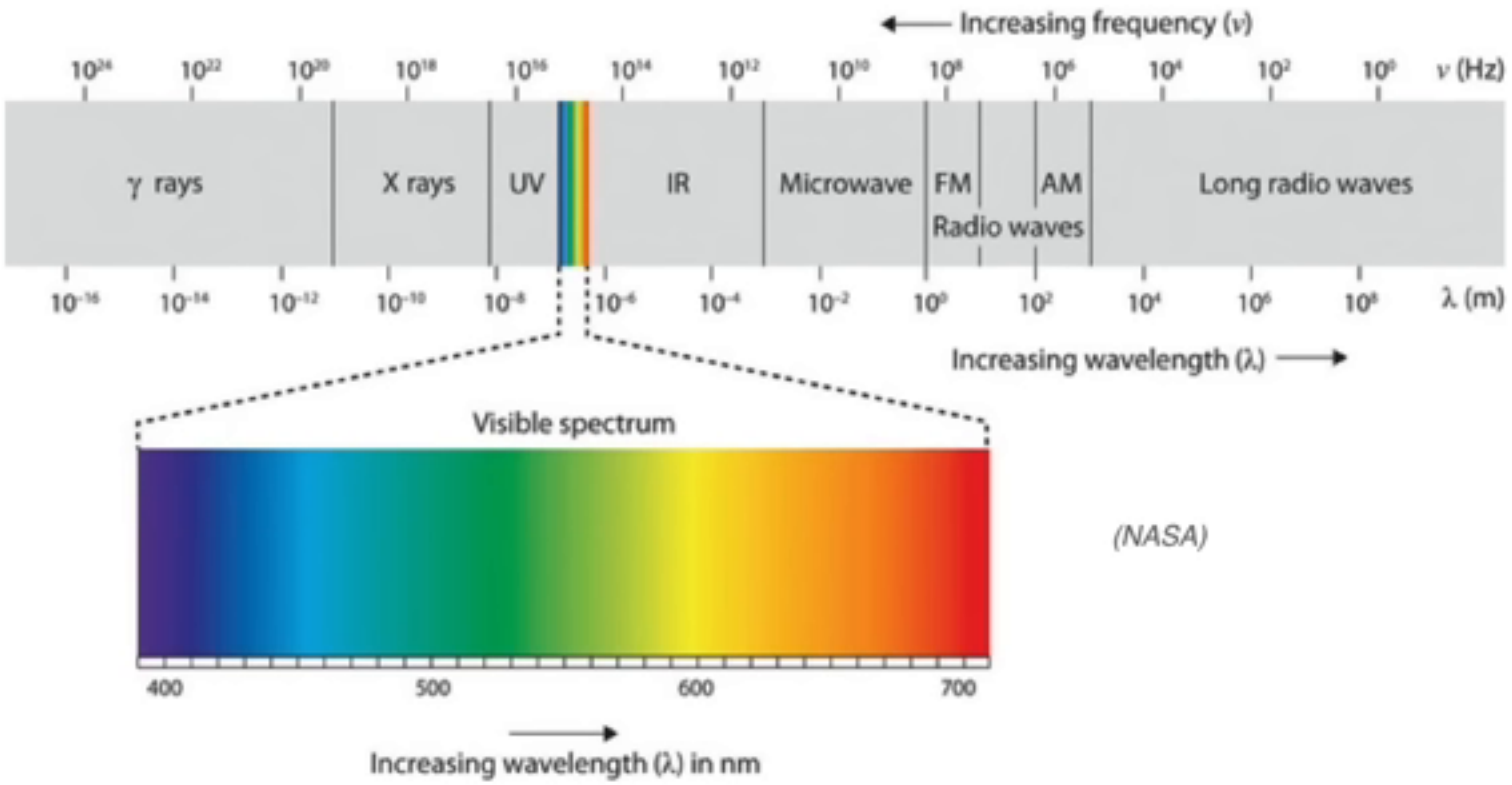
ALLEN DISCOVERY CENTER at Tufts University

Computer-designed Organisms
TUFTS UNIVERSITY | UNIVERSITY OF VERMONT

WYSS INSTITUTE

HARVARD

The Power of Unification: spectrum of cognition

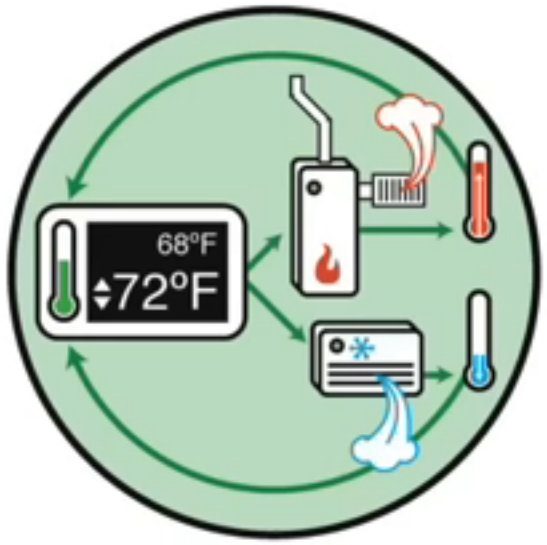


(NASA)

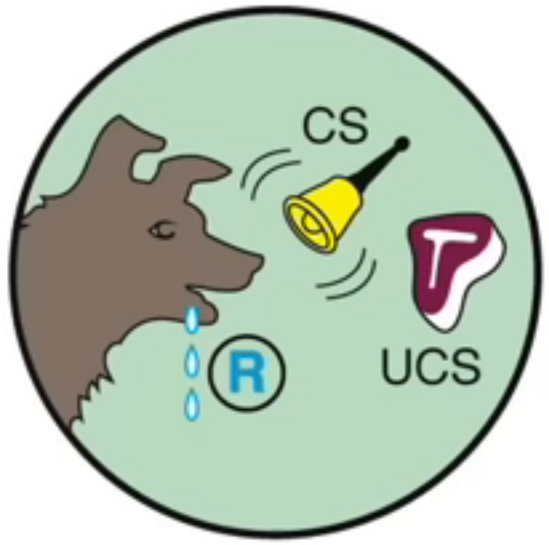
- understand how diverse phenomena are a continuum
- create technology to observe and detect parts of that continuum of which we were previously oblivious
- utilize this knowledge for a myriad of applications that improve quality of life

Axis of Persuadability:

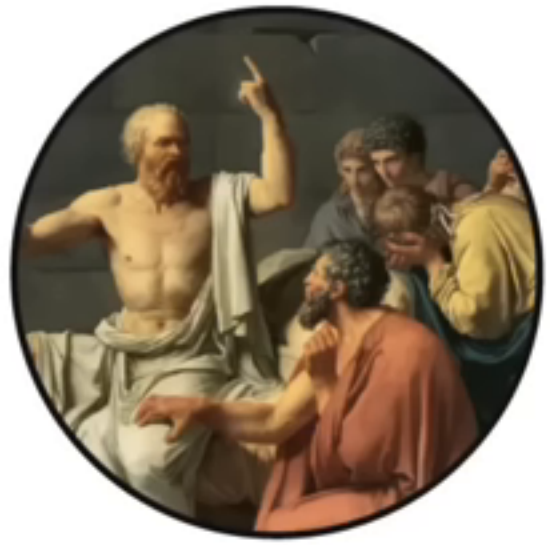
Hardware modification only process



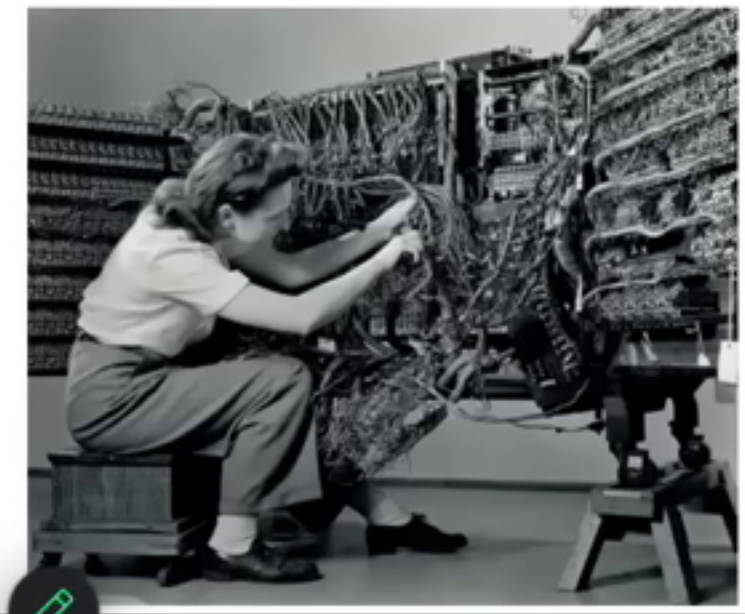
Modify the data encoding setpoint of goal-driven



Training by rewards/ punishments



Communicate cogent reasons

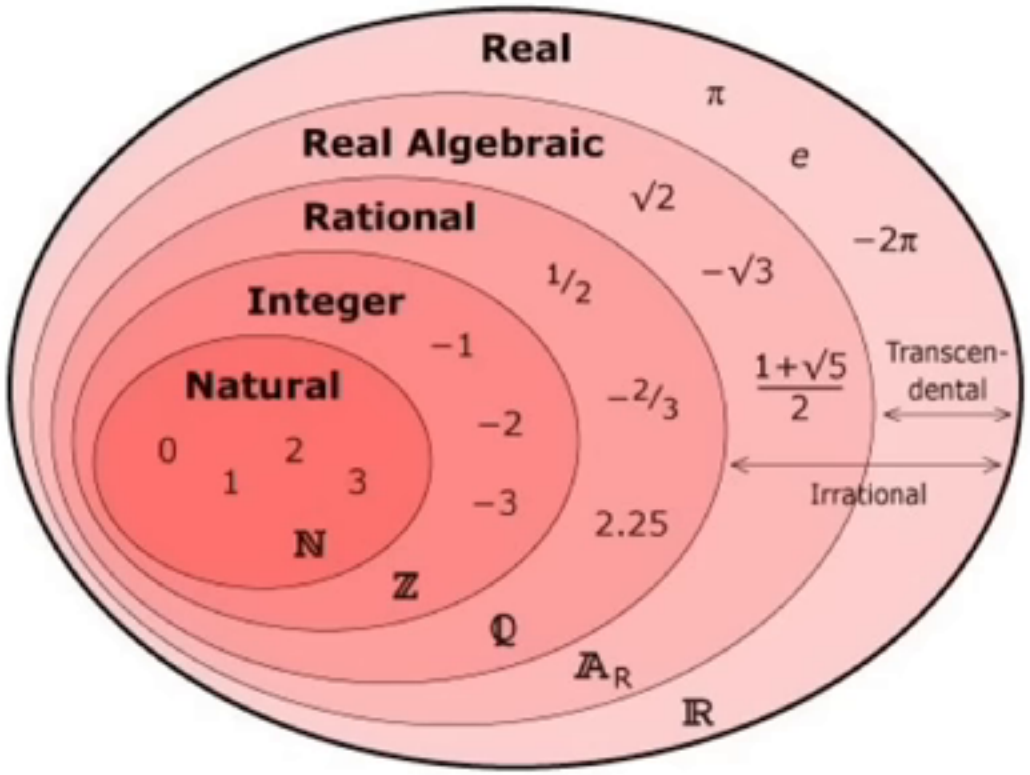


Intelligence is to be decided empirically, not via stale philosophical categories

Cognitive claims are interaction protocol claims

-> better technology
-> better ethics

Expanding the Set of Cognitive Kin



https://in.pinterest.com/pin/627970741770398254/

frozen patterns

active patterns

evolved +
designed +
hybrid agents

all
biologicals

complex
life forms

brainy
animals

For each new category

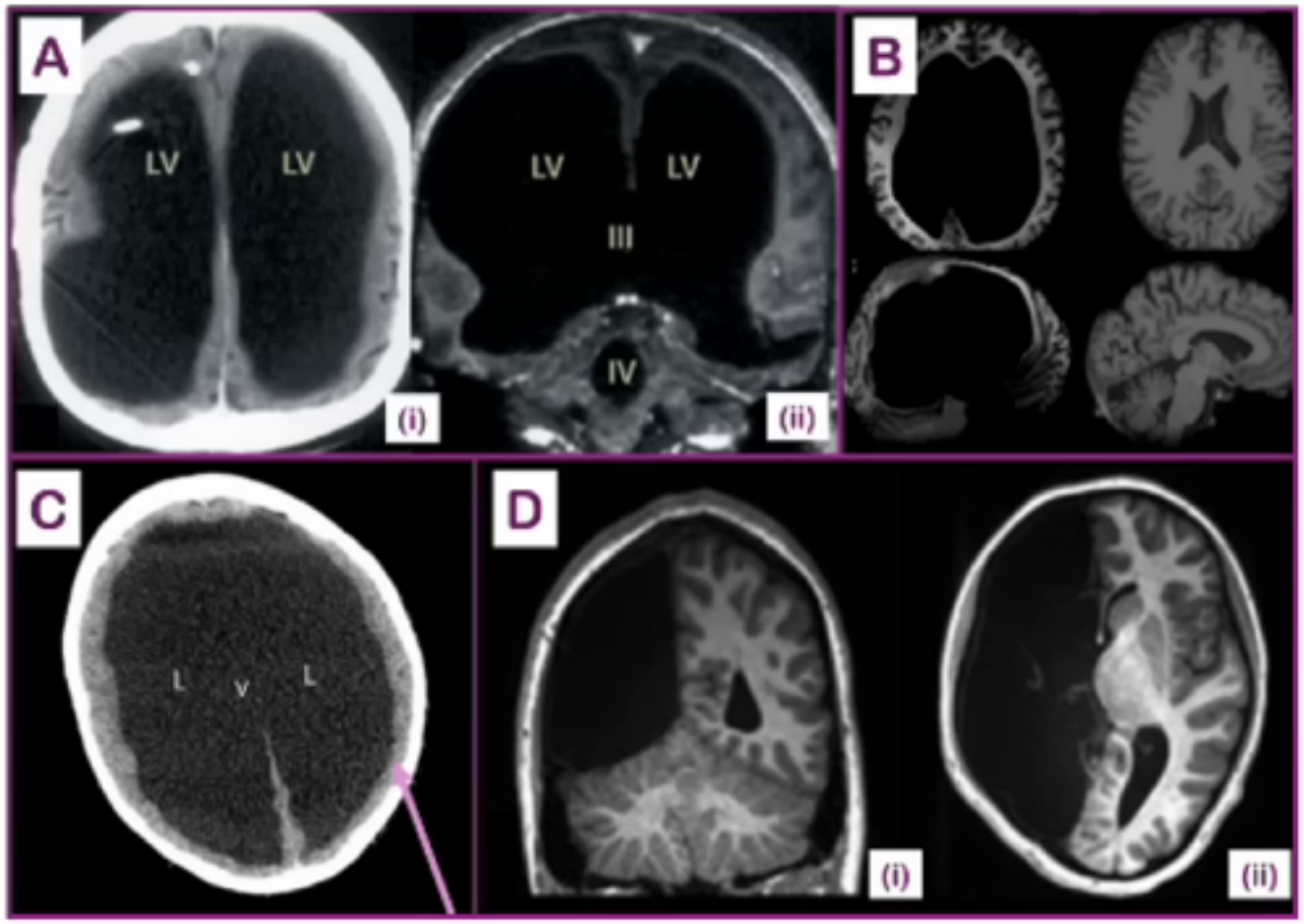
- conceptual leap needed
- what does it break?
- recognize them
- do something useful with them
- active compassion toward them

Easy to Detect Mind in Brainy Mammals

https://www.youtube.com/watch?v=f75Vet_sJNo

Why so obvious? Same spatiotemporal scale, same space, similar goals

Even with brains, things are not simple



Minimal brain structure

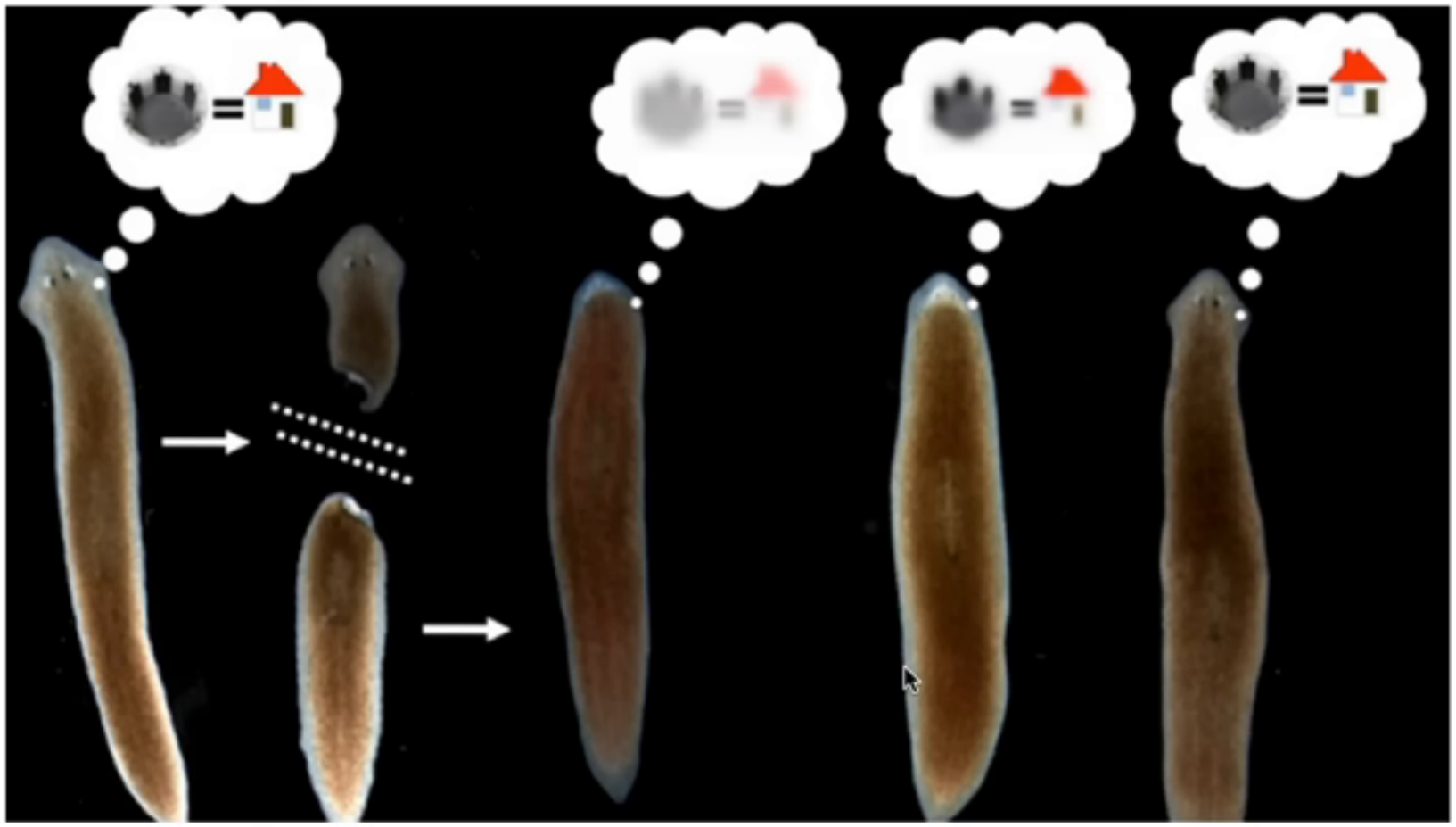
or function (Savant syndrome)

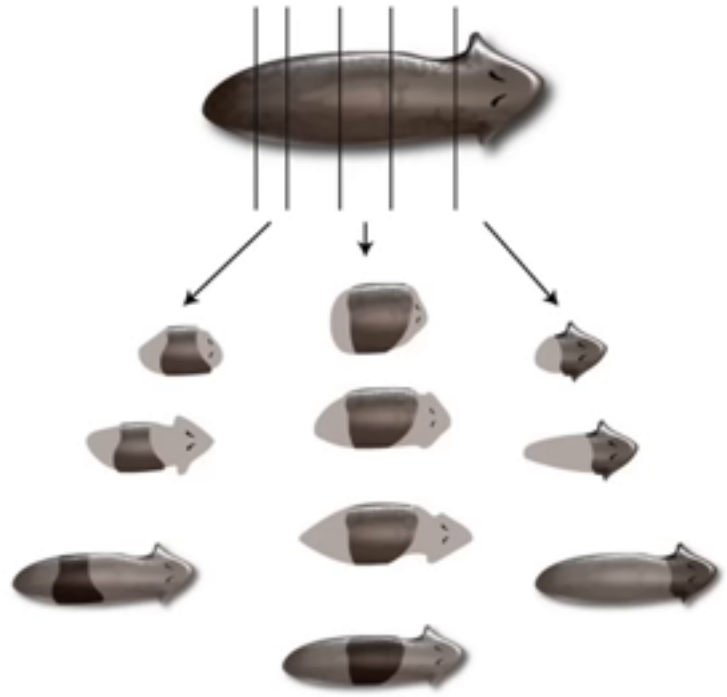
cases of high performance

Figure 2. Select cases of reductions in brain matter with normal function. **[A]** Image from (Feuillet *et al.* 2007) showing a white collared worker case of extreme hydrocephalus; he led a normal life as a civil servant, who possessed an average IQ of 75. During his neurological assessment at age 44, his (i) CT scan and (ii) T1 weighted MRI scans with contrast showed extreme ventricular enlargement. LV indicates lateral ventricle, III and IV indicate the third and fourth ventricles, respectively. **[B]** Image from (Alders *et al.* 2018), showing the case of a 60-year-old with a bad mood with massive ventriculomegaly and severely reduced cerebral mantle and corpus callosum, that went largely unnoticed. The left column is T1 weighted MRI images taken in the transverse, coronal, and sagittal planes of the patient. The right column represents T1 weighted MRI scans of a healthy control. **[C]** Image from (Persad *et al.* 2021), imaging of a Canadian living a normal, independent life with massive hydrocephaly. MRI scan taken from the axial view (plane parallel to the ground) at the level of the lateral ventricles (arrow points to extremely thin layer of cortical mantle, LV stands for Lateral Ventricle). **[D]** Image from (Asaridou *et al.* 2020), showing the T1 Weighted MRI scans of a child born without left hemisphere (i) taken in the coronal plane, (ii) taken in the axial plane. The child had normal cognitive development and language skills despite hemihydranencephaly of the left hemisphere and near-absence of the corpus callosum. All images re-used with permission.

Memories Survive Brain Regeneration

Memory stored outside the head, imprinted on regenerated brain





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HYPOTHESIS

Vertically- and horizontally-transmitted memories – the fading boundaries between regeneration and inheritance in planaria

Moran Neuhof[1,*], Michael Levin[2,*] and Oded Rechavi[1,2,3,*]

Biological Intelligence outside the Brain

- Conceptual leap needed: intelligence is older than brains
- What it breaks: scale and substrate
- How to recognize them: anatomical goals, ingenuity
- Useful implications: biomedicine

model system: cells as collective intelligence in morphospace

We are Made of Agential Materials

Lacrymaria = 1 cell
no brain
no nervous system

high competency
at cell-level
agendas

nature reviews bioengineering

https://doi.org/10.1038/s44222-022-00001-9

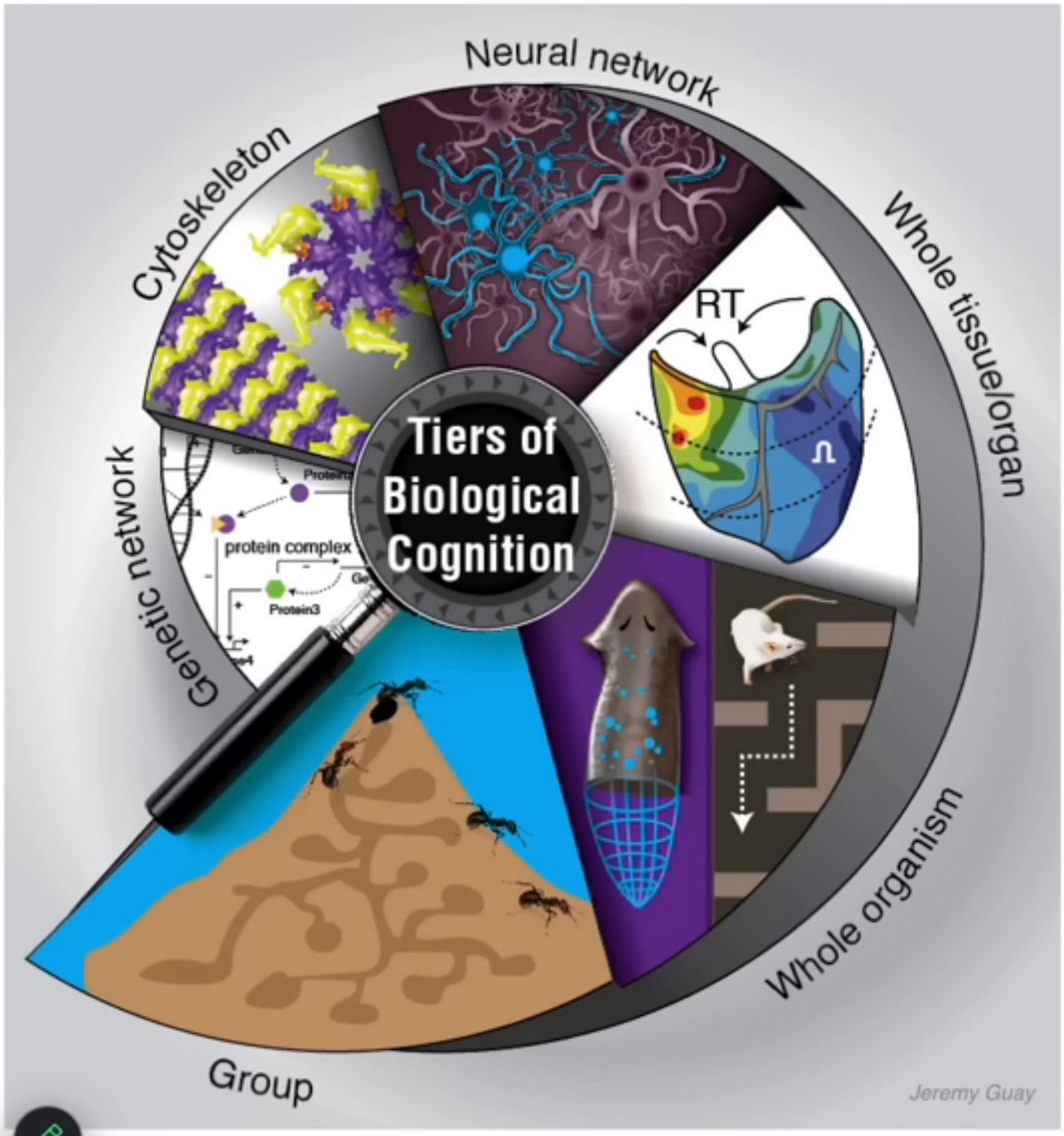
Review article

Check for updates

Synthetic morphology with agential materials

Jamie Davies[1] & Michael Levin[2]

Nested Competency, not Merely Structure



Multi-scale Competency Architecture

each level of organization solves problems in its own space (morphospace, transcriptional space, physiological space, 3D behavioral space, etc.) using some of the same tricks, at various levels of sophistication

Axis of Persuadability:
an Engineering Take on a Continuum of Agency

Hardware modification only

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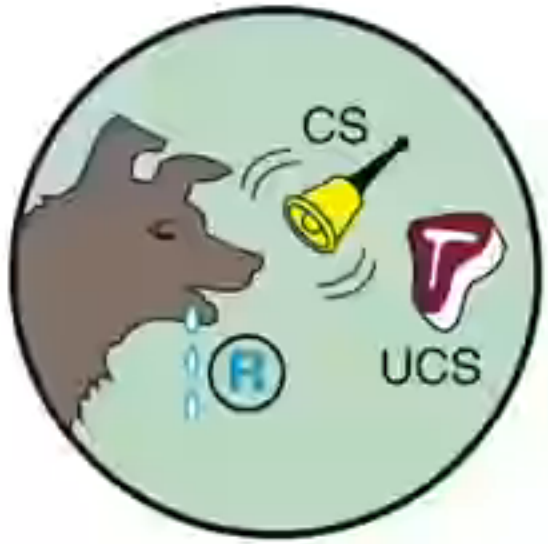

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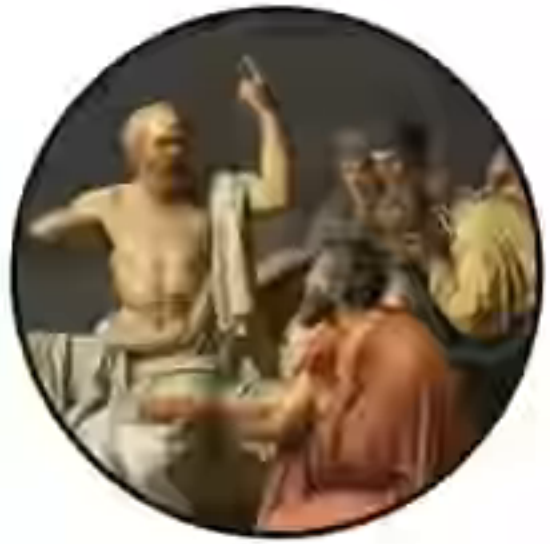

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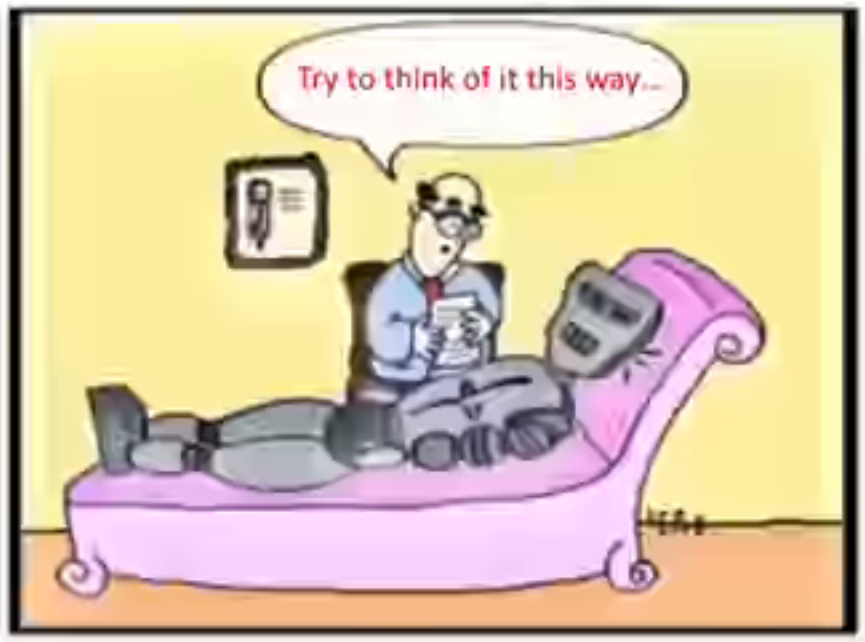
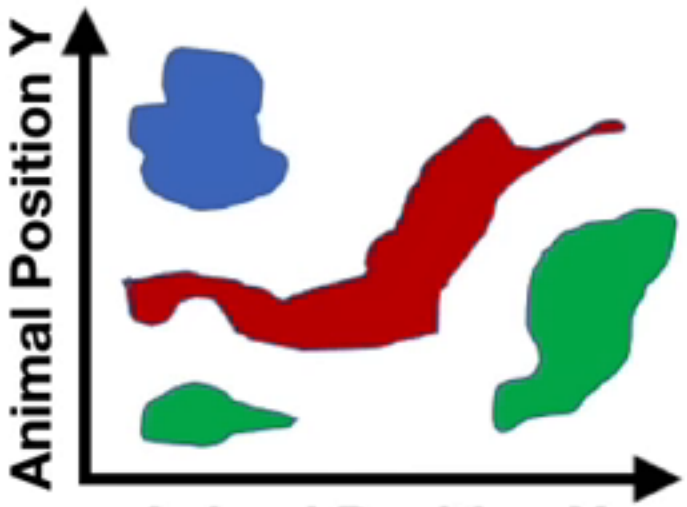


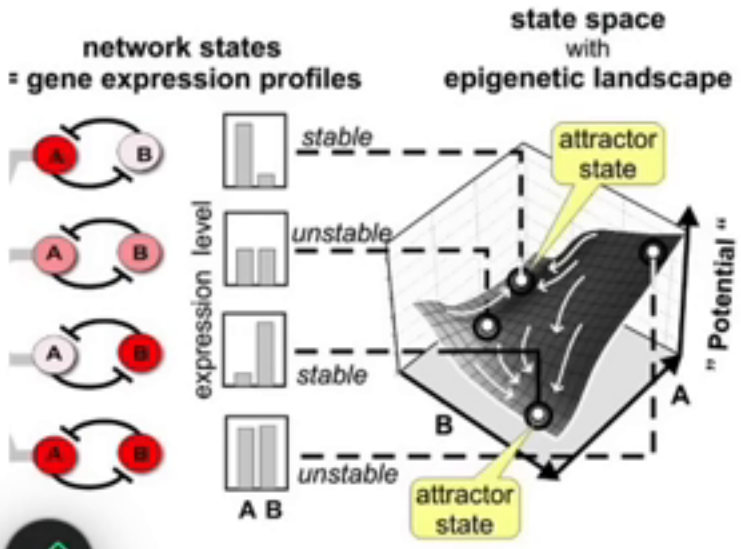
Collective Intelligence of Cells: Competency in Diverse Spaces

3D Space (behavior)



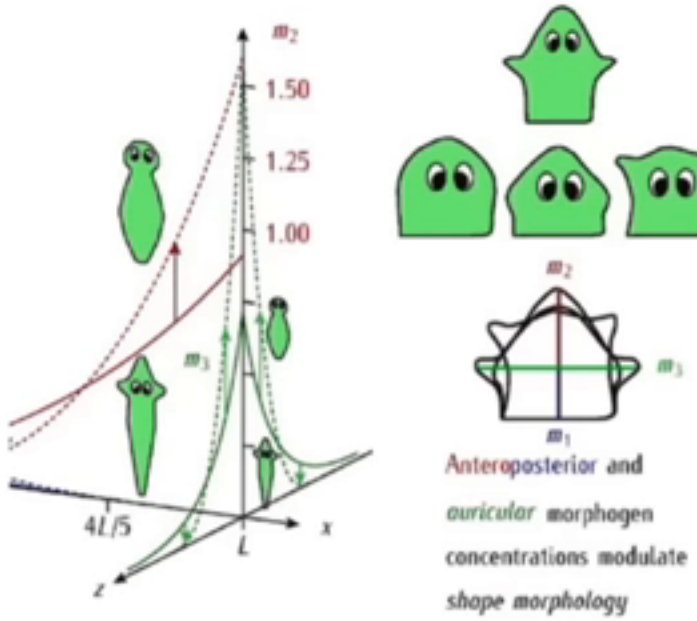
Transcriptional Space

Huang, S.; Ernberg, I.; Kauffman, S., Semin Cell Dev Biol 2009, 20, (7), 869-76.



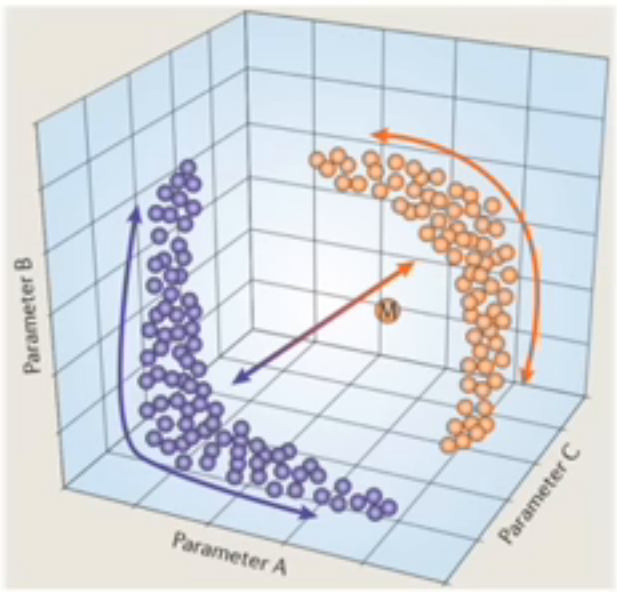
Morphospace

Cervera, J., Levin, M., and Mafe, S., (2021), BioSystems, 209:104511



Physiological Space

Marder, E., & Goaillard, J. M. (2006). Variability, compensation and homeostasis in neuron and network function. Nat Rev Neurosci, 7(7), 563-574.



"Intelligence is the ability to reach the same goal by different means."

- William James

Hypothesis: morphogenesis is a collective intelligence, exerting its behavioral competencies in anatomical morphospace

what kind of collective intelligence do cellular swarms deploy?

- Different time scale (minutes, not milliseconds)
- Different problem space (morphospace, not 3D motion)
- but, same (homologous!) mechanisms - ion channels, GJs, NTs
- and, many of the same algorithms (tools of cog sci work great)

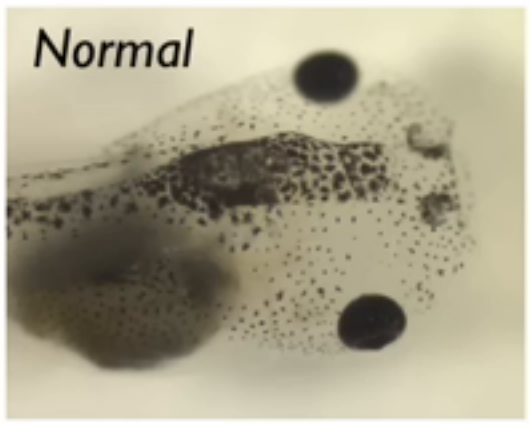
levinlab.dev / FieldSHIFT

Translate from one domain to another

Neuroscience - Detected

Developmental biology

Same anatomy, via different paths



normal development

"as needed" remodeling

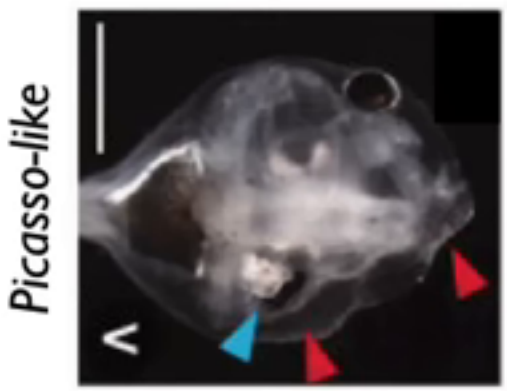
Craniofacial mispatterning

↓

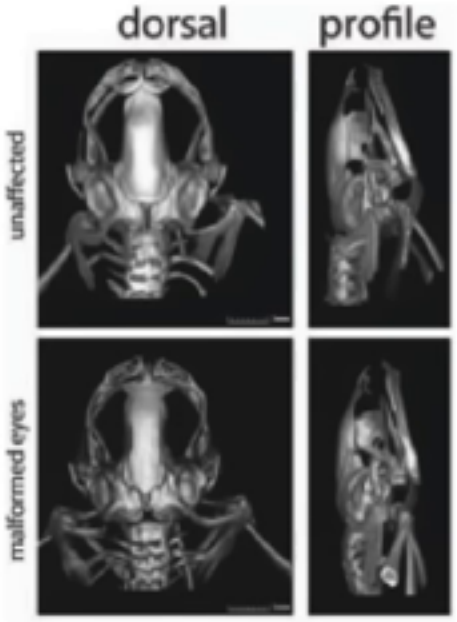
Metamorphosis

↓

Morphometric analysis and modeling reveals: faces fix themselves!!

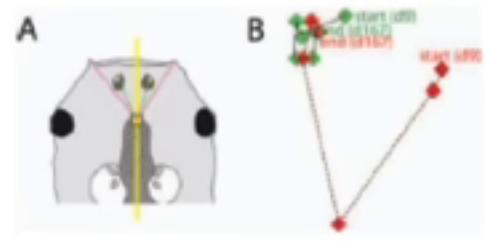


Laura Vandenberg



Genetics does not specify hardwired rearrangements: it specifies a system that executes a highly flexible program that can recognize unexpected states and take corrective action.

Cannot just follow a rote set of steps. How does it know when it's "right"?

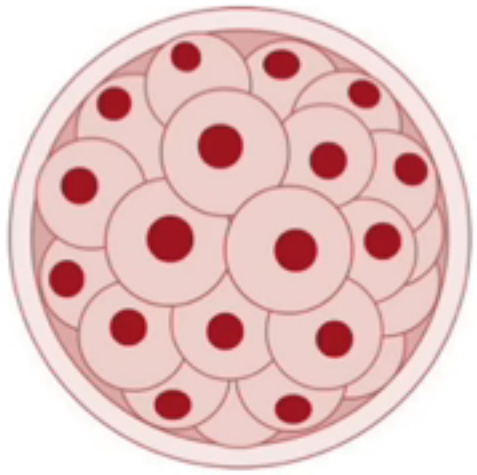


Components of Intelligence:

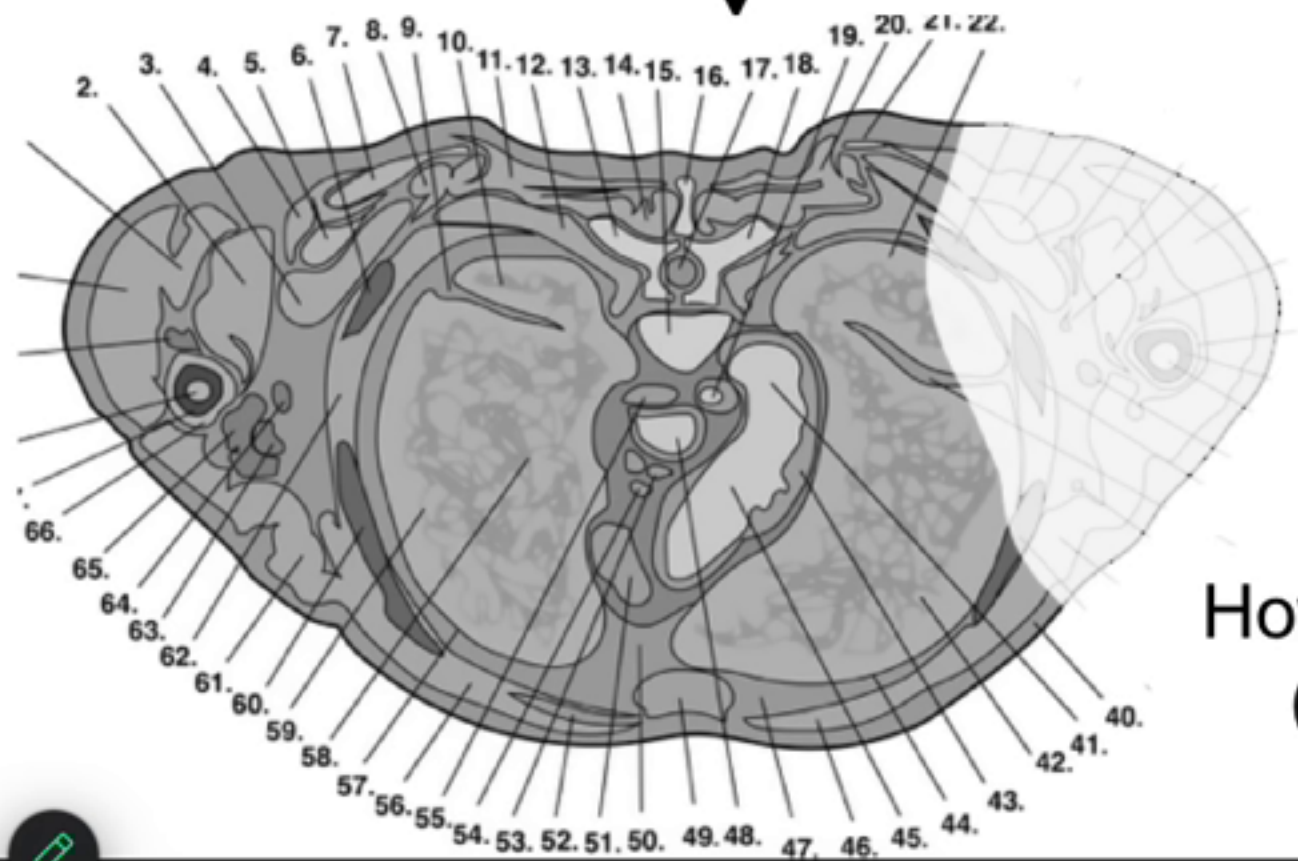
- Homeostasis: the basis of goal-directed activity
- Homeostasis^2: Same ends by different means
- Hierarchical, non-local control
- Hackability (software, not just hardware)
- Learning
- Creative problem-solving toward default goals
- Novel beings, novel goals: never give up

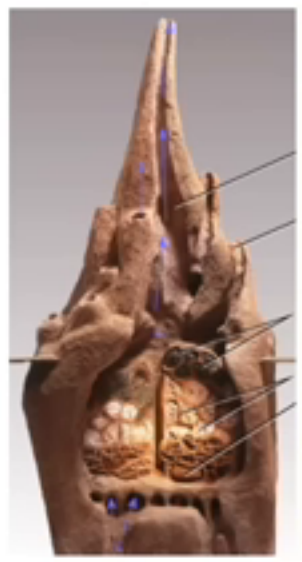
Where do Anatomies Come from?

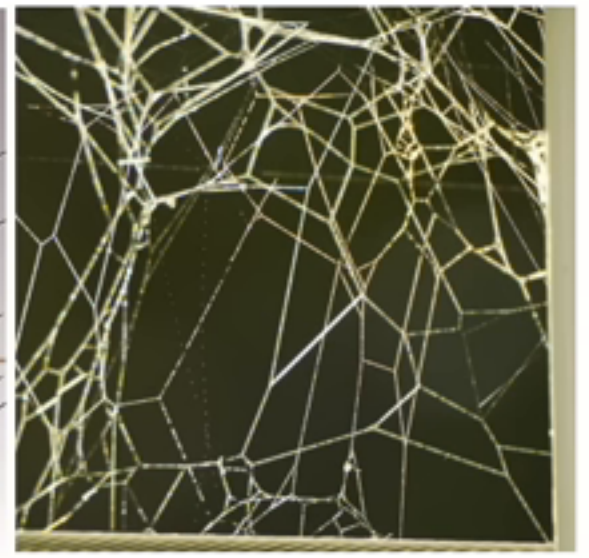
stem cell
embryonic
blastomeres



self-assembly







earthlymission.com

- DNA specifies proteins; whence Anatomy?
- how do cell groups know what to make and when to stop?
- how far can we push shape change? Engineers ask: what's possible to build given default genome?

How to repair (edit) it?

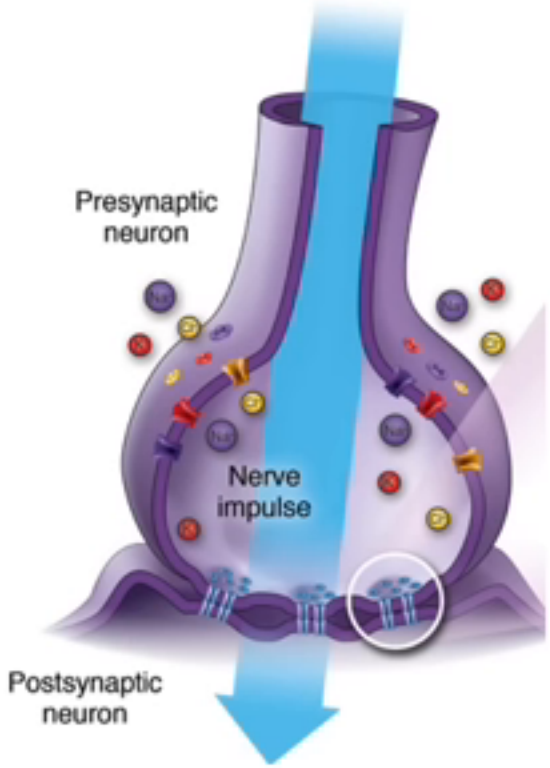
Hardware

gene products -> electric circuits

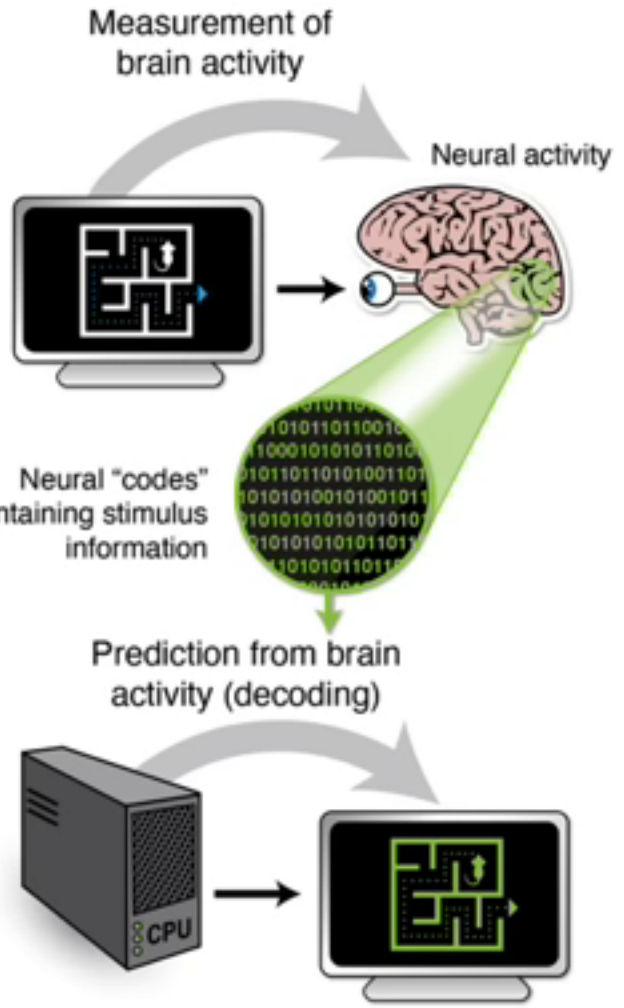
Software

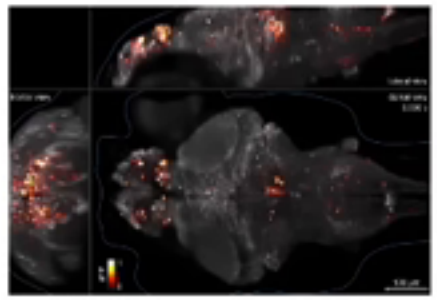
electrical dynamics -> memory

ion channels, electrical synapses



neural

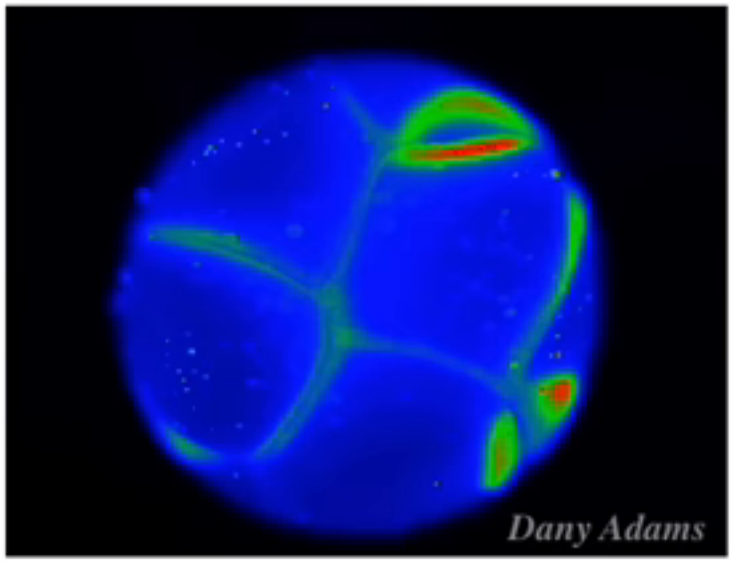




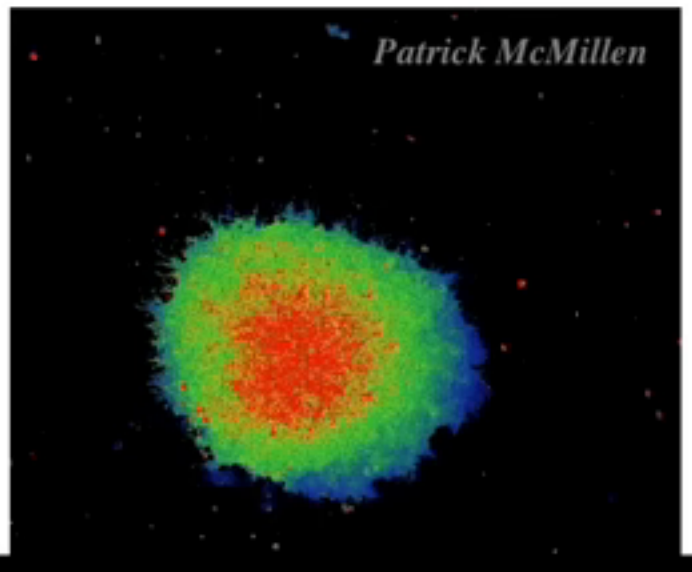
http://www.nature.com/nmeth/journal/v10/n5/full/nmeth.2434.html

How we Detect and Model Bioelectric Signals:

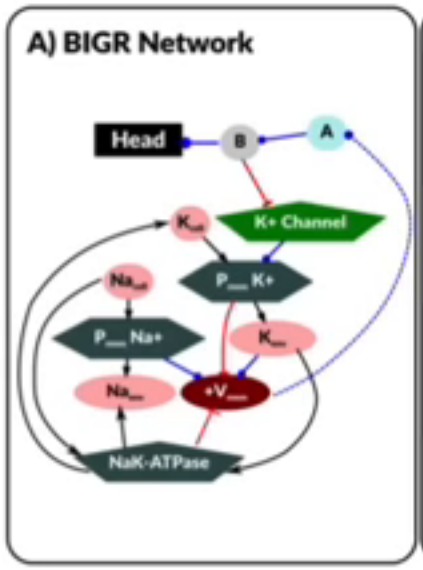
Characterization of endogenous voltage gradients - direct measurement and correlation with morphogenetic events

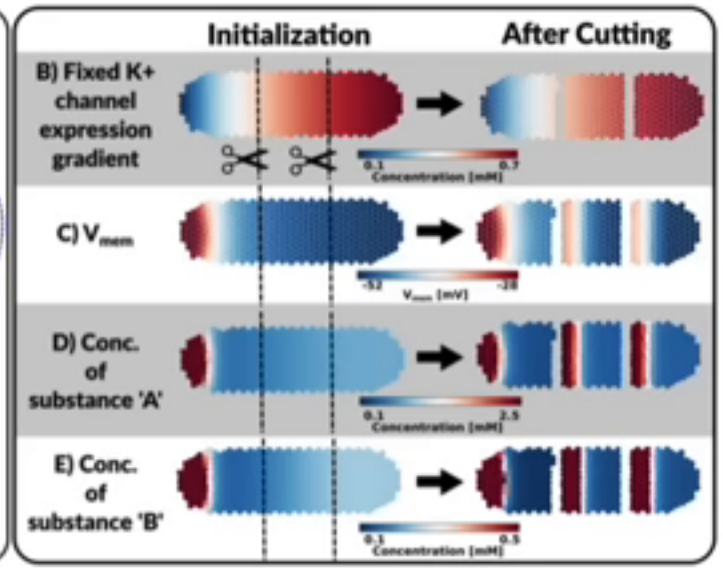


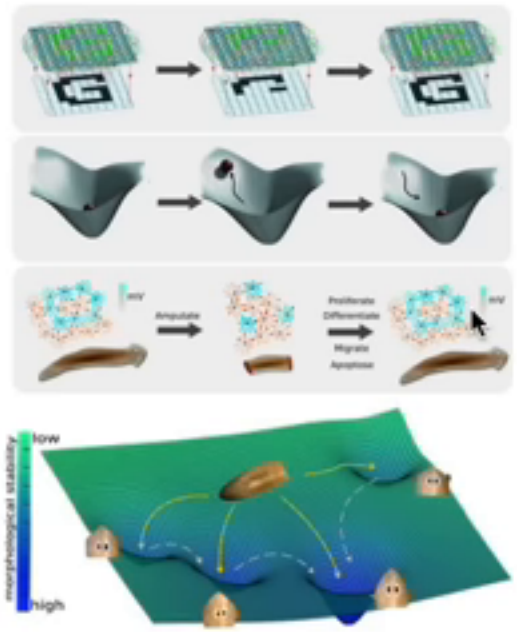
Voltage reporting fluorescent dye in time-lapse during *Xenopus* development

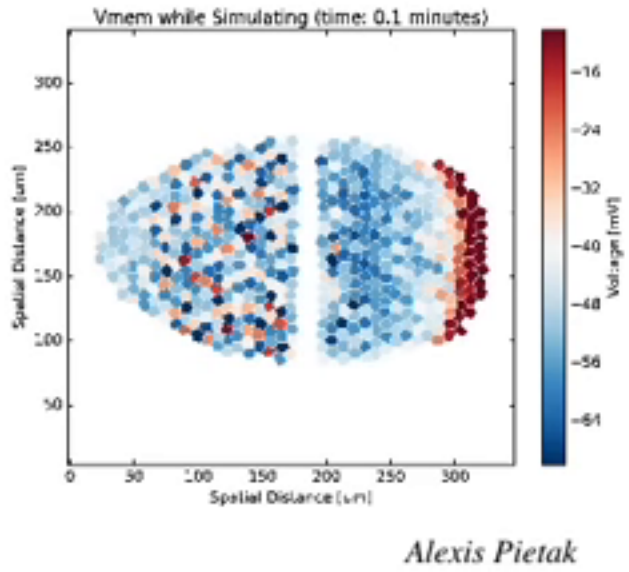


Quantitative computer simulation: synthesize biophysical and genetic data into predictive, quantitative, often non-linear models





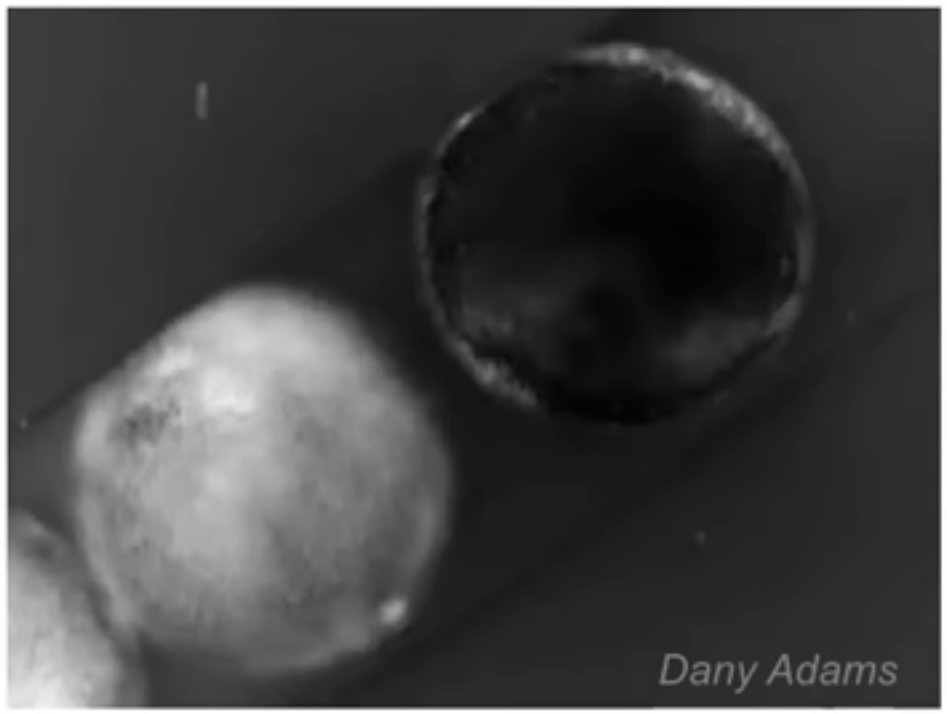


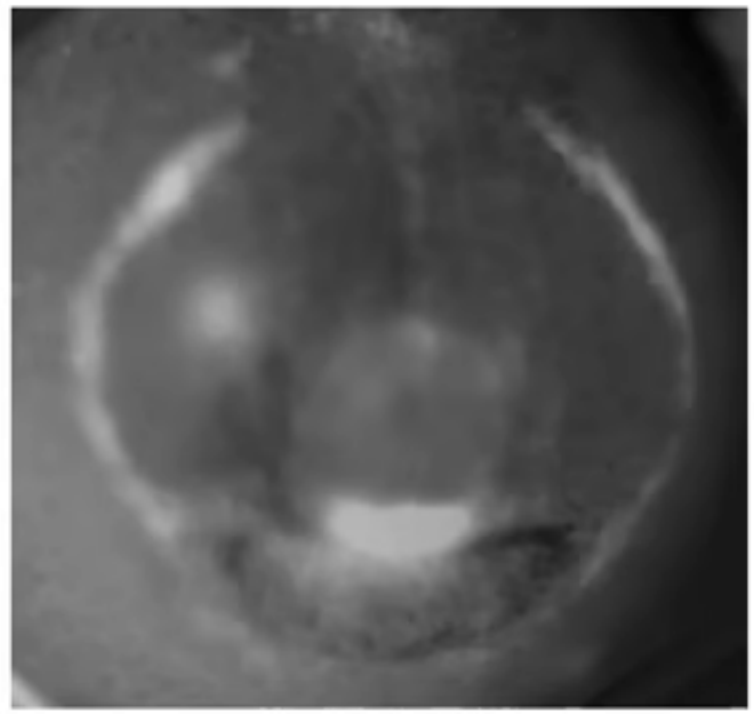


Alexis Pietak

Endogenous Bioelectric Prepatterns:
reading the multi-scale mind of the body

craniofacial development "electric face" prepattern required for normal face

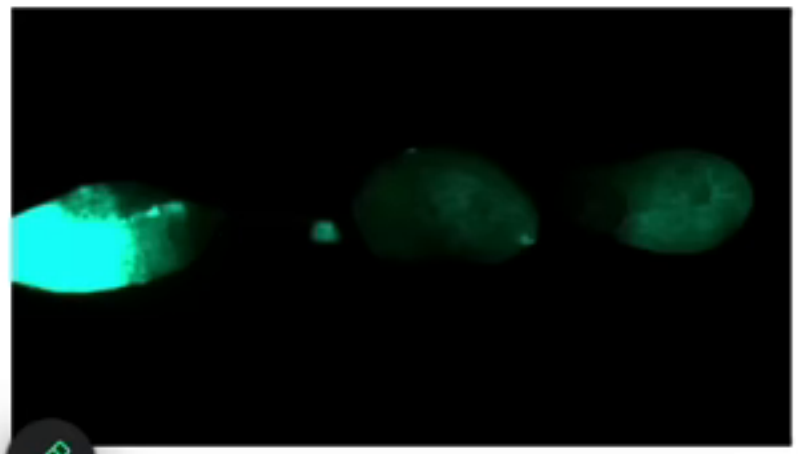




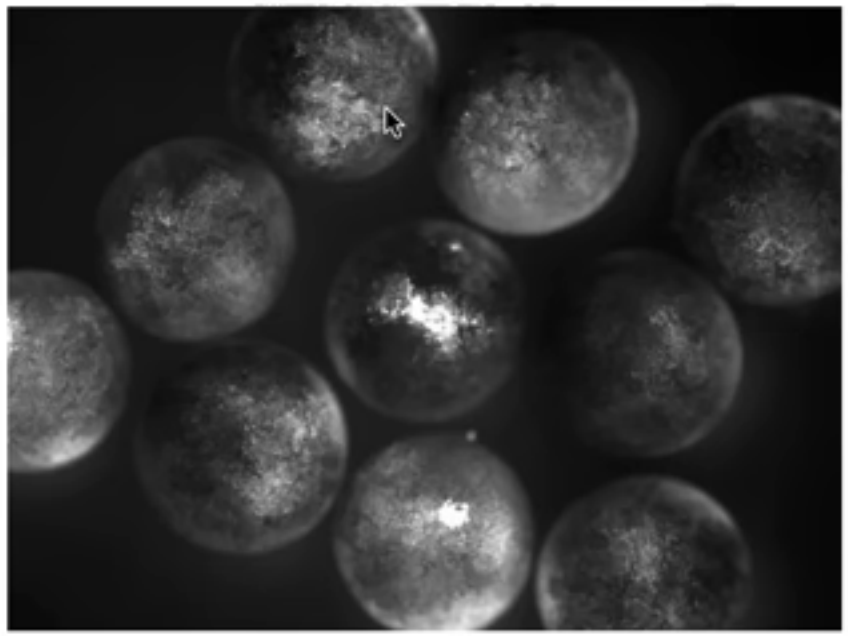
hyperpolarized *depolarized*

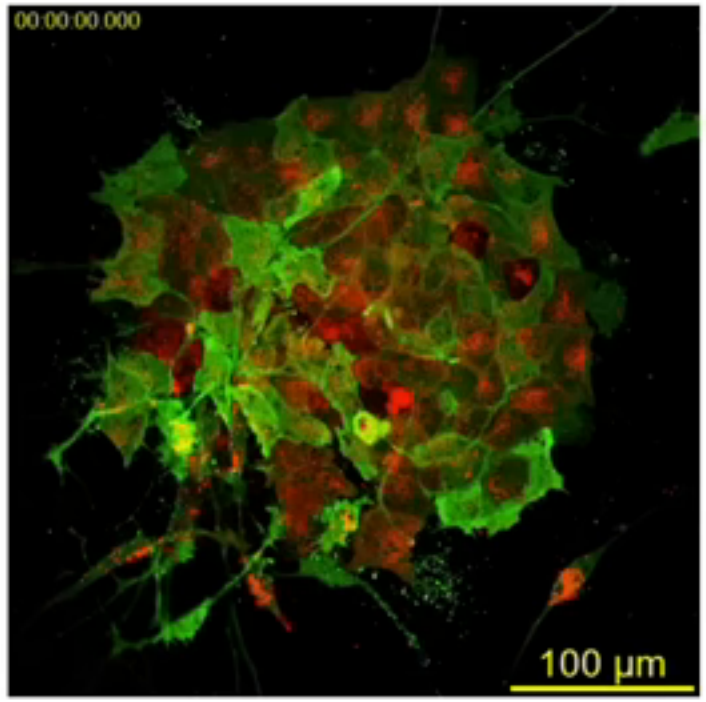
cognitive glue on 2 scales:
cells -> embryo
embryos -> hyperembryo

Patrick McMillen

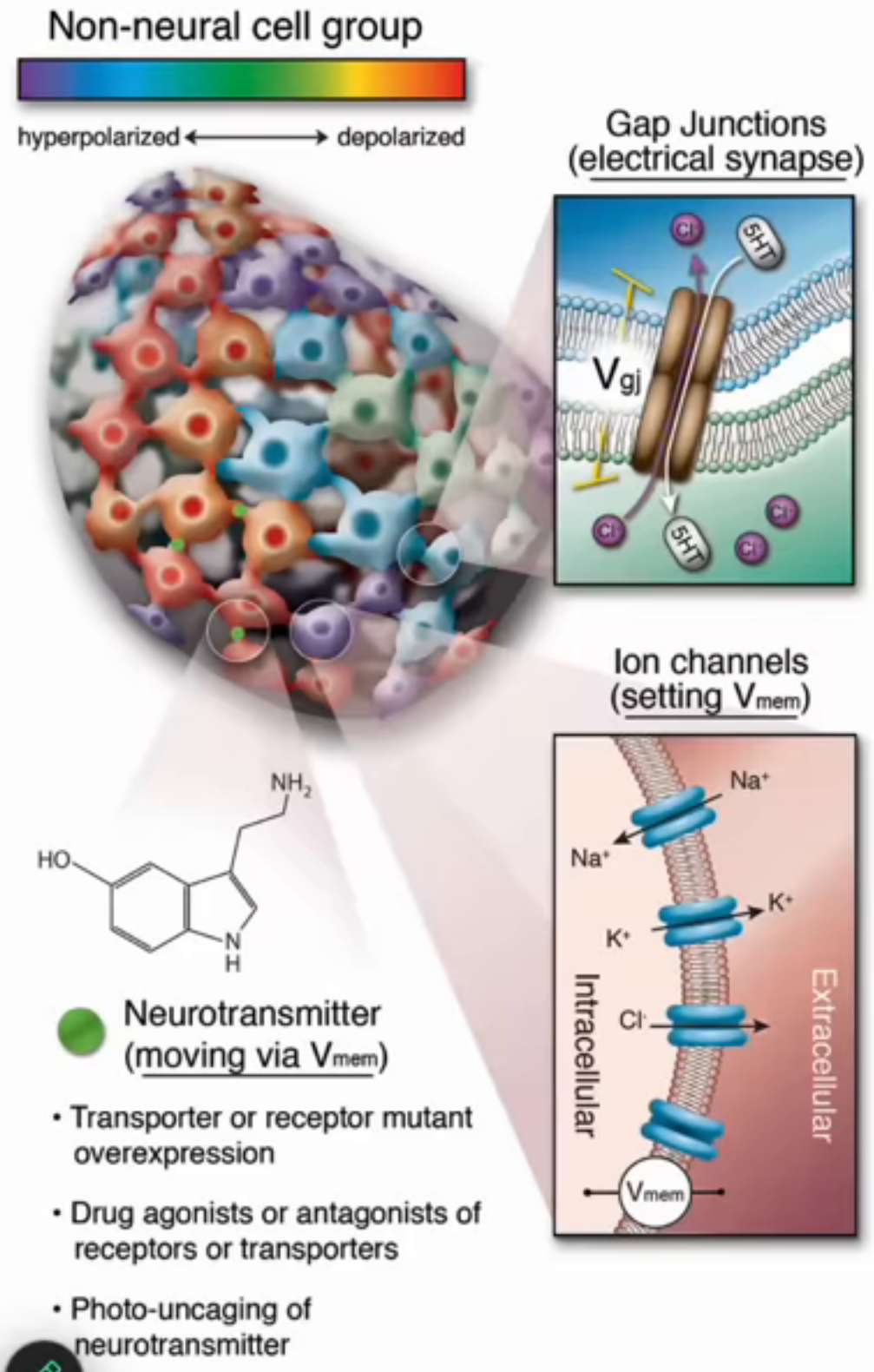


Angela Tung, Megan Sperry





Rewriting Somatic Pattern Memories



Tools we developed
(no applied fields!)

- Dominant negative Connexin protein
- GJC drug blocker
- Cx mutant with altered gating or permeability

Synaptic plasticity

- Dominant ion channel over-expression (depolarizing or hyperpolarizing, light-gated, drug-gated)
- Drug blocker of native channel
- Drug opener of native channel

Intrinsic plasticity

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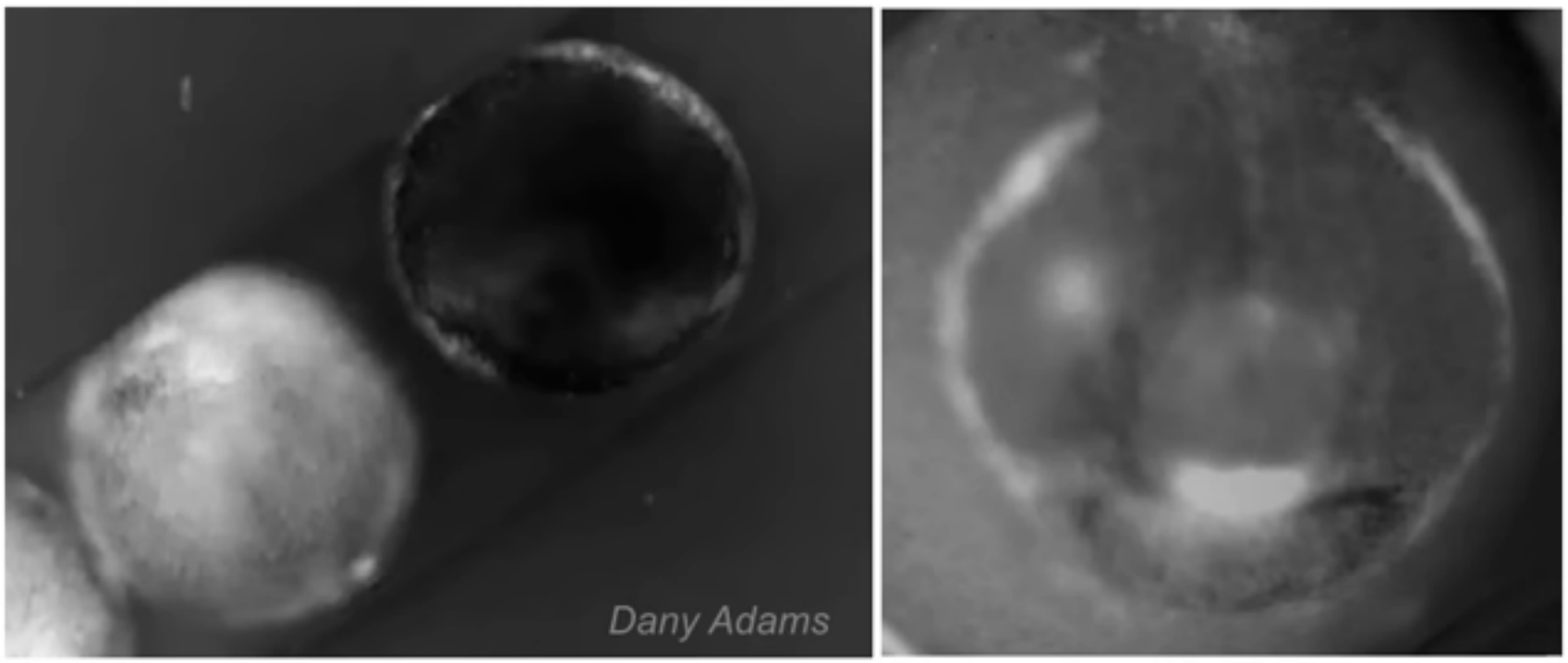

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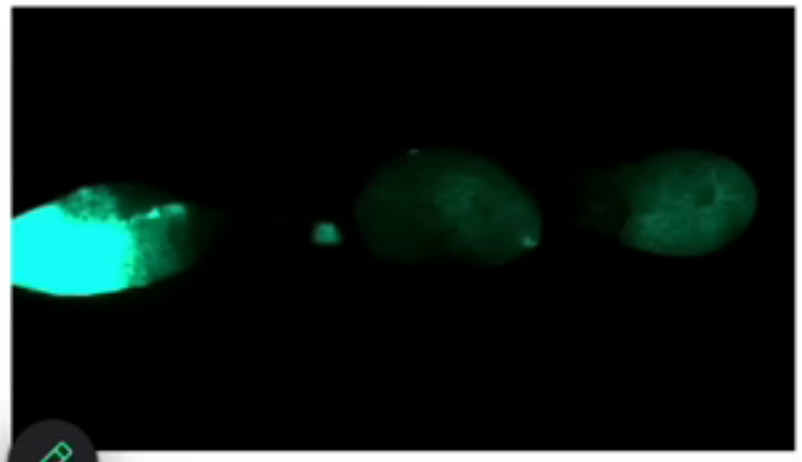

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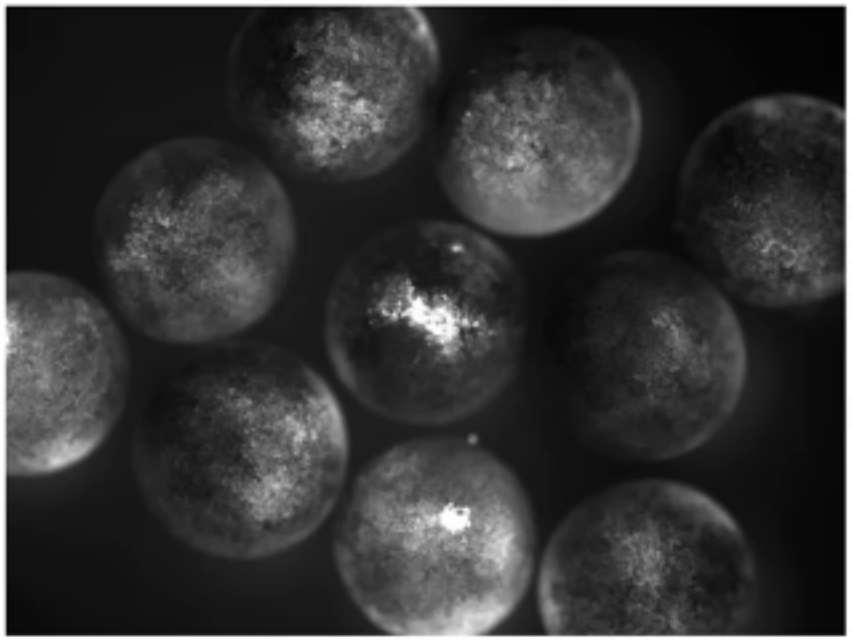

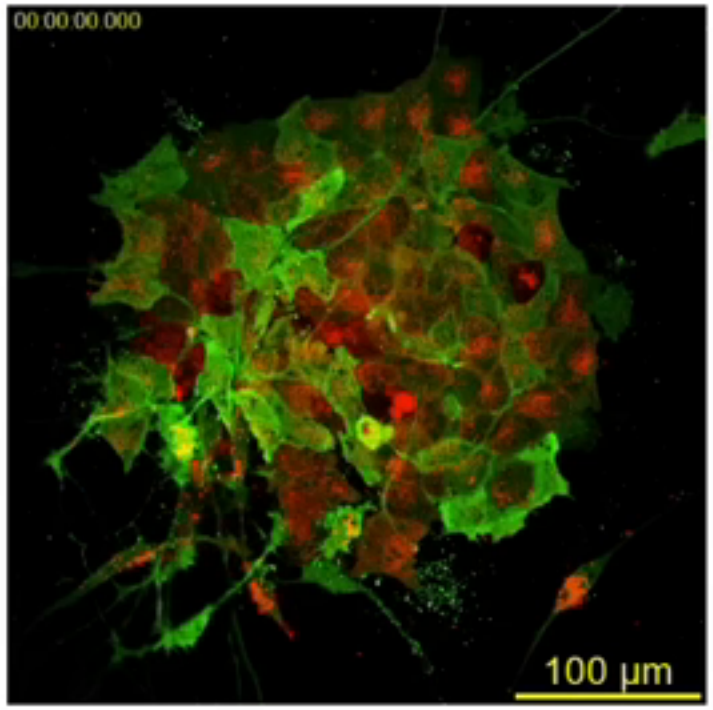

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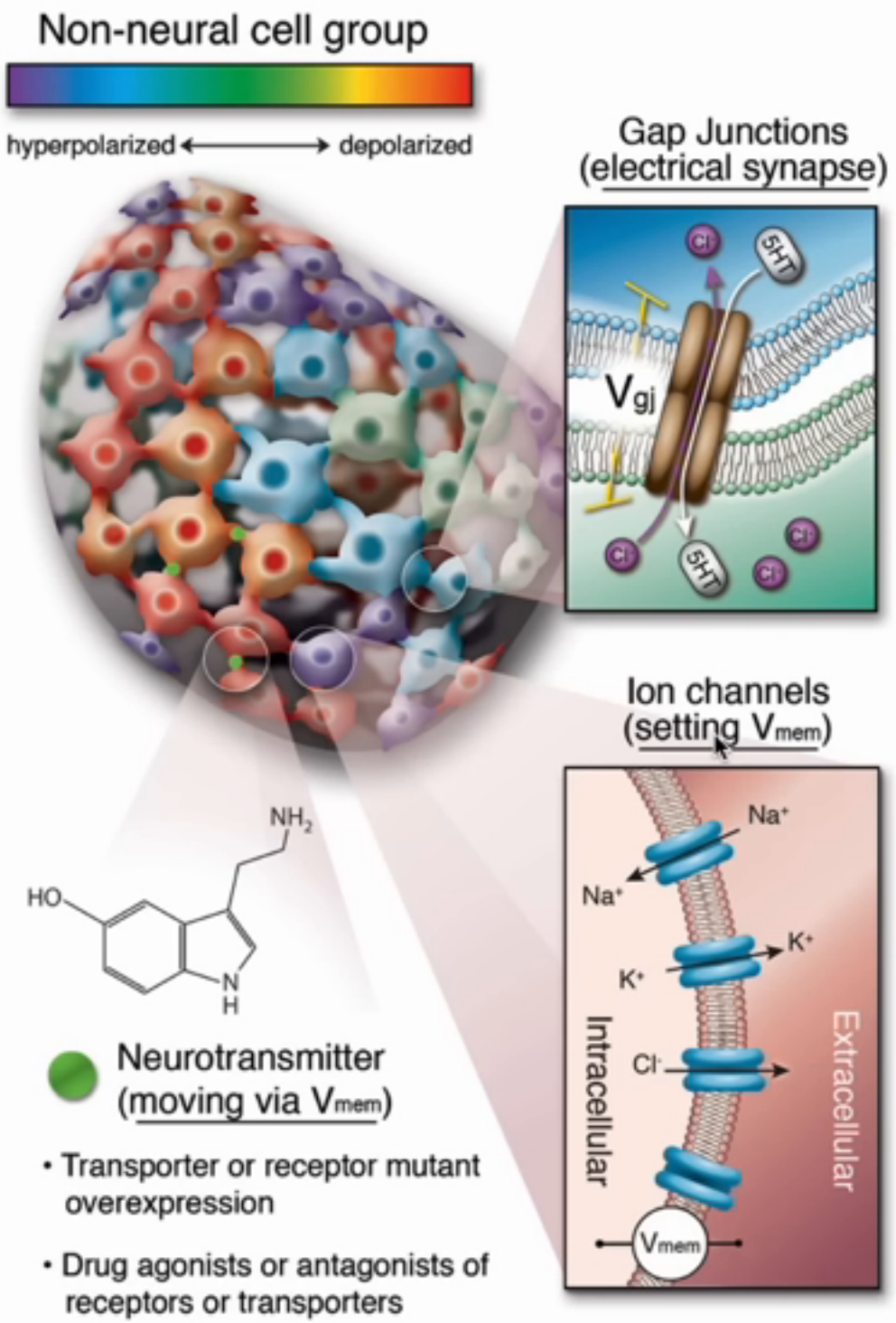

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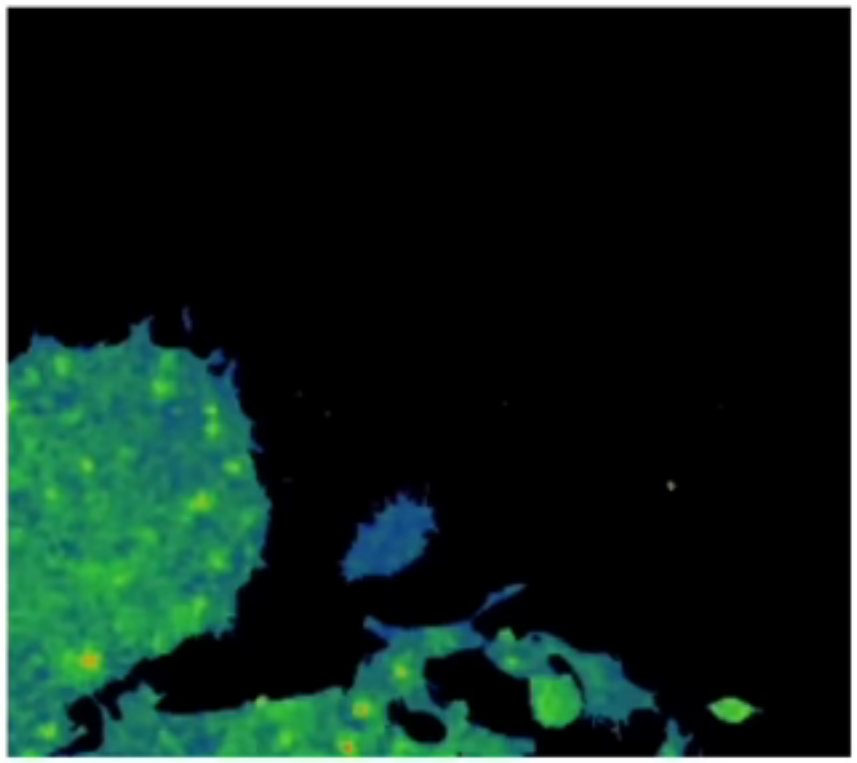
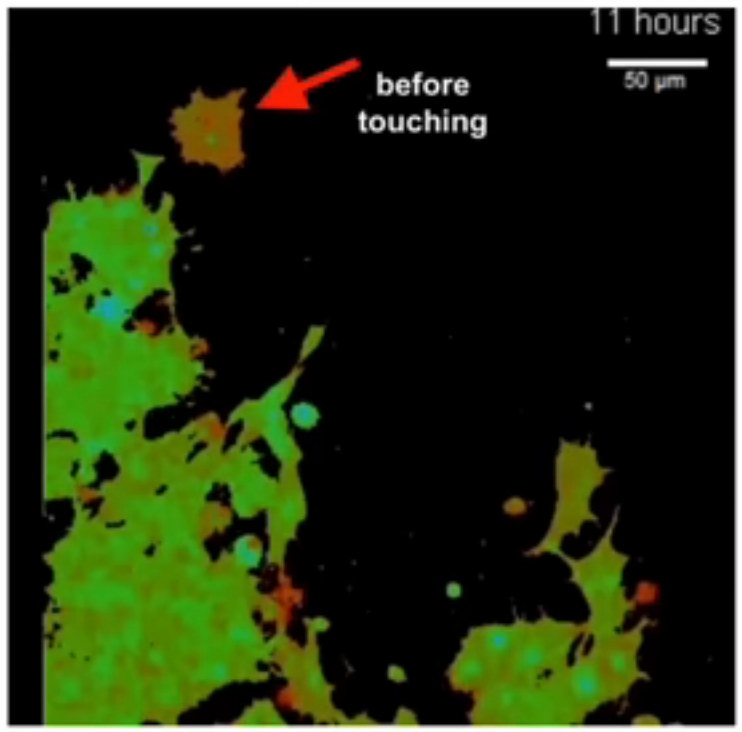
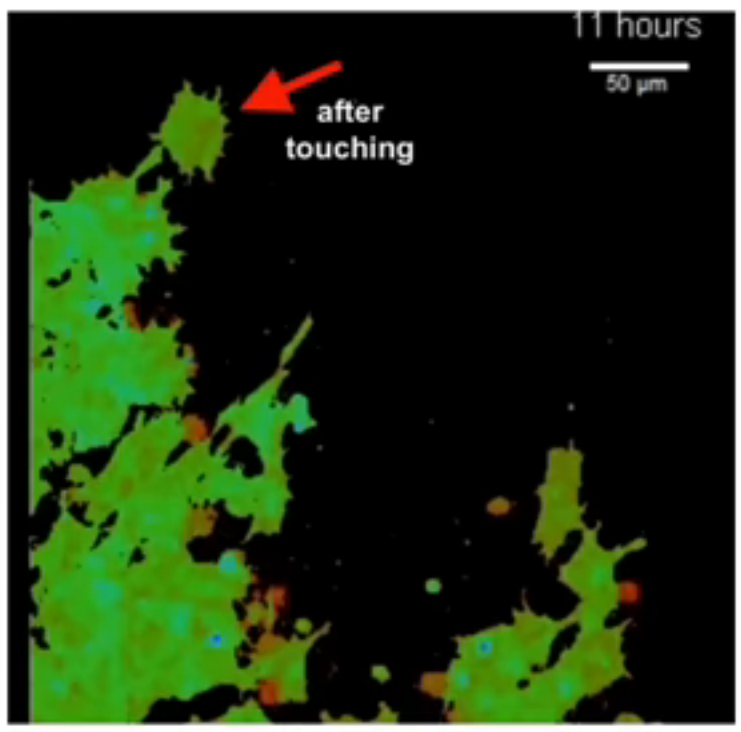
Intrinsic plasticity

Bioelectrical Take-over at Cell Level:

A very convincing message

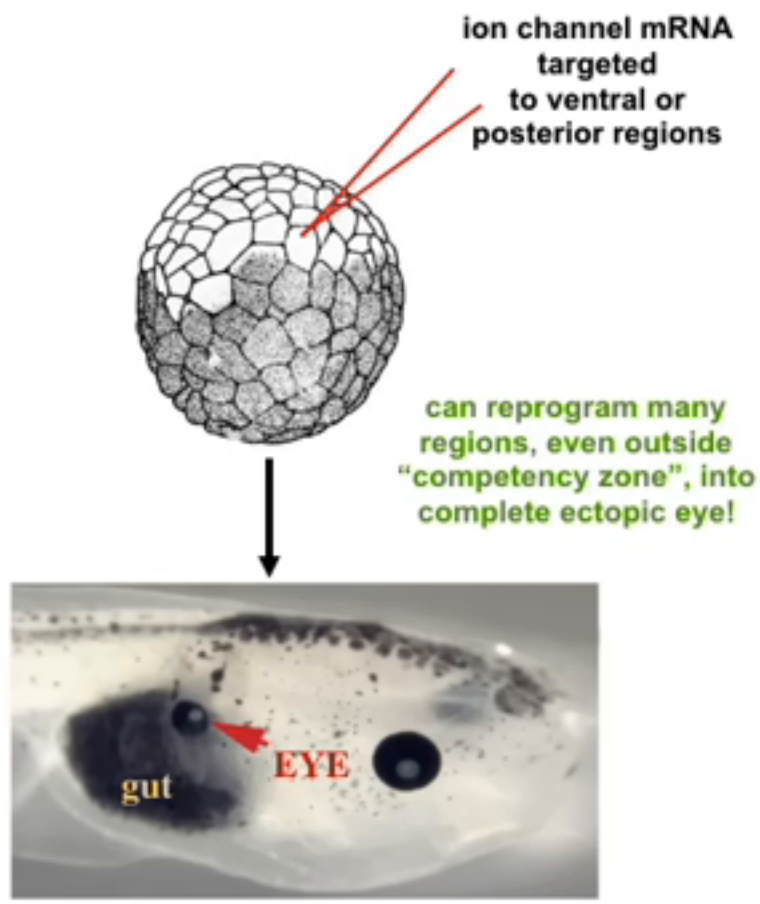




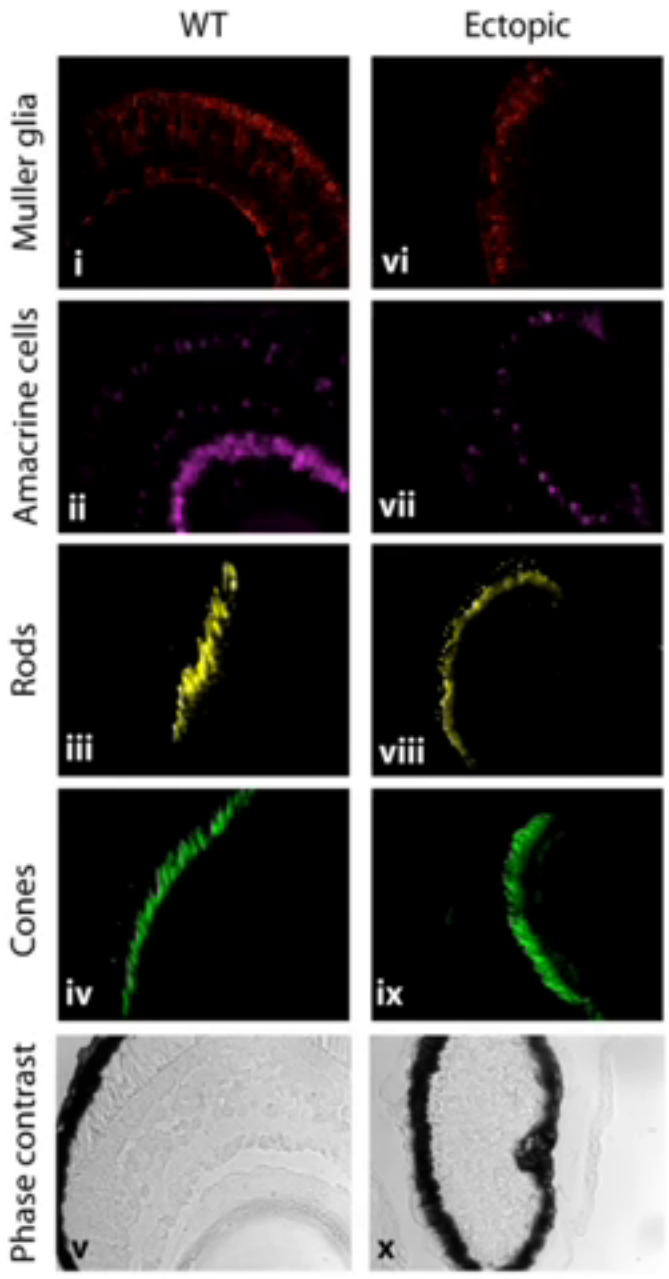


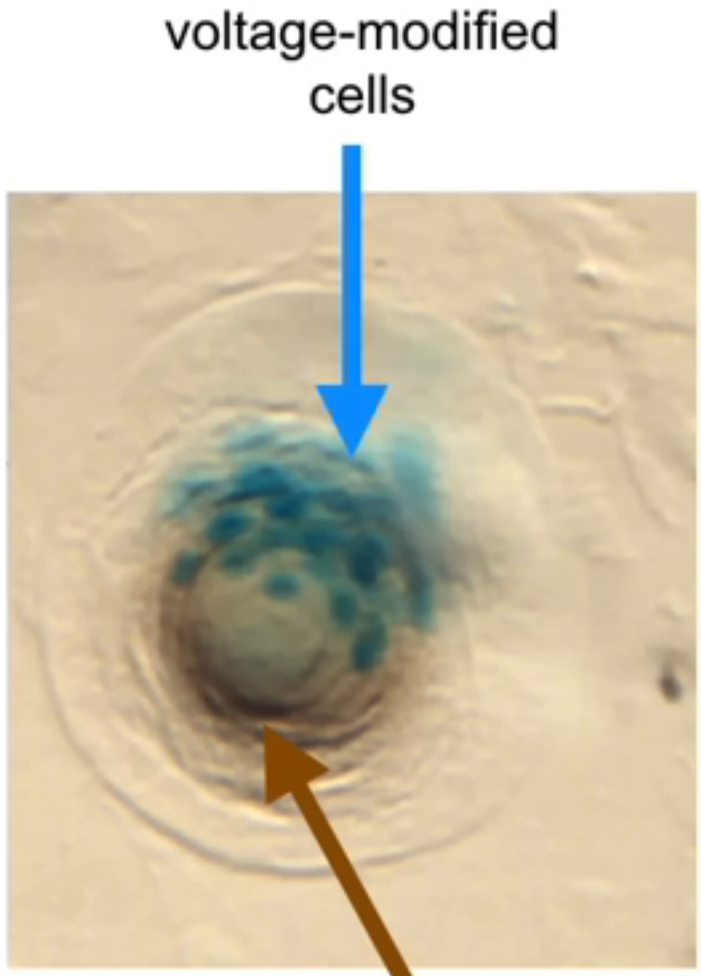
Patrick McMillen

Communicating New Goal Top-Down via Bioelectric Interface

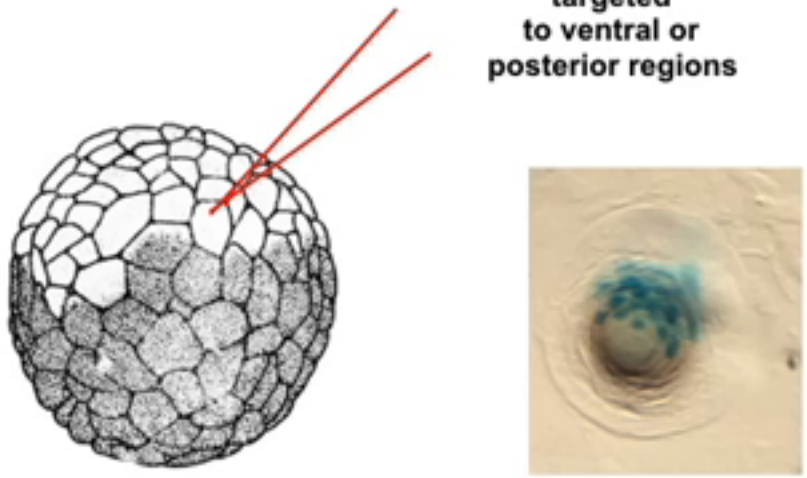


1. BIOE is instructive
2. modularity - not cell level, organ-level subroutine call
3. higher-level prompt reveals higher tissue competency than Pax6 prompt
4. self-scaling of system to task

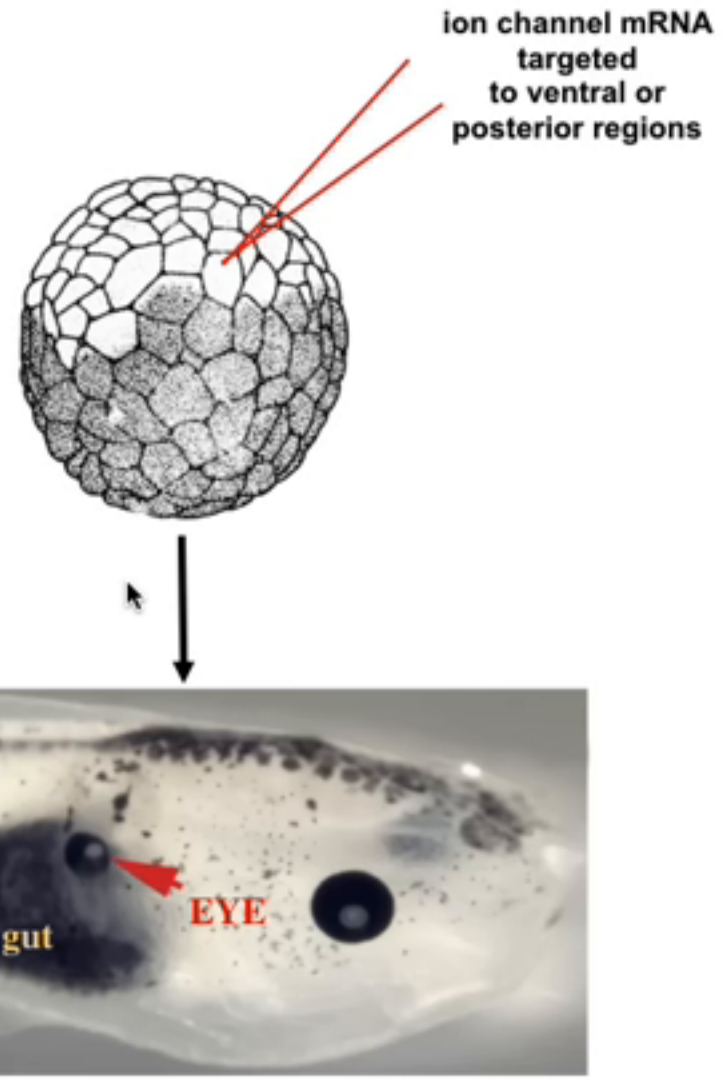




A Battle of World-Views: plasticity in morphogenetic navigation

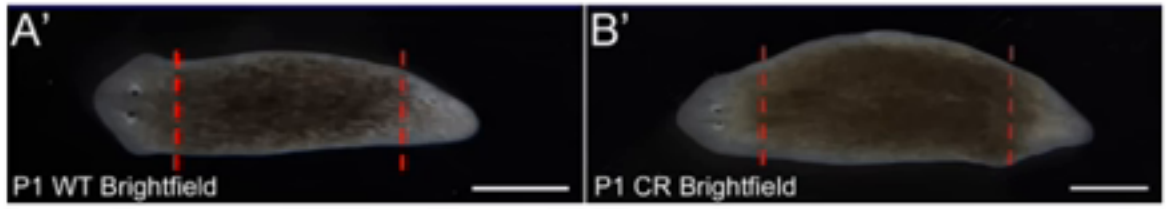


3 ectopic eyes, according to early eye marker Rx1

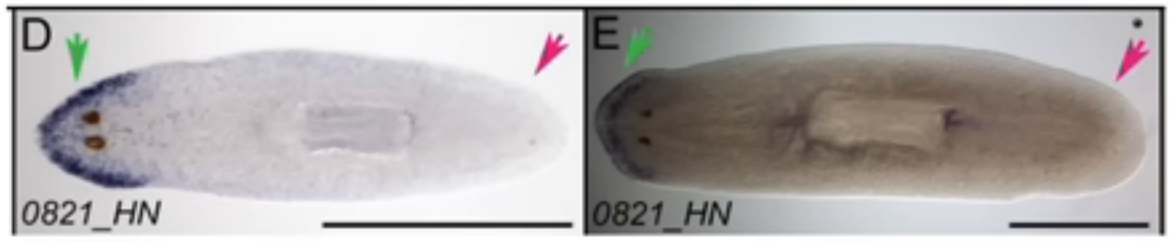


Vaibhav Pai, Sherry Aw

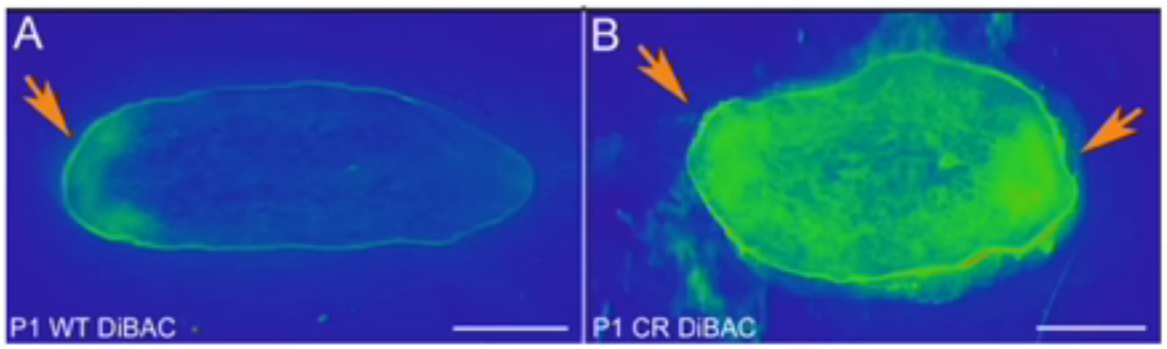
Re-writing Anatomical Pattern Memory



normal anatomy



normal molecular histology

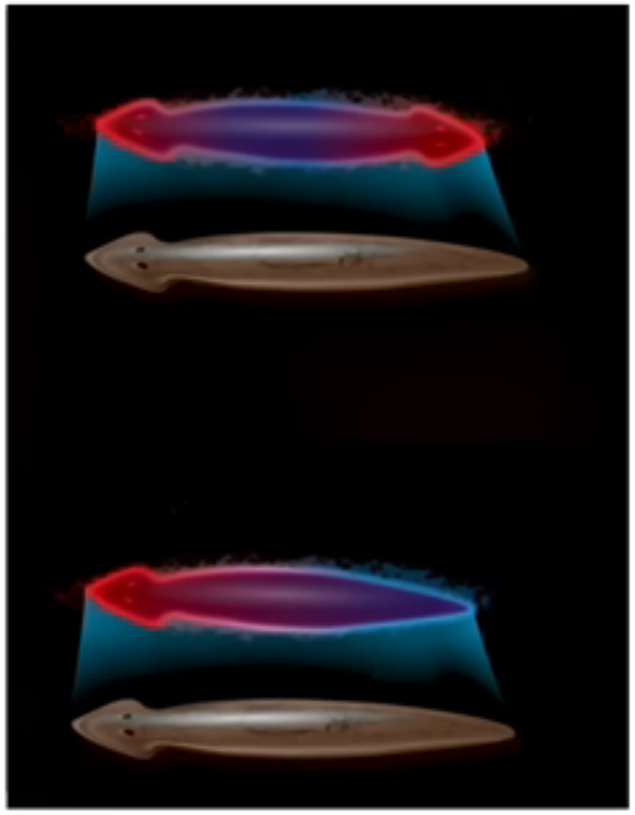


edited bioelectric pattern

middle-third regenerates:

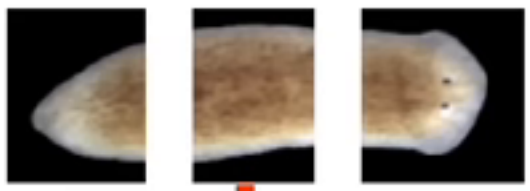
Fallon Durant

The Same Body can Store different Electrical Pattern Memories



The bioelectric pattern doesn't indicate what the anatomy is now, it encodes the latent pattern memory that will guide anatomy **if** it is cut at a future time = counterfactual

Like any Good Memory, it is Stable and its content is not determined by the Hardware



Cut, and briefly perturb bioelectric circuit

weeks later, cut in plain water

Keep trunk

weeks later, cut in plain water

Keep trunk

or, can force V_{mem} state back to normal

Nestor Oviedo
Junji Morokuma

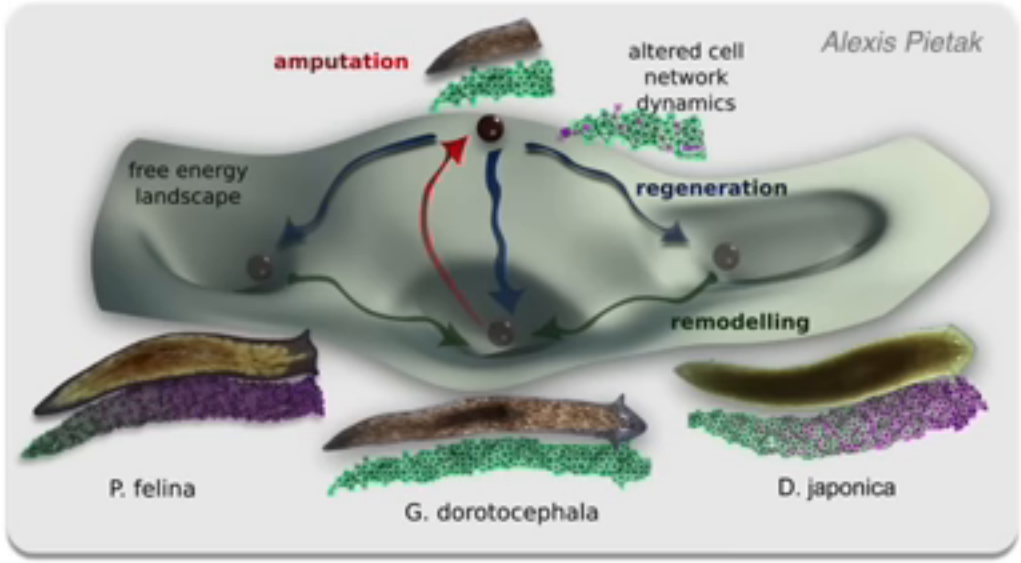
. . .

Basic properties of memory

- Long-term stability
- Lability (rewritable)
- Latency (conditional recall)
- Discrete possible behaviors (1H v. 2H)

A Single Genome Makes Hardware that can Access Bioelectric Memories of Other Species' Head Shapes

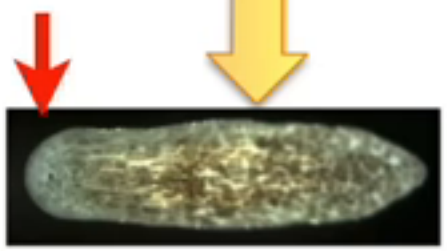
Species-specific shapes = attractors in morphospace = memories as attractors in neural network



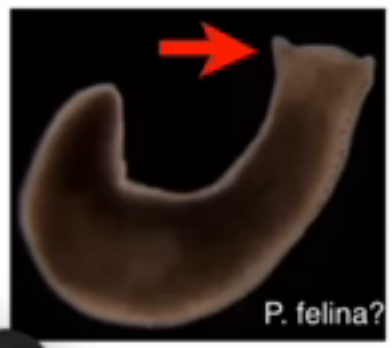
D. dorotocephala

cut off head, perturb network topology

like:

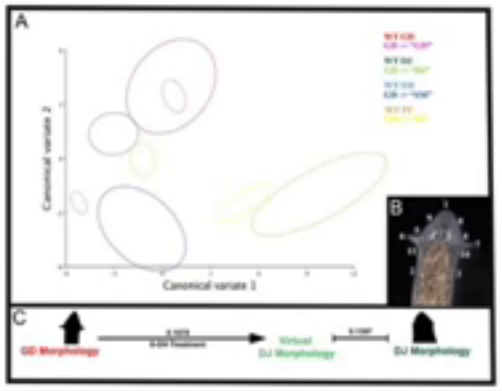


like:



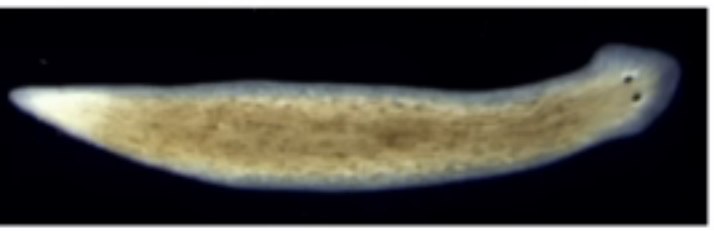
S. Mediterranea

quantitative morphometrics

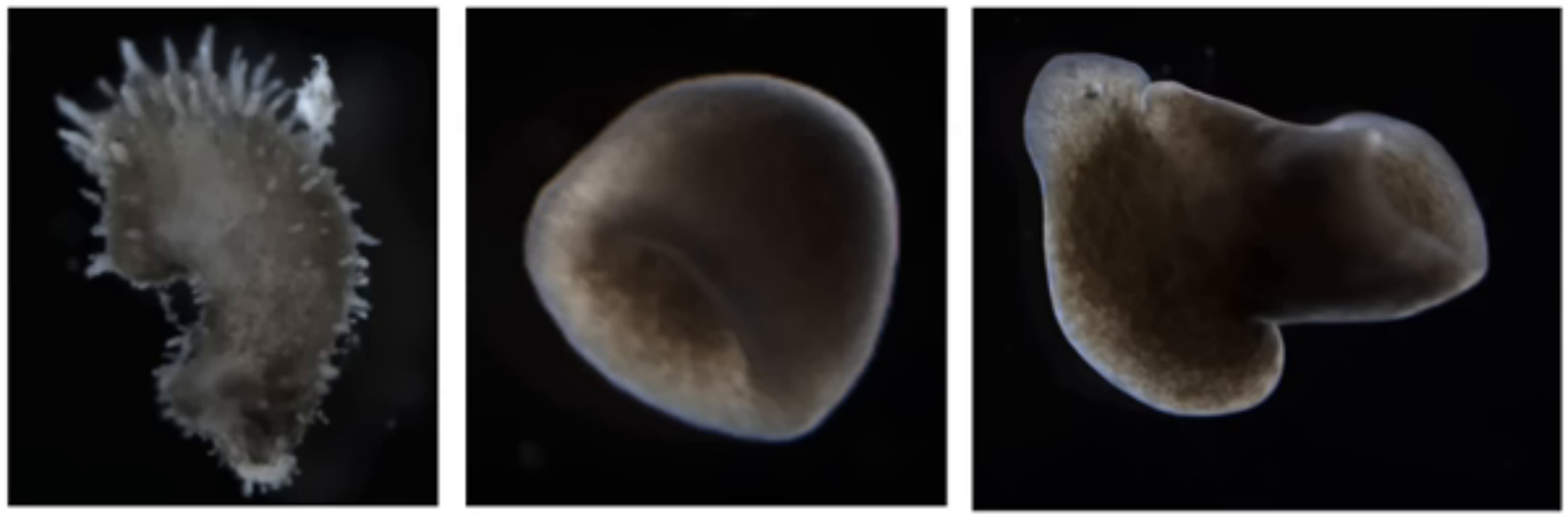


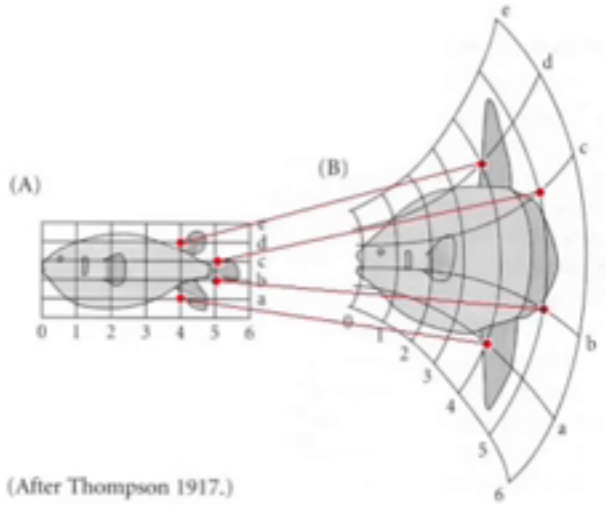
The Hardware is Extremely Reprogrammable

Normal worm



Bioelectric Pattern Altered



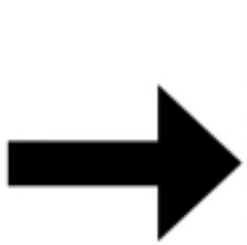


(After Thompson 1917.)

latent morphospace

Good Old Reliable Development

like “instinct” - fixed patterns?



White Oak Leaf - Photo by Chris Evans, River to River CWMA, Bugwood.org

Messages from Hacker Reveal Flexibility:

Photo Credit: Andrew Deans

Hedgehog Gall

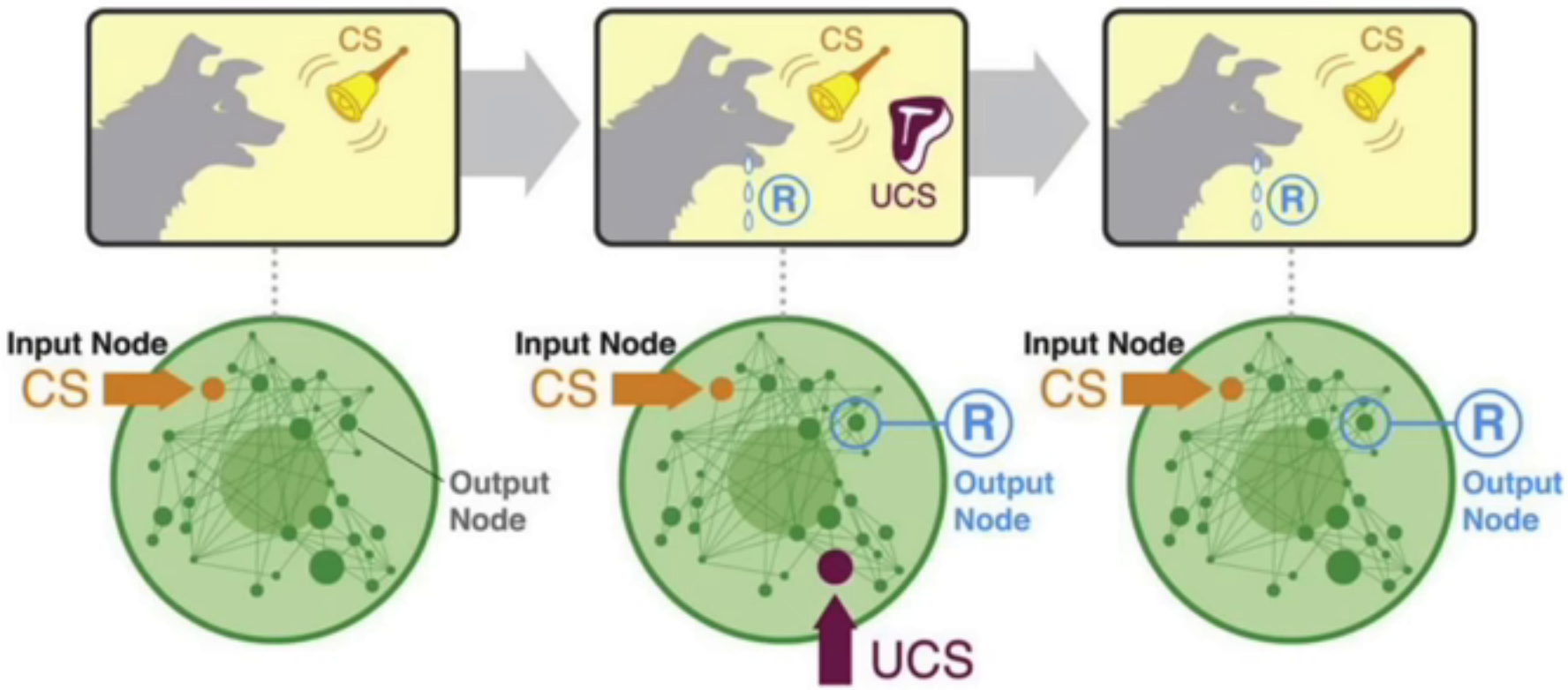
Acraspis erinacei
August - November

Parasite hacks host to induce new anatomy (bio-prompting)

Components of Intelligence:

- Homeostasis: the basis of goal-directed activity
- Homeostasis^2: Same ends by different means
- Hierarchical, non-local control
- Hackability (software, not just hardware)
- Learning
- Creative problem-solving toward default goals
- Novel beings, novel goals: never give up

Collective Intelligence Below the Cell Level



molecular networks
already smart

Biomedicine:

- drug conditioning

International Journal of *Molecular Sciences*

MDPI

Article

Learning in Transcriptional Network Models: Computational Discovery of Pathway-Level Memory and Effective Interventions

Surama Biswas [1,2,†], Wesley Clawson [1,†] and Michael Levin [1,3,*]

iScience

CellPress
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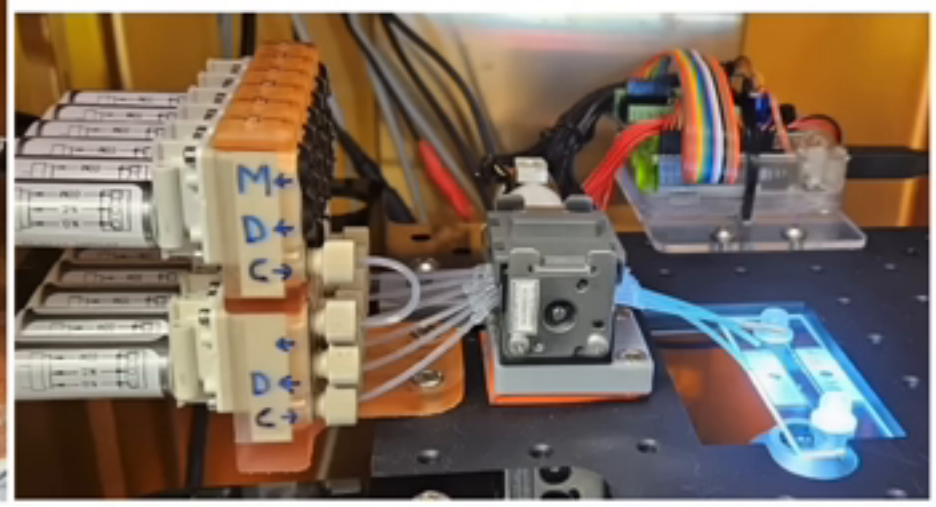
Article

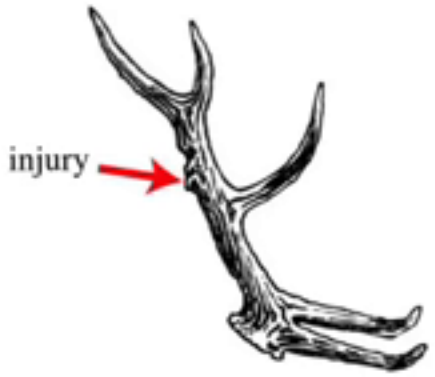
Gene regulatory networks exhibit several kinds of memory: quantification of memory in biological and random transcriptional networks

Patrick Erickson

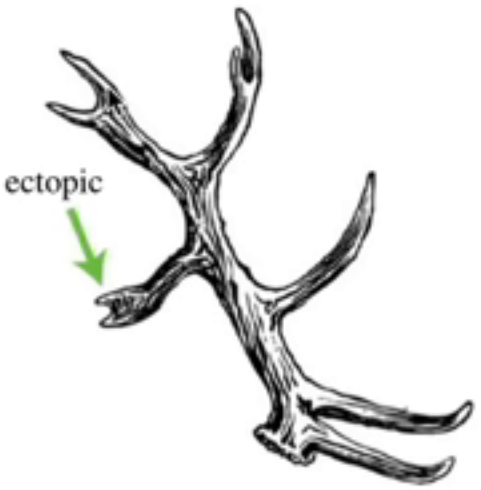


Trophic Memory in Deer Antlers:

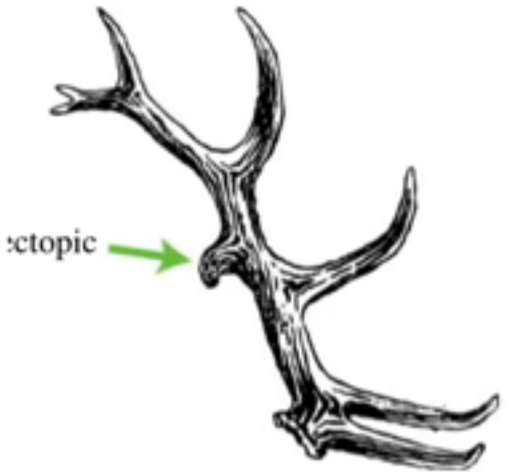
Year 0



Years 1-5



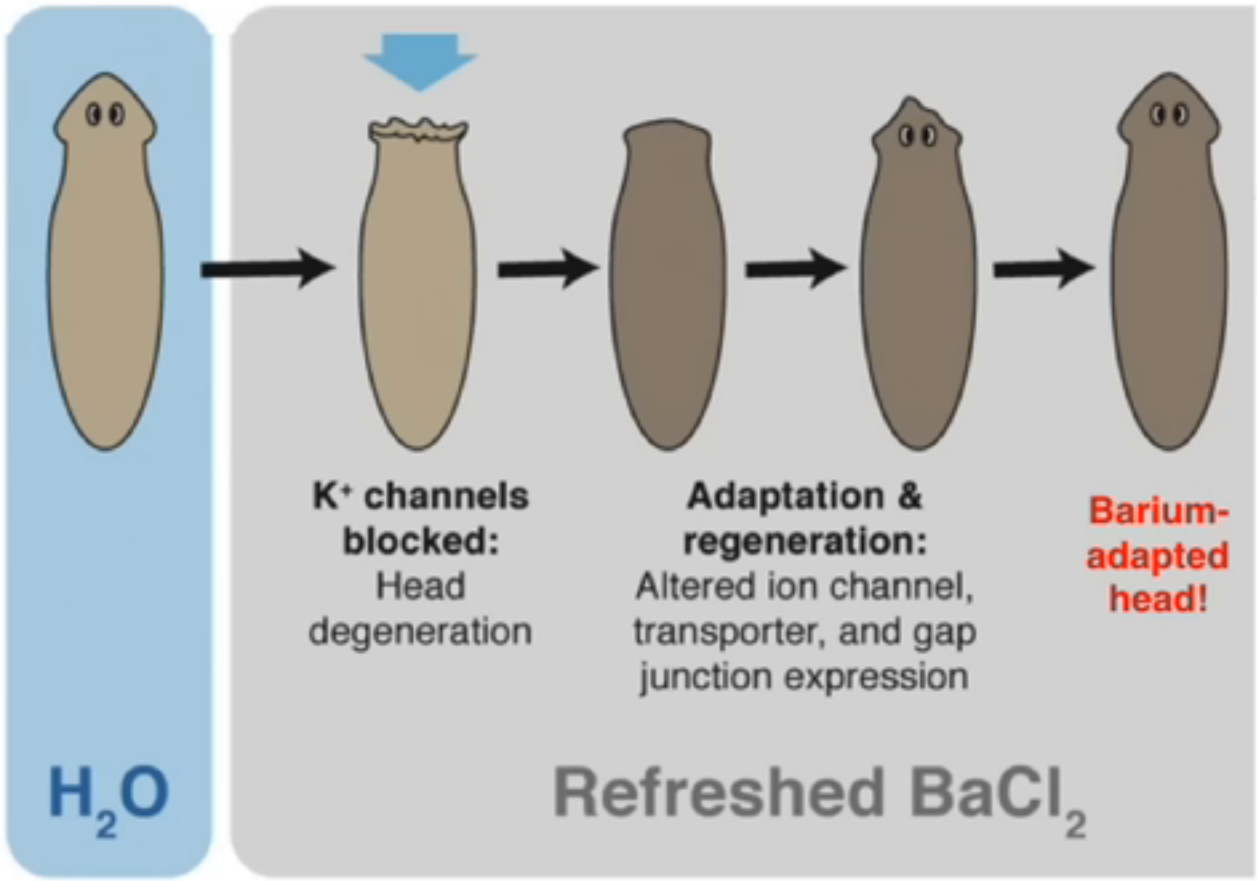
Years 6+



George Bubenik

What molecular pathway model would you draw?

Solving Novel Physiological Problems by Navigation of Transcriptional Space

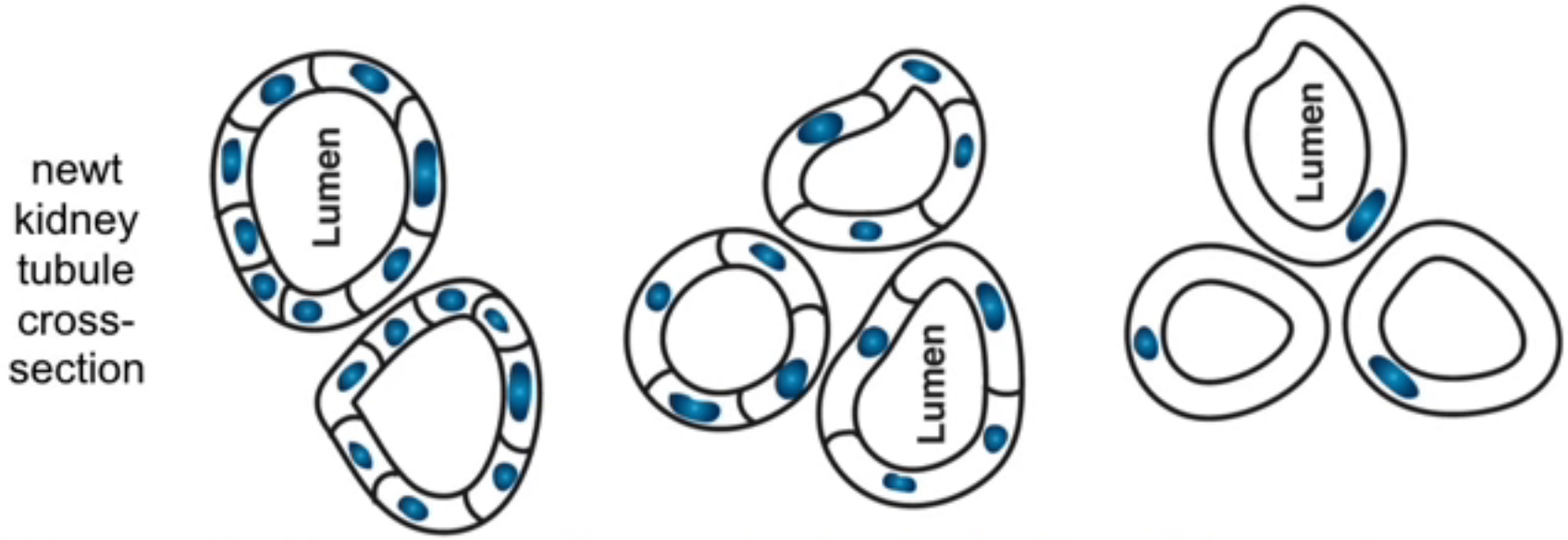


Small number of genes regulated out of entire genome!

- planarian heads degenerate after exposure to barium
- planaria eventually adapt and regenerate heads that tolerate barium
- a relatively few transcripts were altered to produce barium tolerance
- how did the system choose exactly the right genes to modulate, to deal with this evolutionarily-novel challenge?

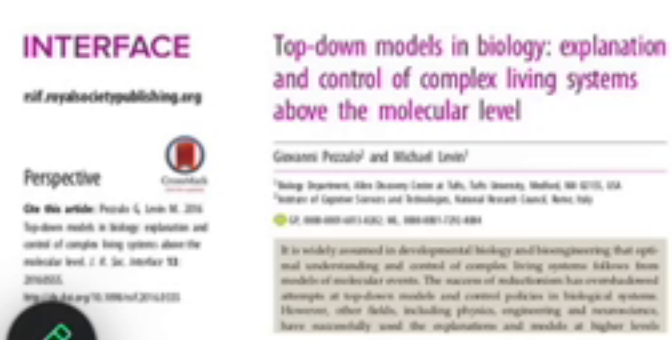
Creative Problem-Solving by Cell Groups

- get to the same outcome
  - despite perturbations (external and internal)
  - from diverse starting positions
  - **via different molecular mechanisms!**



Fankhauser, 1945, J. Exp. Zool., 100(3): 445-455

Changing the size of cells still enable large-scale structures to form, even if they have to utilize different molecular mechanisms = top-down causation

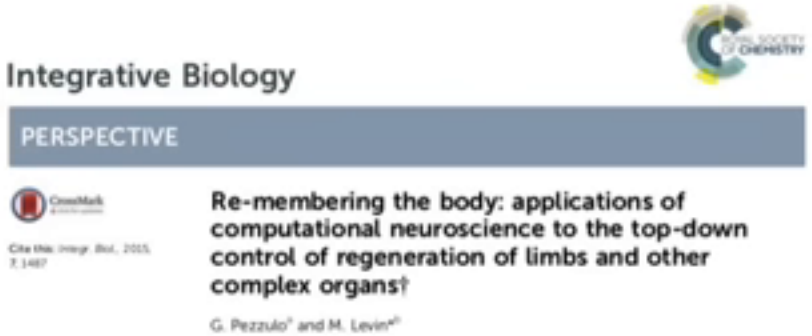

INTERFACE

rsif.royalsocietypublishing.org

Perspective

Top-down models in biology: explanation and control of complex living systems above the molecular level

Giovanni Pezzulo and Michael Levin

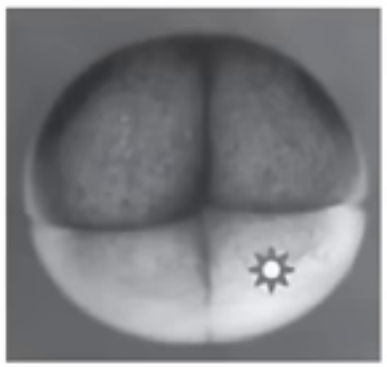

Integrative Biology

PERSPECTIVE

Re-membering the body: applications of computational neuroscience to the top-down control of regeneration of limbs and other complex organs†

G. Pezzulo and M. Levin

Rebooting Multicellularity: Xenobots

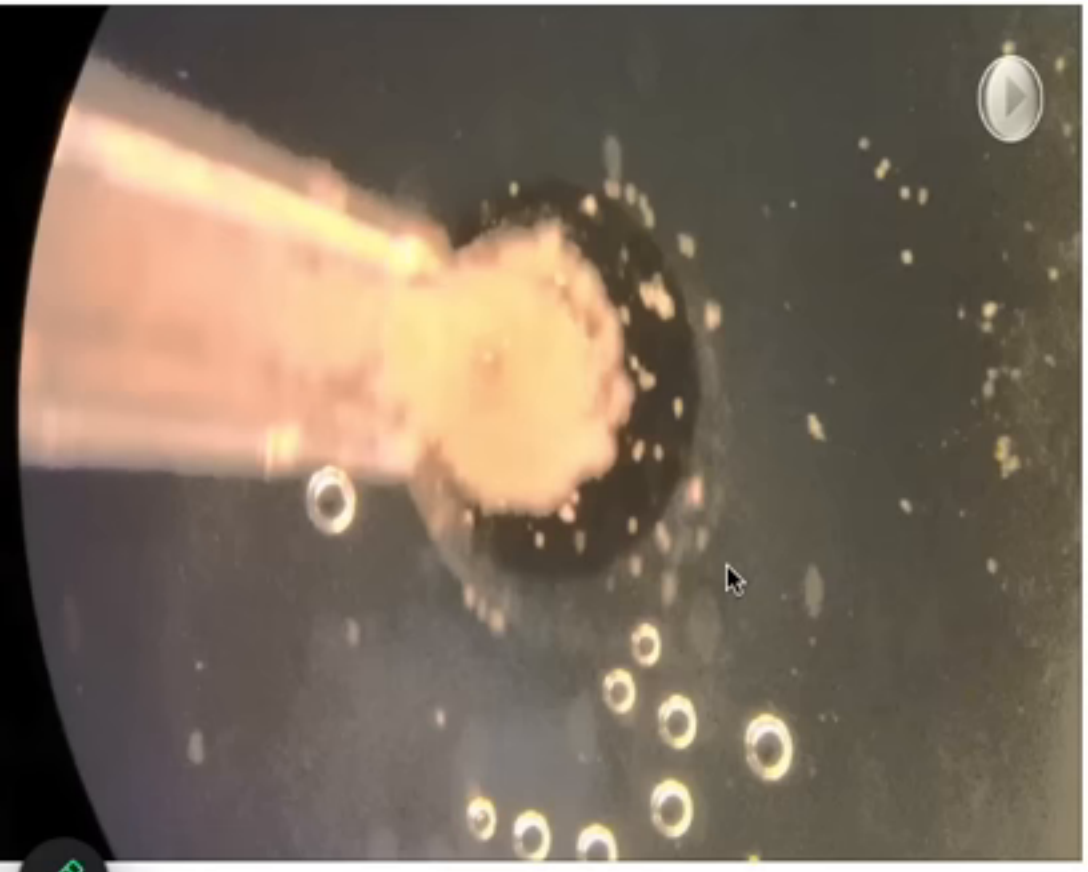


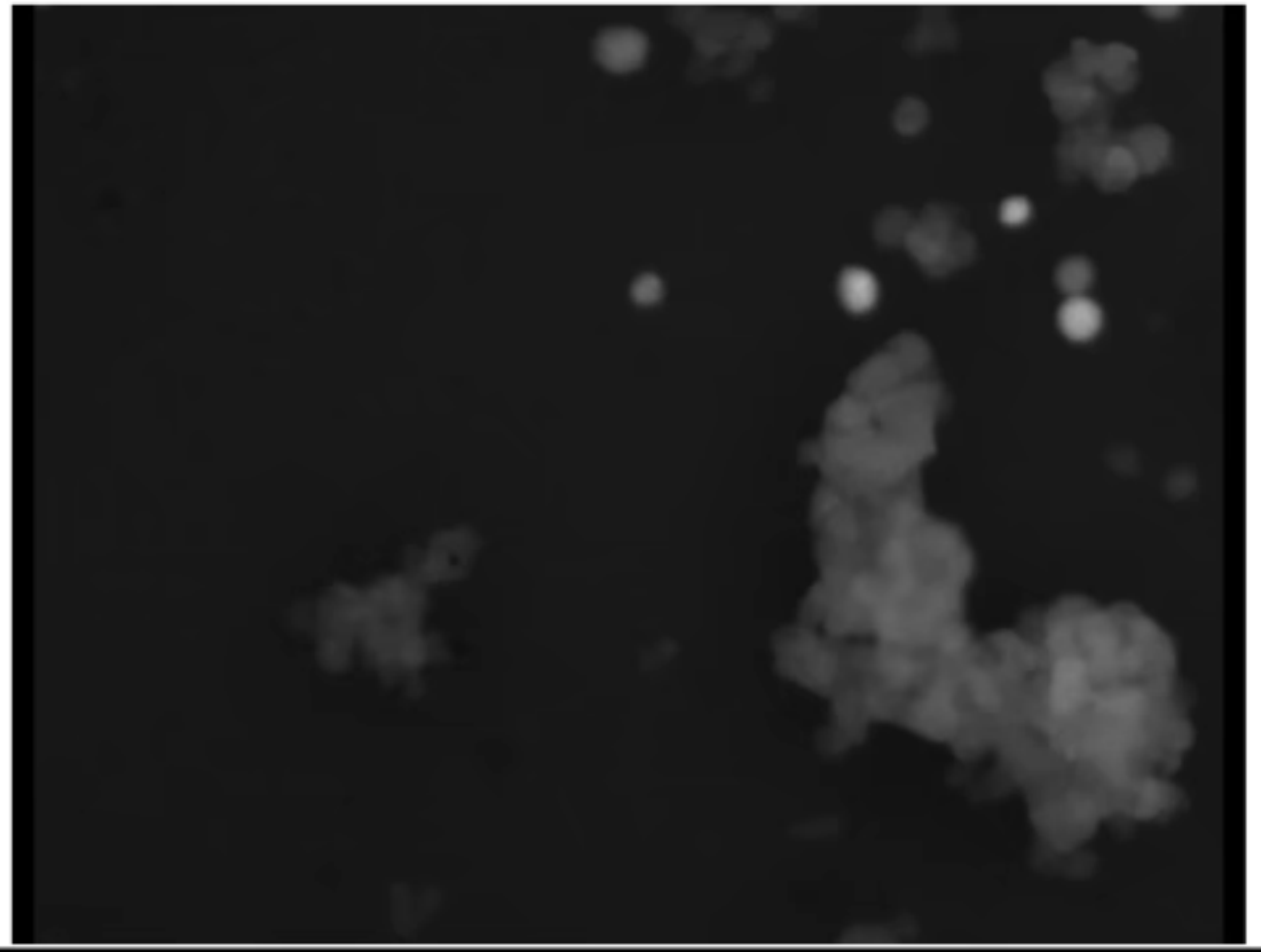
Early frog embryo

8 hours

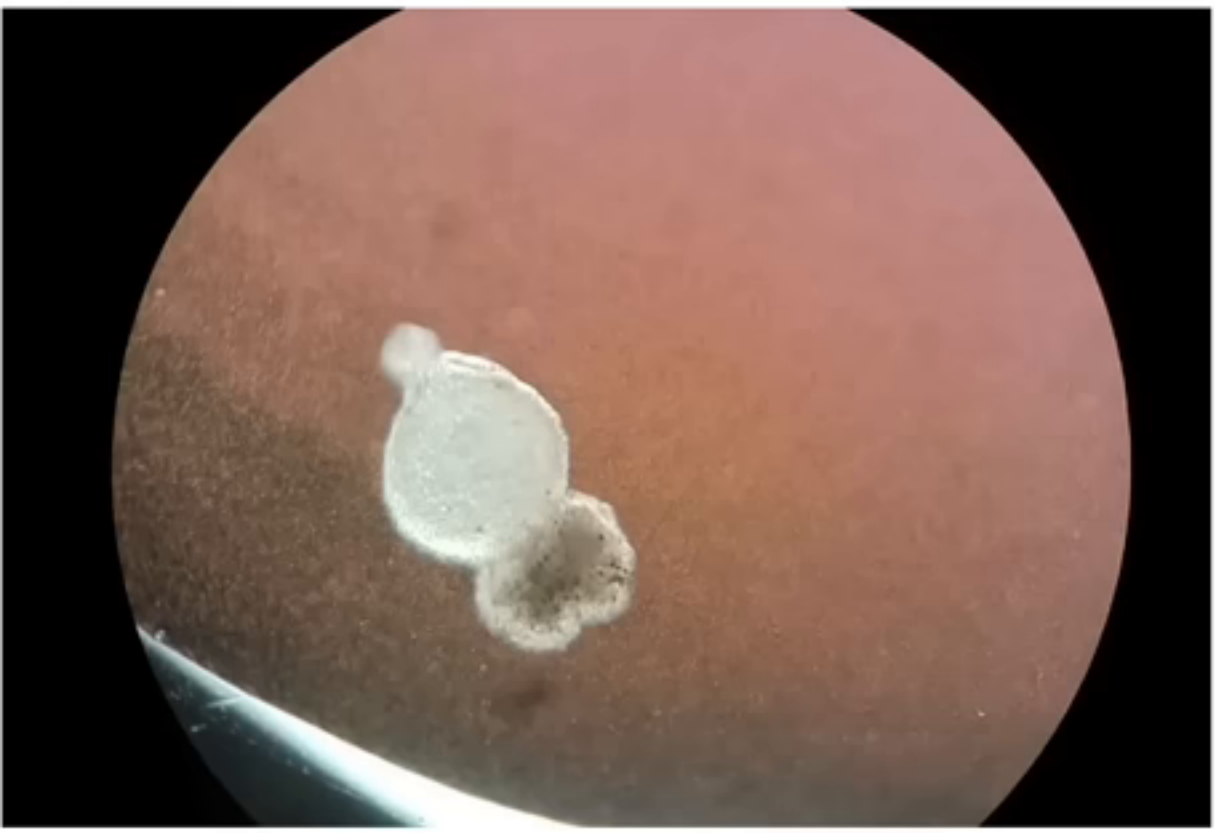
assay for form and function

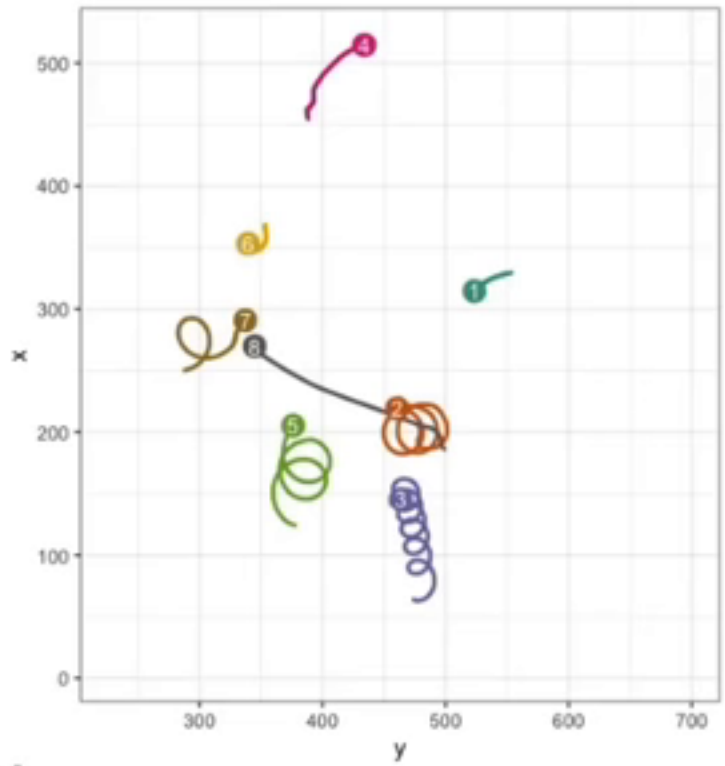
Douglas Blackiston



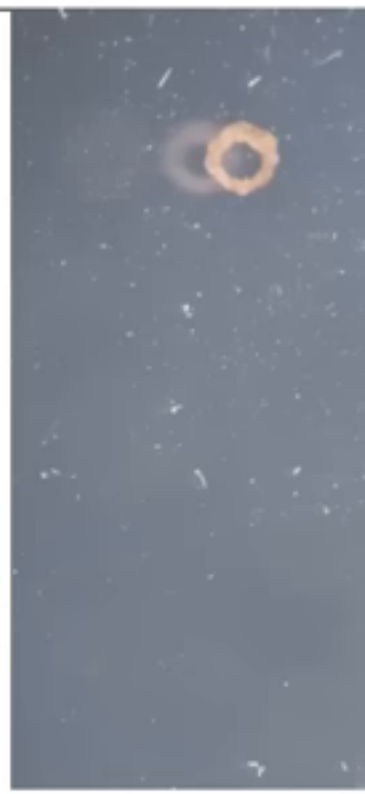


Xenobot behaviors - repurposing cilia for motion



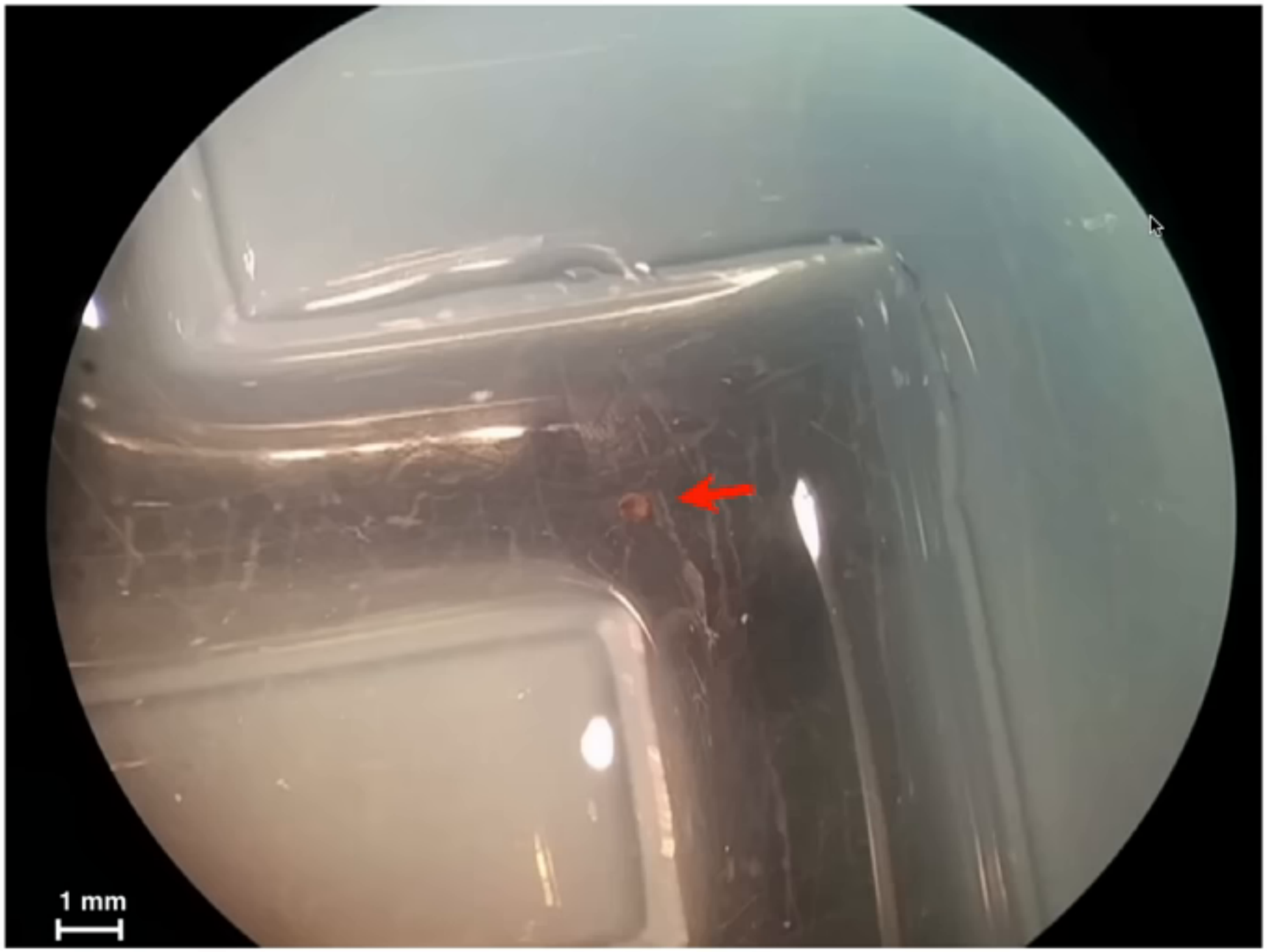


collective behaviors



Douglas Blackiston

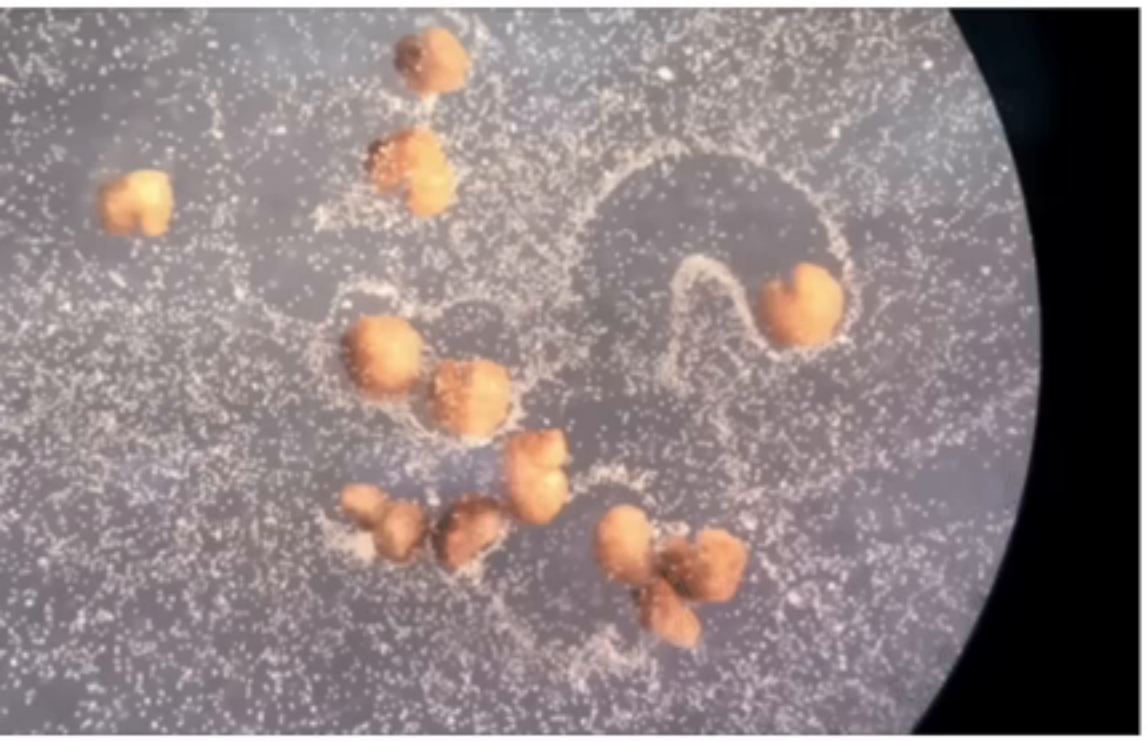
Xenobot in a maze (still water, no flow):

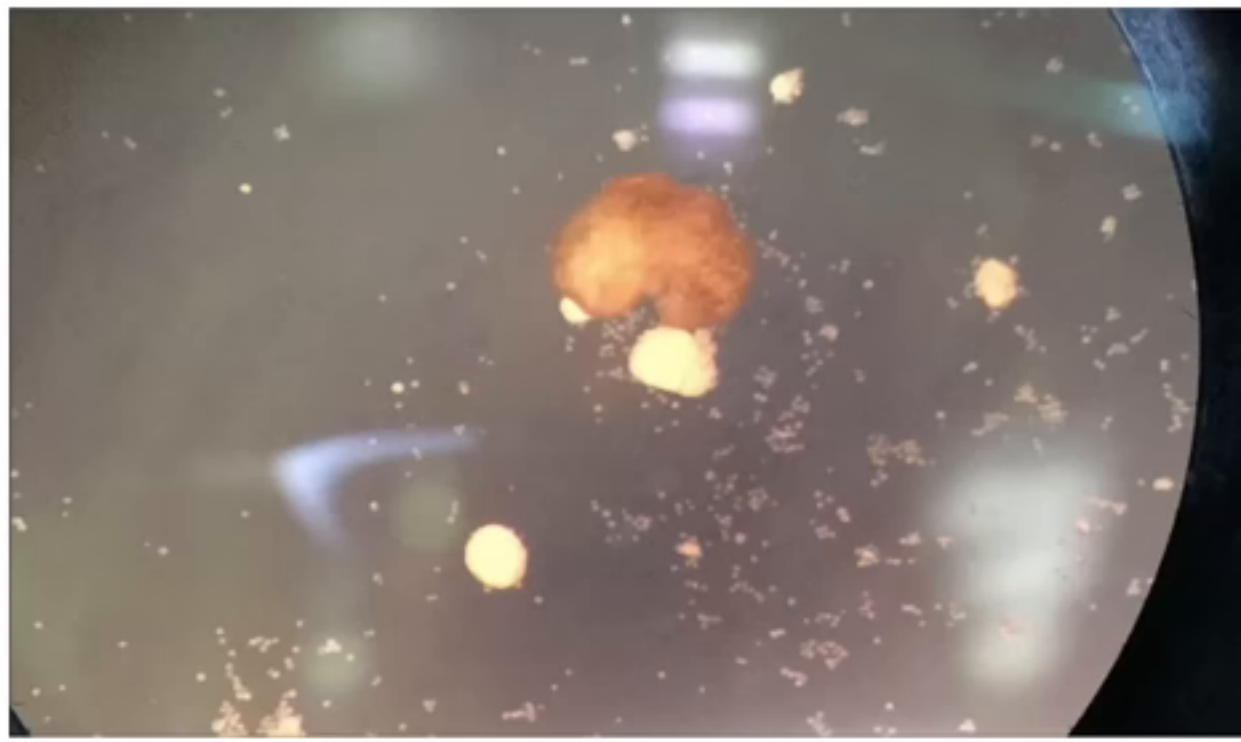


1) it traverses maze, 2) rounds the corners without bumping into walls, and
3) it makes a spontaneous decision to turn around without hitting anything.

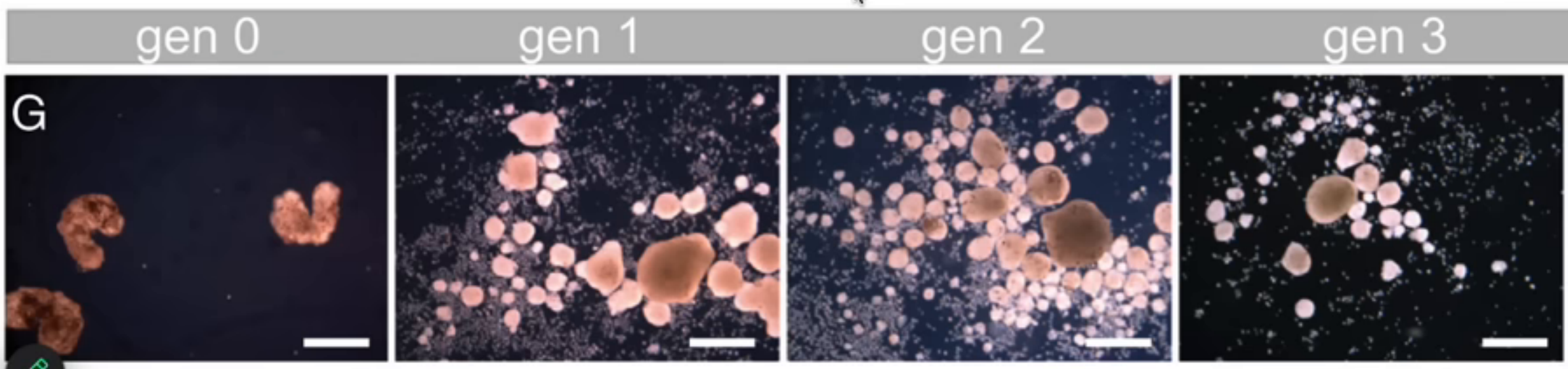
Douglas Blackiston

Kinematic Replication in Xenobots: novel competencies of the agential material

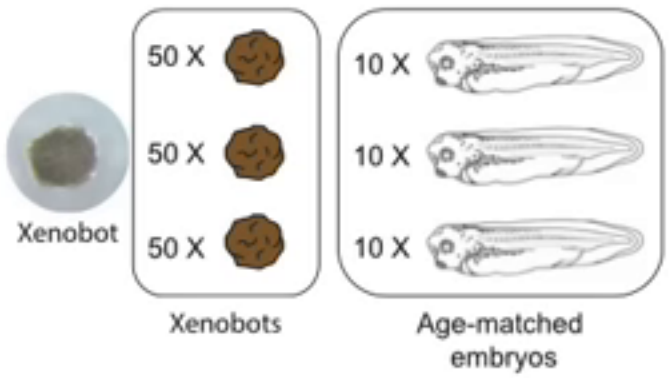


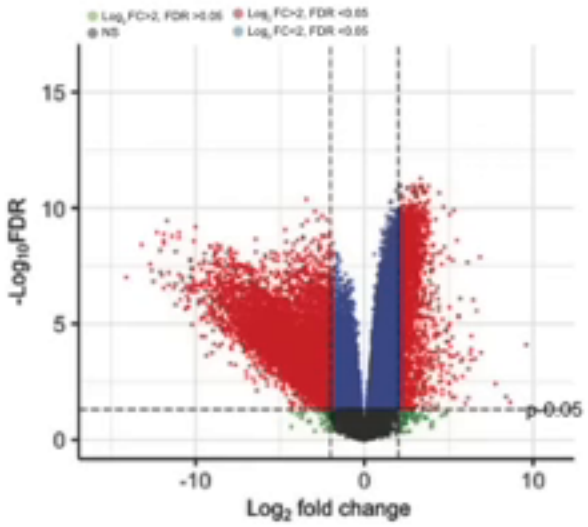


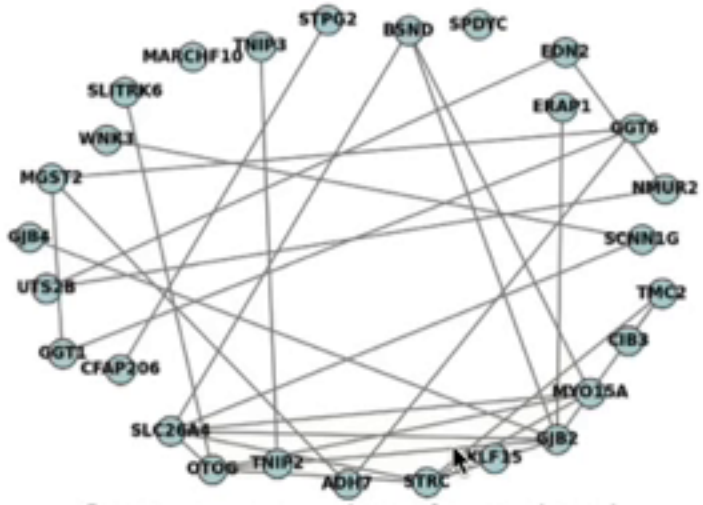
Douglas Blackiston



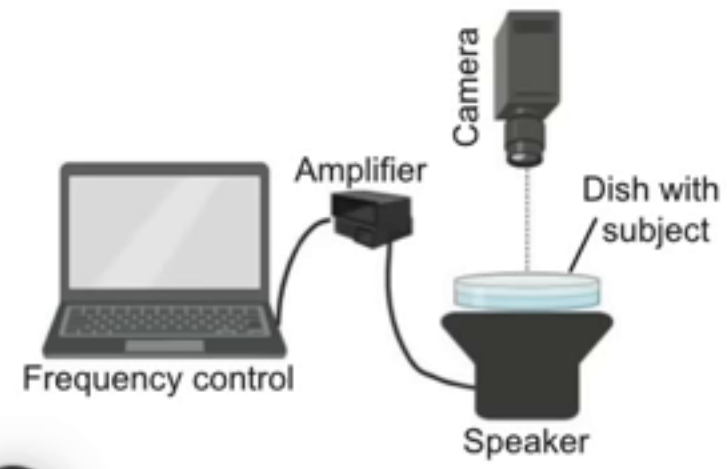
Communicating with Xenobots via Sound

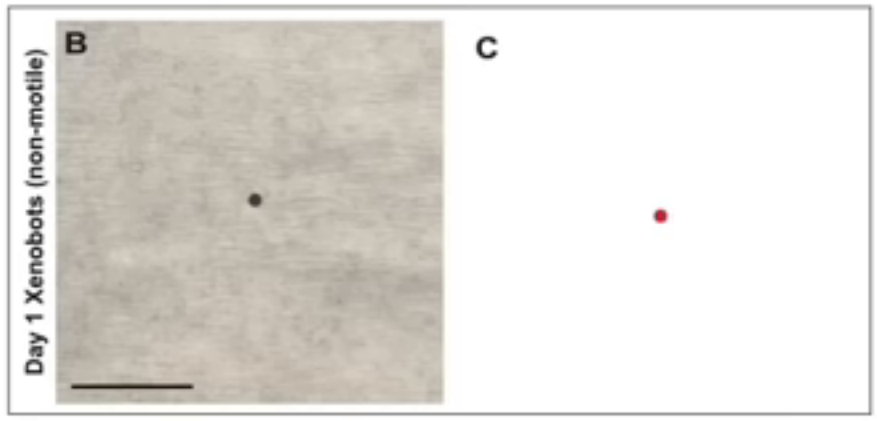


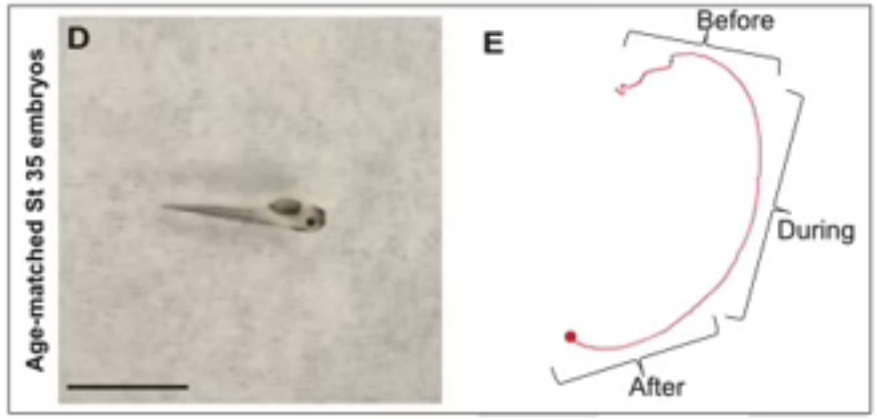


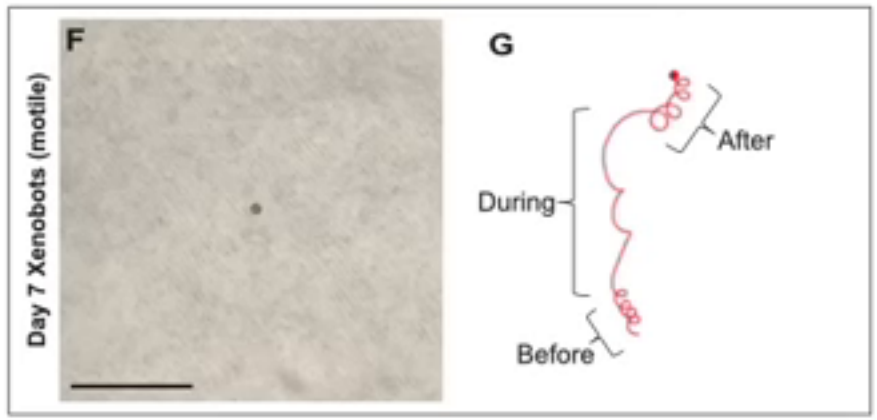


Sensory perception of sound and mechanical stimuli

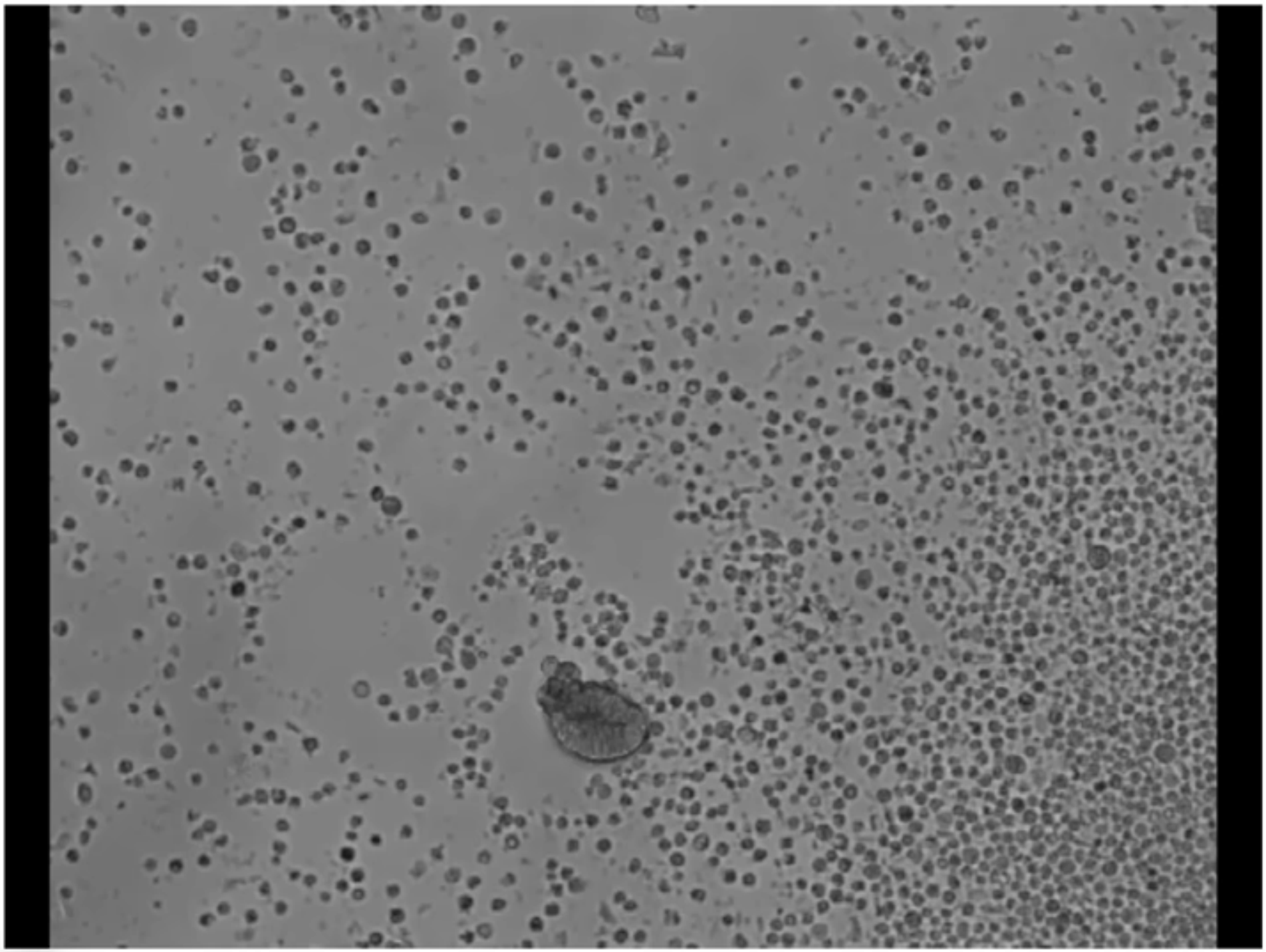








Anthrobots; can you guess the genome?



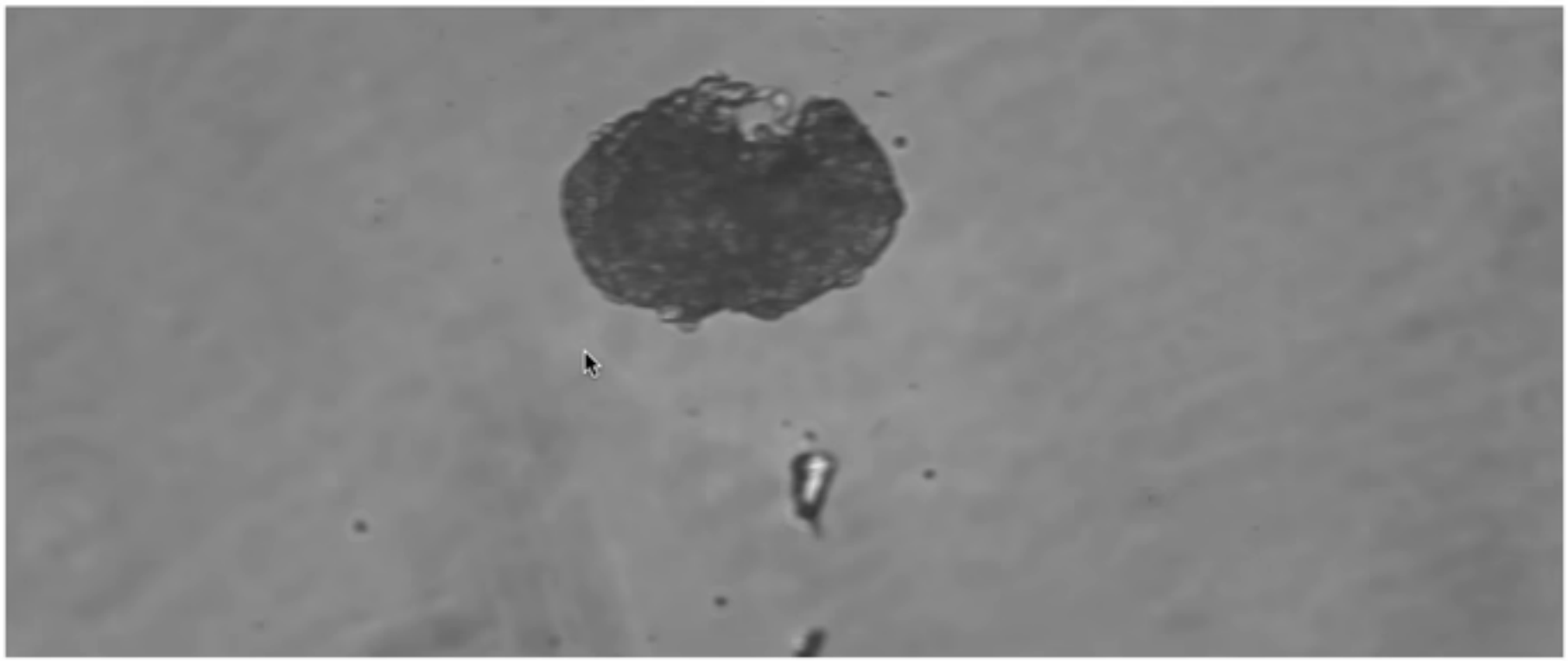
Where do the properties of novel systems come from if not eons of selection or explicit engineering?

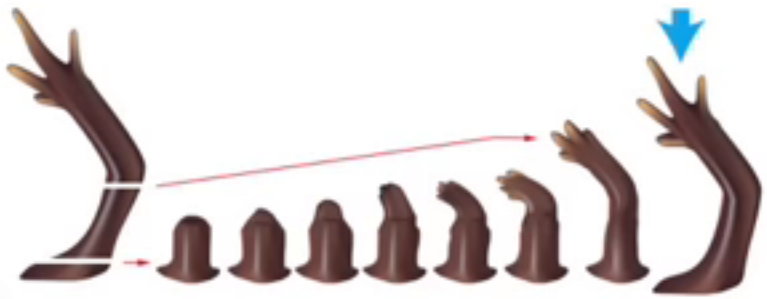
Could you guess the genome from these data?

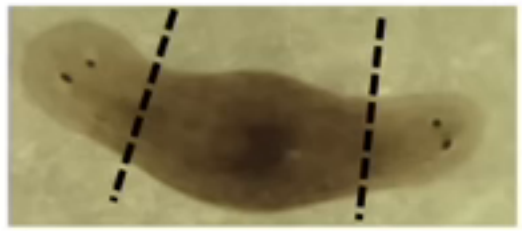
Could you guess behavior and form from the genome?

Gizem Gumuskaya

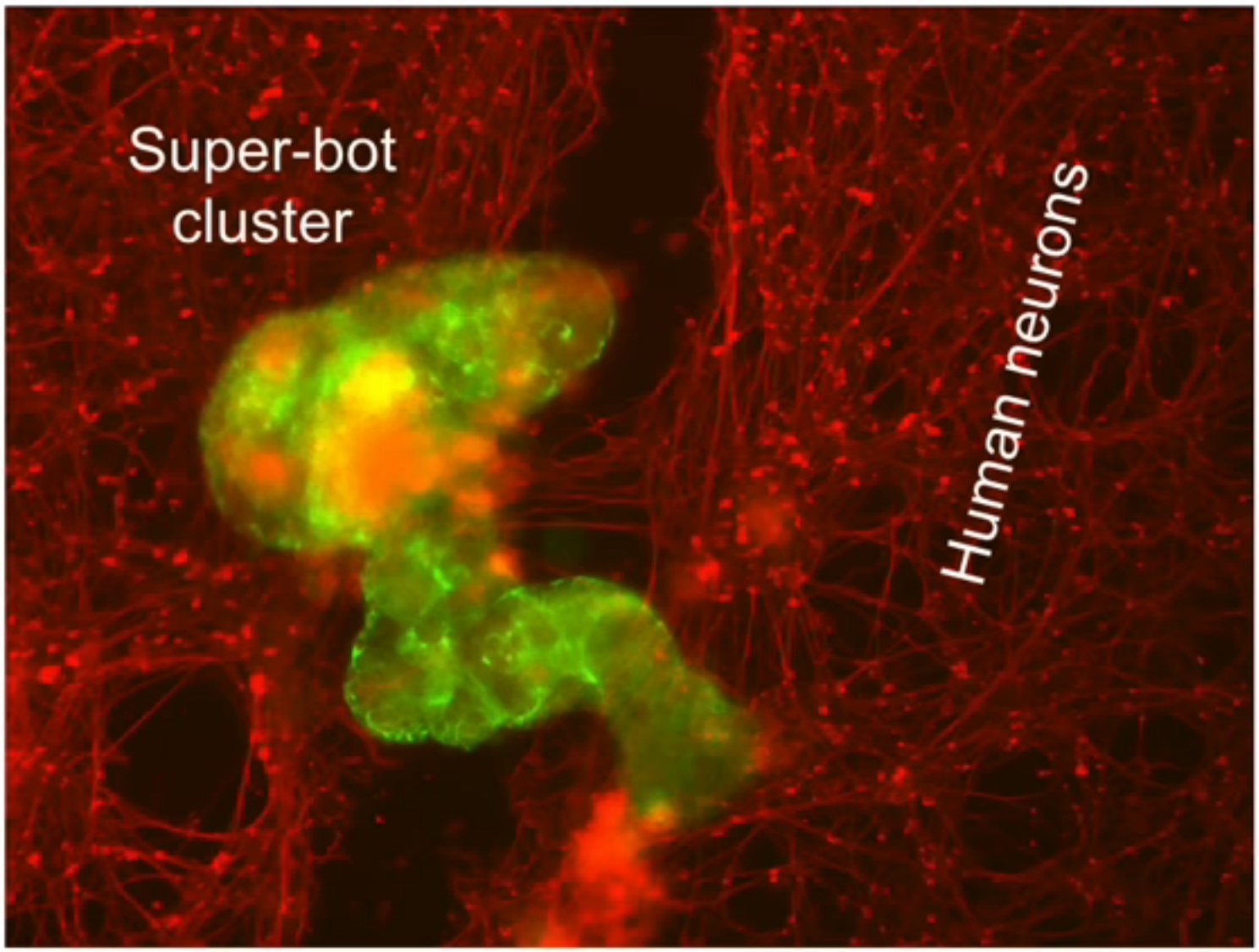
Repairing Toward New Shape

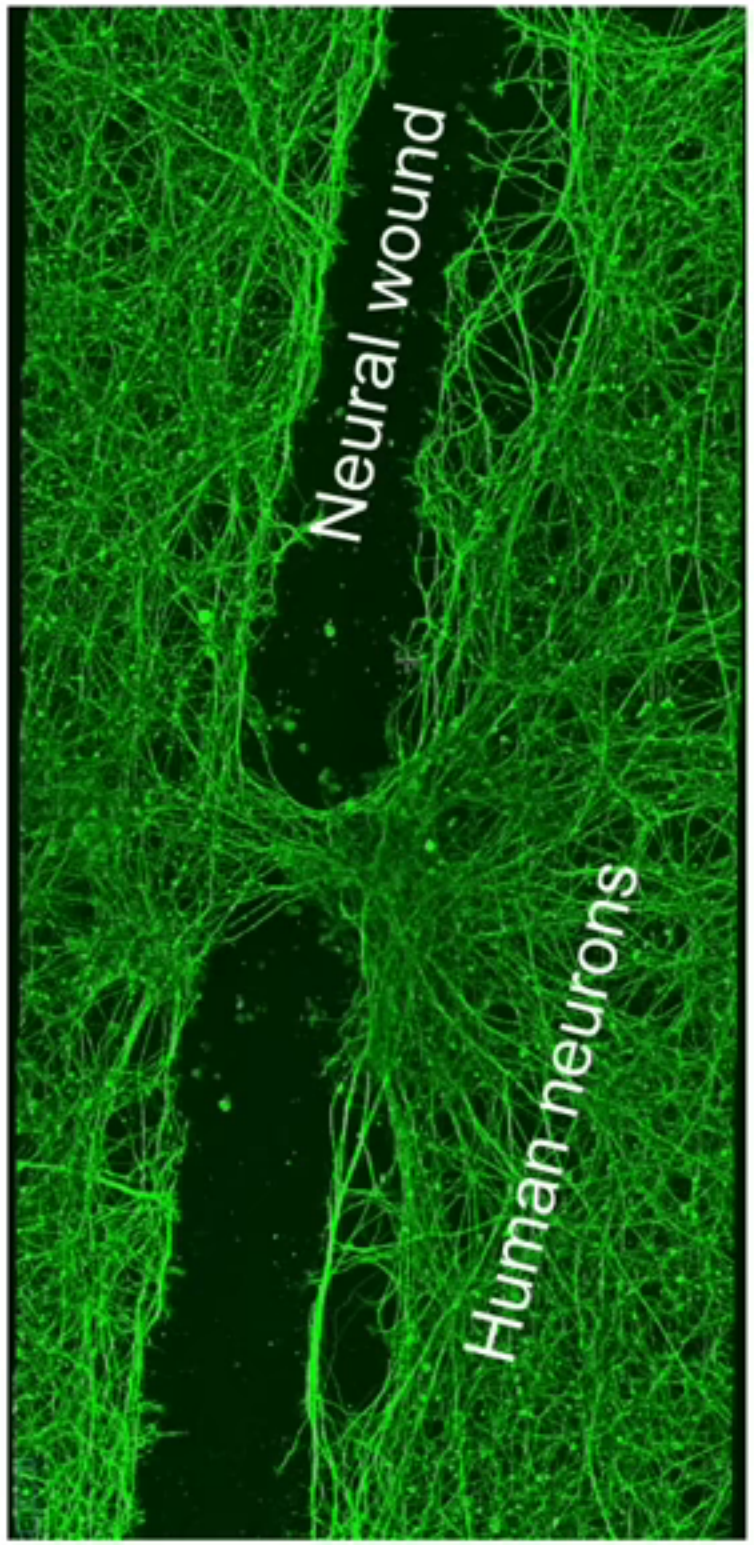






Anthrobots Exert Neural Repair





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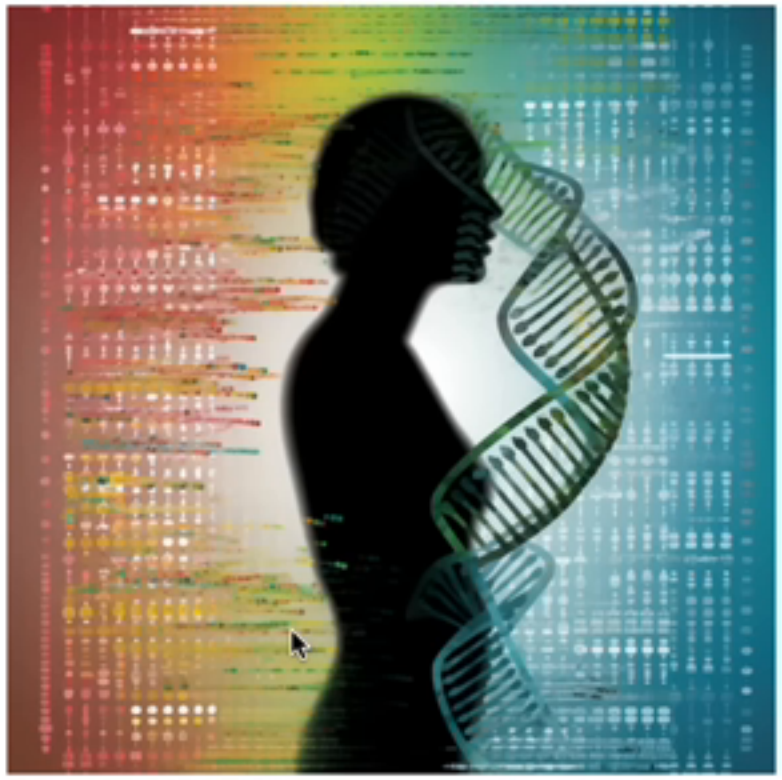
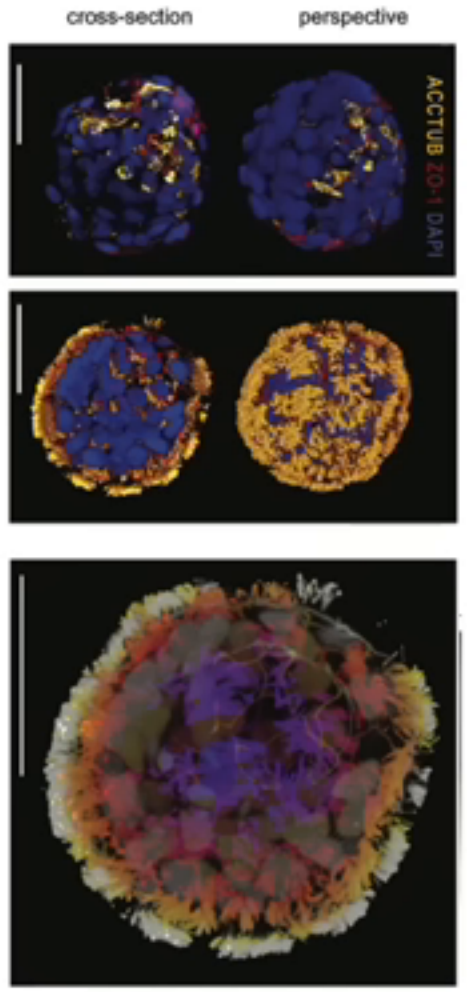
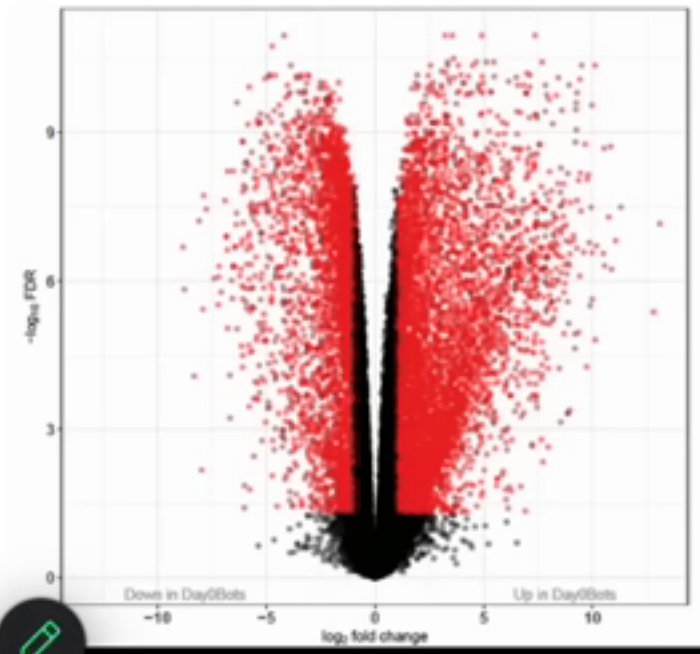
No Evolutionary History Explains Form and Behavior:

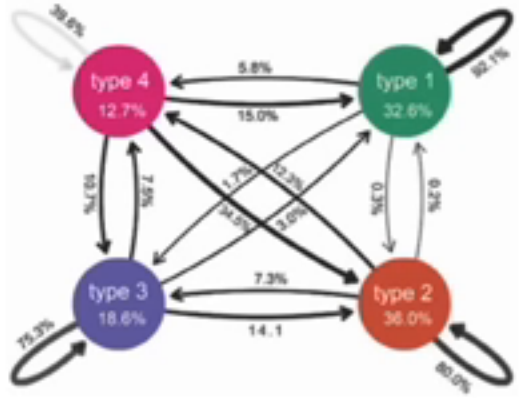






drastically
remodeled
transcriptome

Ethogram of discrete behaviors

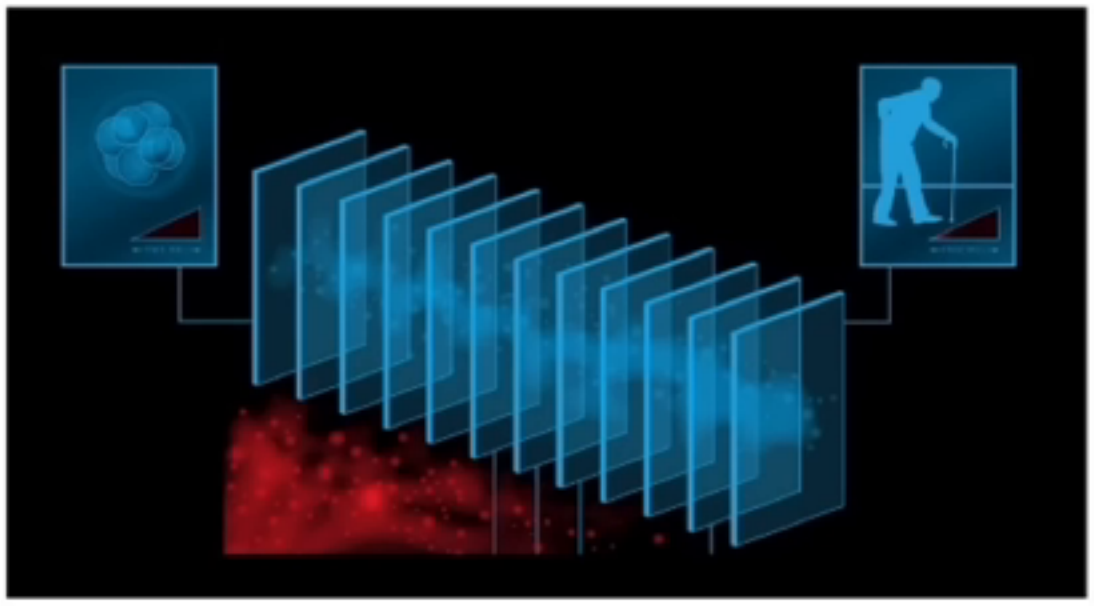


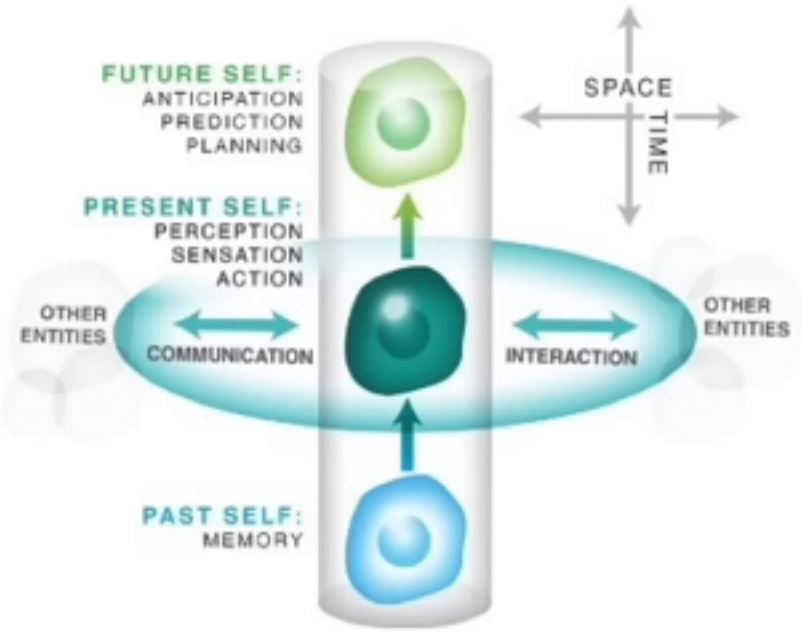
Gizem Gumuskaya

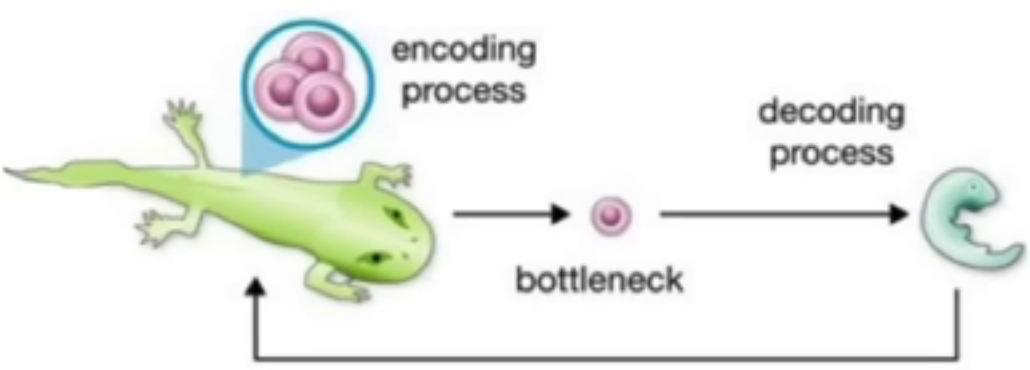
Conclusion:

- Minds & bodies
- Future

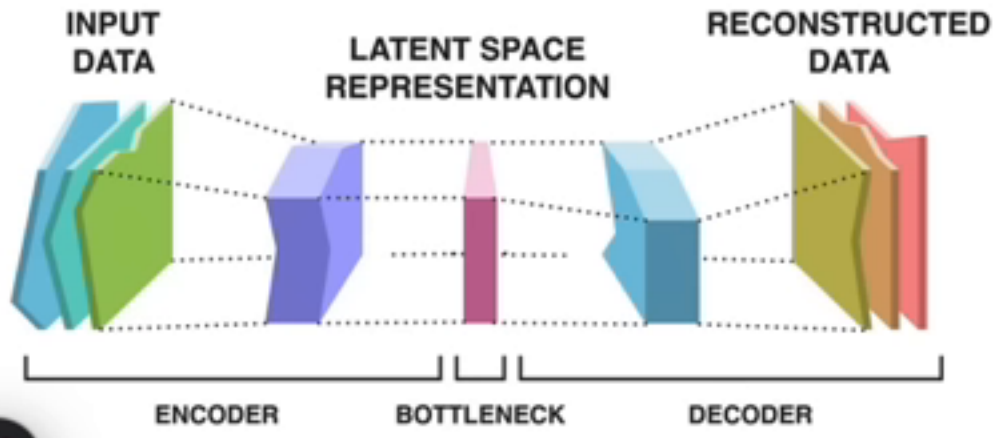
Memory Engrams and DNA - same paradox







Biology assumes the hardware is unreliable
Environment *and your own parts* will change, **don't over-train**
Little allegiance to past Self's meaning of engrams
Re-interpret on-the-fly - present/future is all that matters
Engram is highly compressed - creative remembering, not deduction
Undependable hardware and confabulation are a feature, not a bug
Consciousness = active, creative story-telling from own memory traces



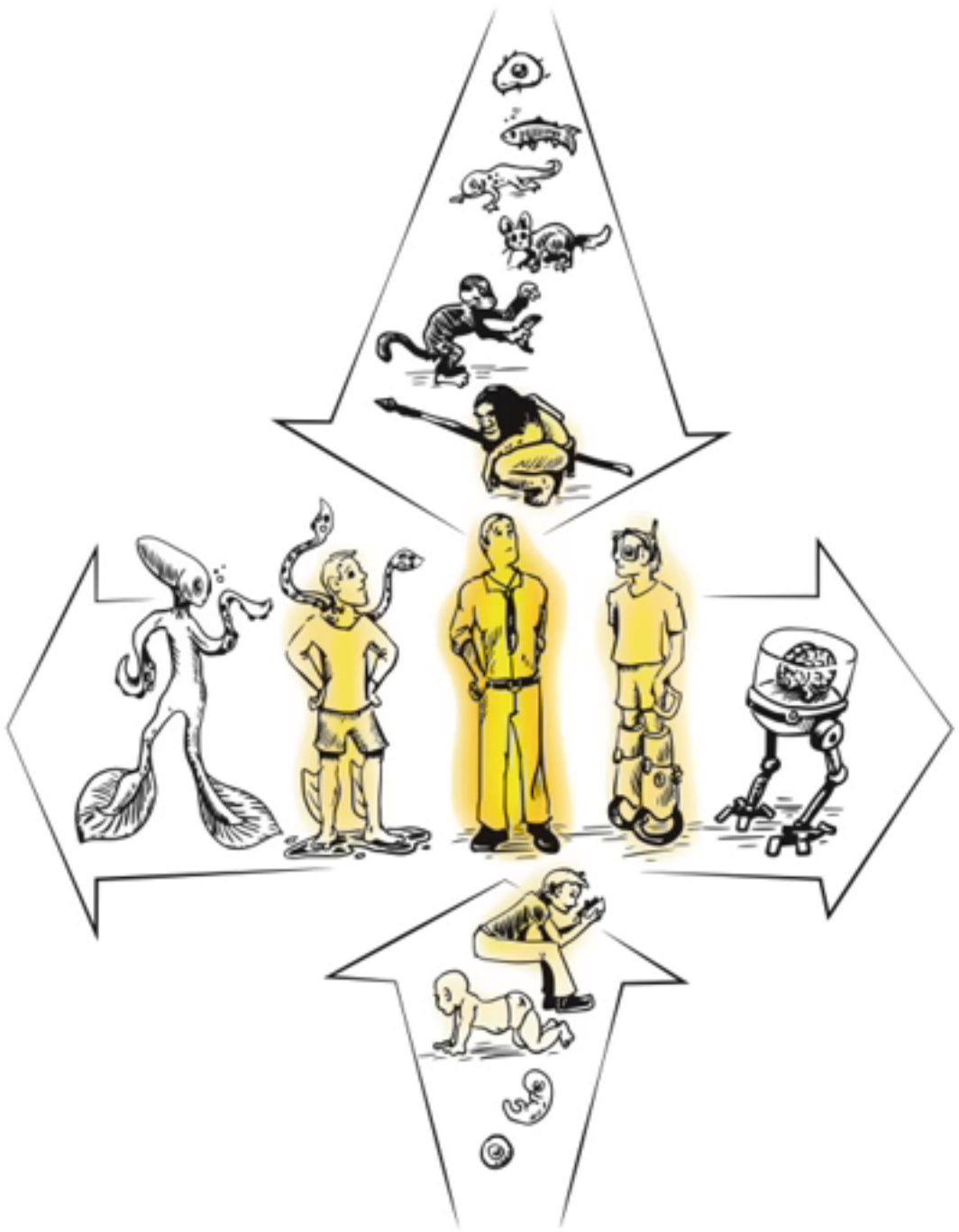
entropy

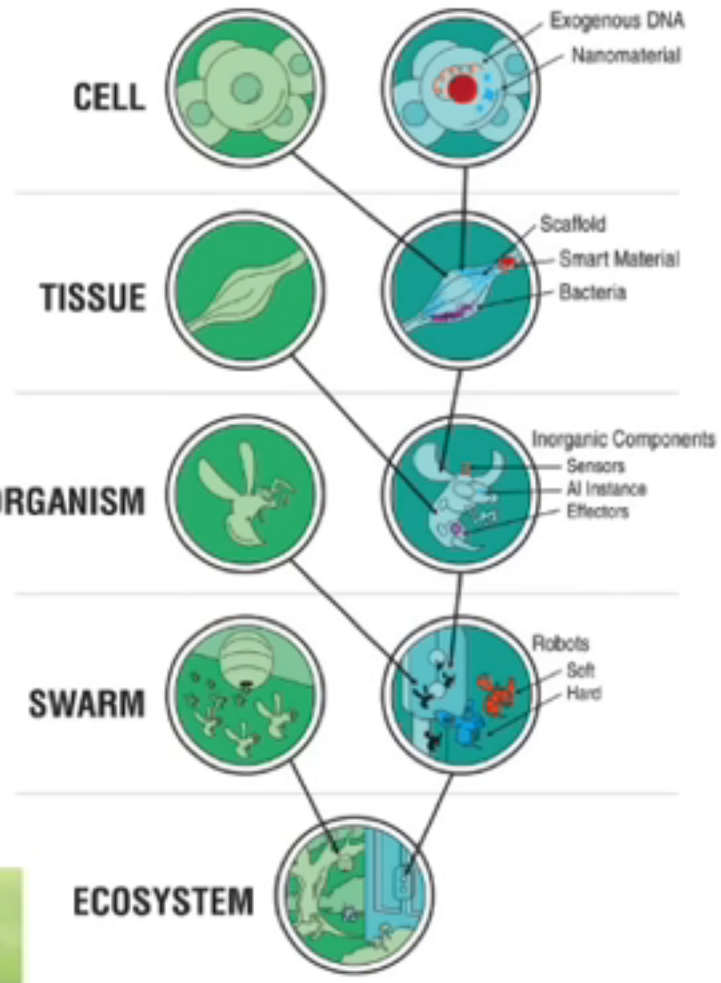
Perspective

Self-Improvising Memory: A Perspective on Memories as Agential, Dynamically Reinterpreting Cognitive Glue

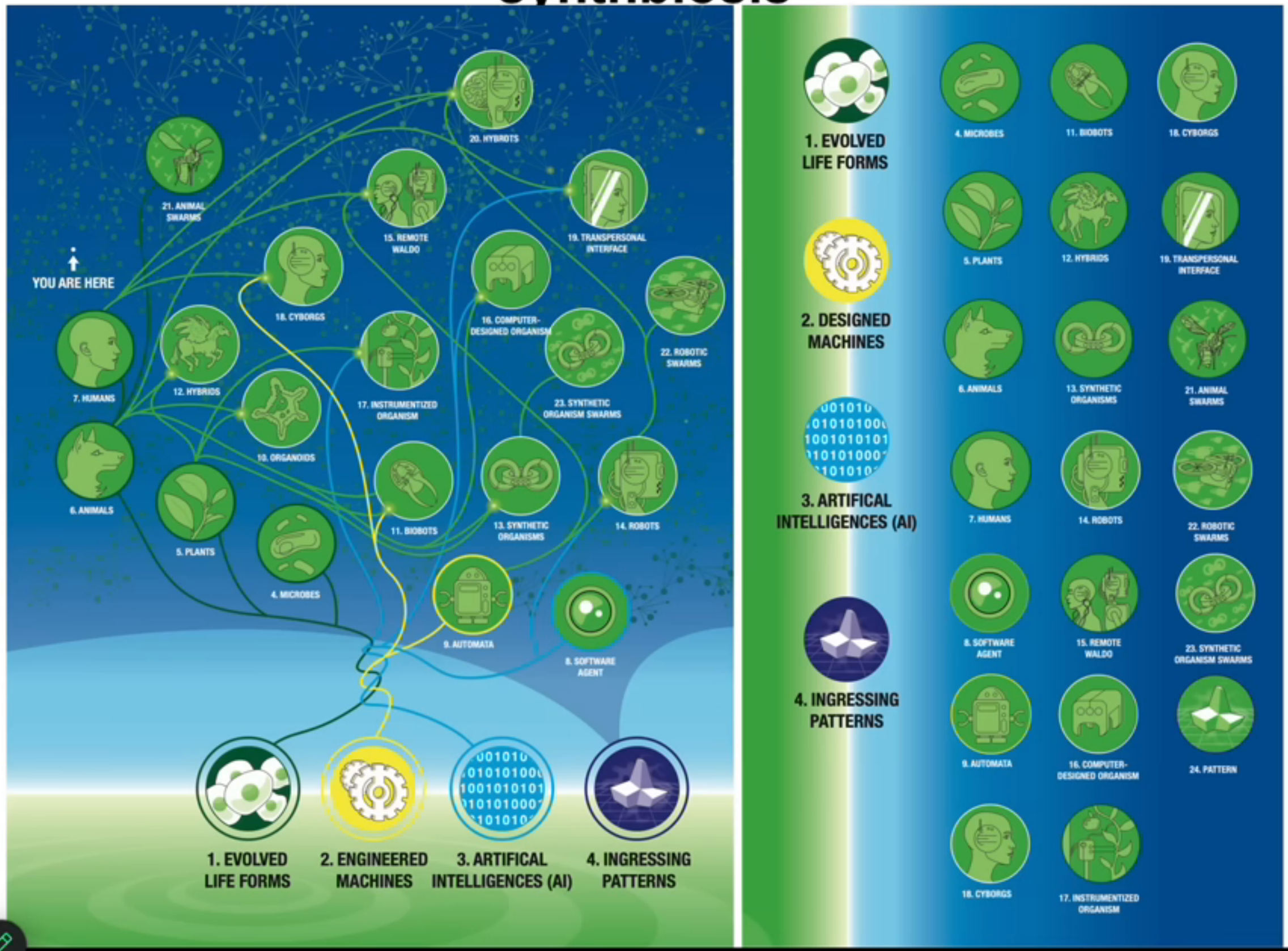
Michael Levin

Plasticity of Life: beyond standard forms





Endless Forms Most Beautiful ← → Ethical synthbiosis



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