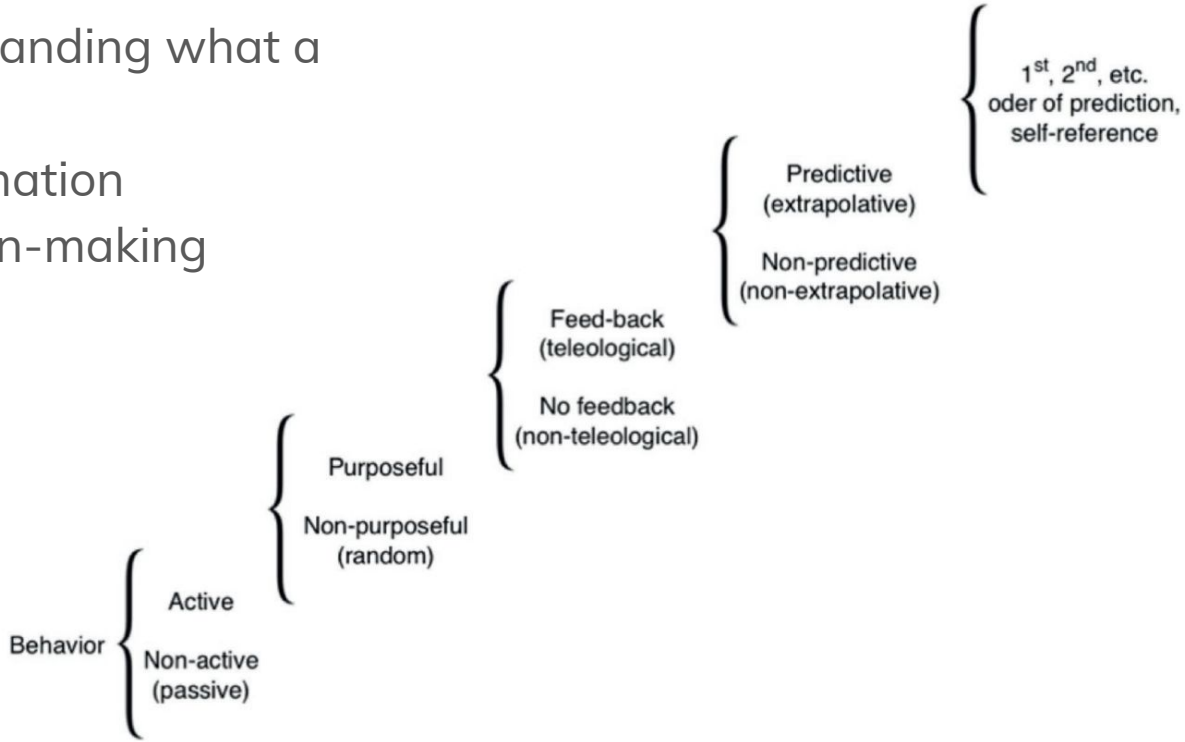
The Computational Boundary of a Self

Presented by Brennen Hill and Melyne Zhou
Focusing on work by Dr. Michael Levin

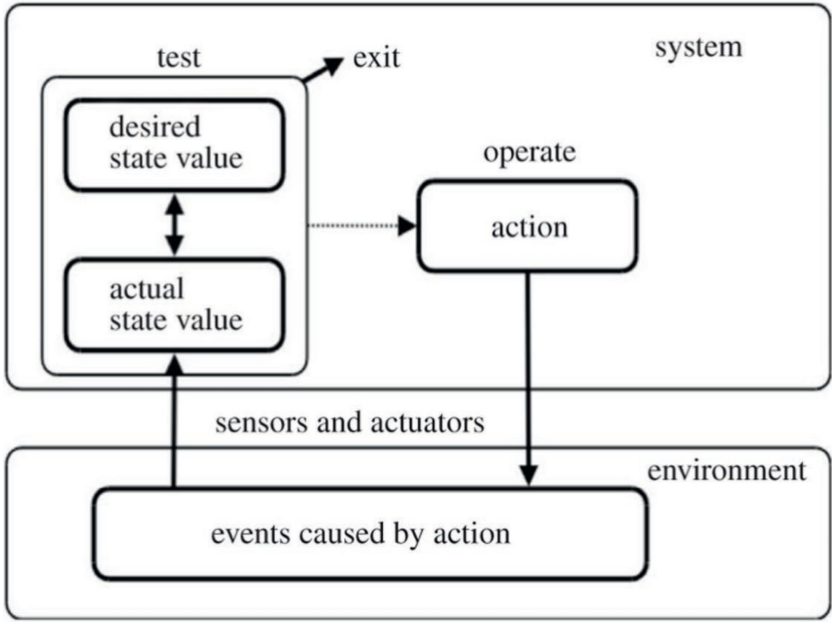
Defining Individuals

- The problem is understanding what a coherent Individual is
- We will focus on information processing and decision-making



From the Perspective of Three Core Assumptions

1) A commitment to evolution
2) All metaphors are judged by their utility in driving scientific progress
3) Goal-directedness is a feedback system

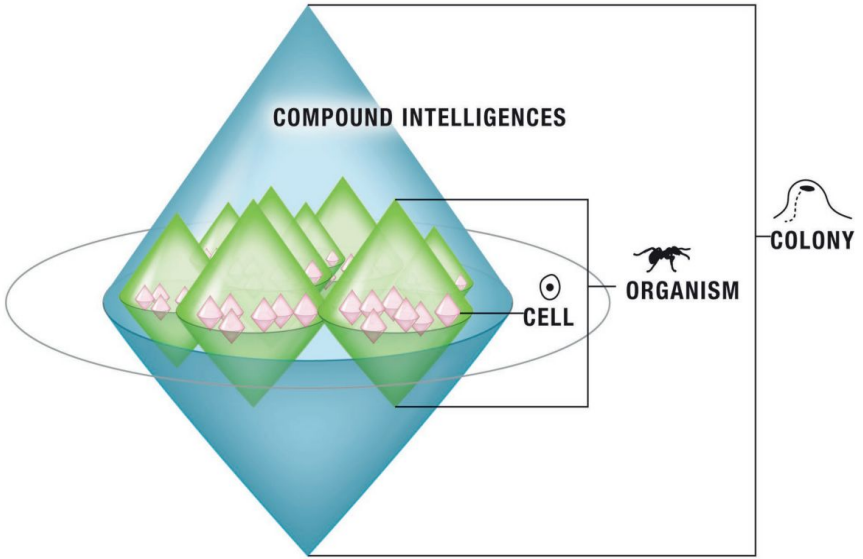


“Of course there is no question that a tree or an elephant is one individual, and we have a very clear mental picture of what this means, for we ourselves are individuals. But there are lower forms in the borderland between one-celled organisms and multicellular organisms that are more bothersome in this respect.”

–J. T. Bonner, 1950

Defining a self

- A self is composed of interacting neural regions with centralized agency and planning
- Much work has been done on defining compound Individuals
- A self is defined by information and goal-directedness

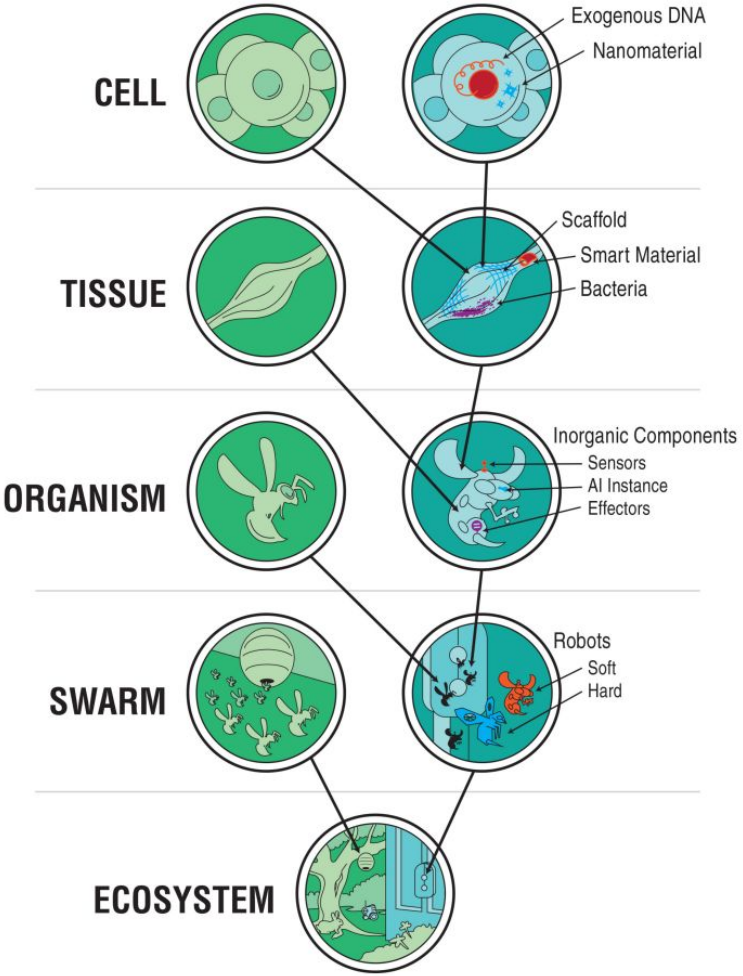


"Our life is shaped by our mind; we become what we think."

— Gautama Buddha

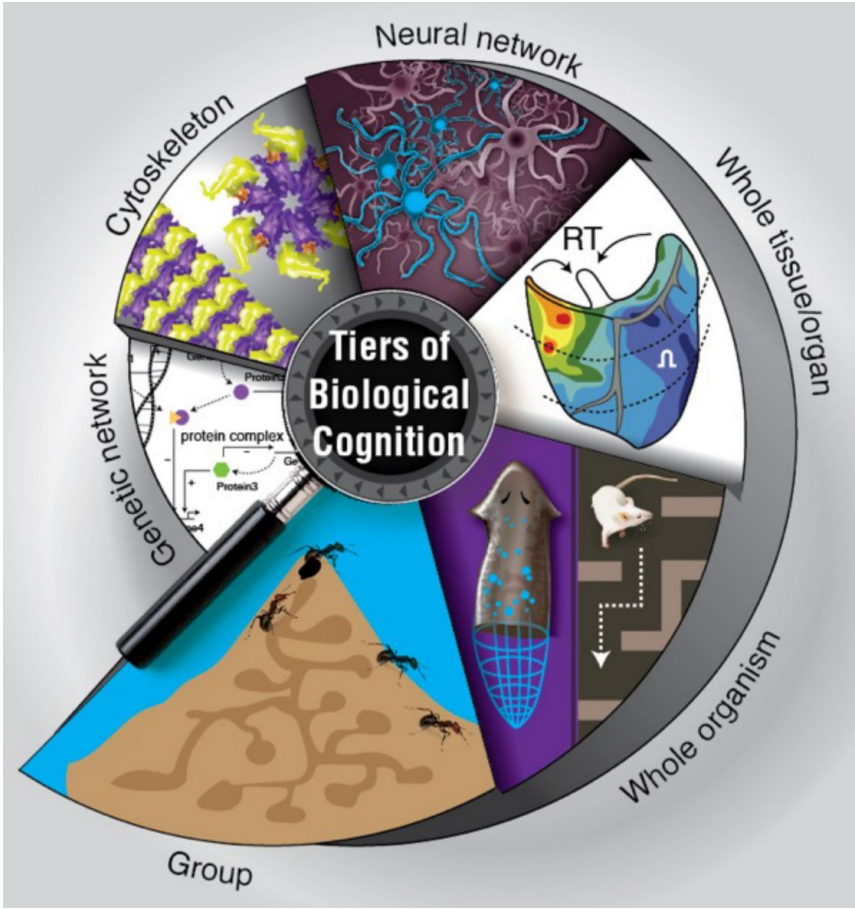
The nested biosphere

- Selves exist at multiple levels of organization
- Complex behavior occurs on large and small scales
- Intelligence exists even at the cellular level



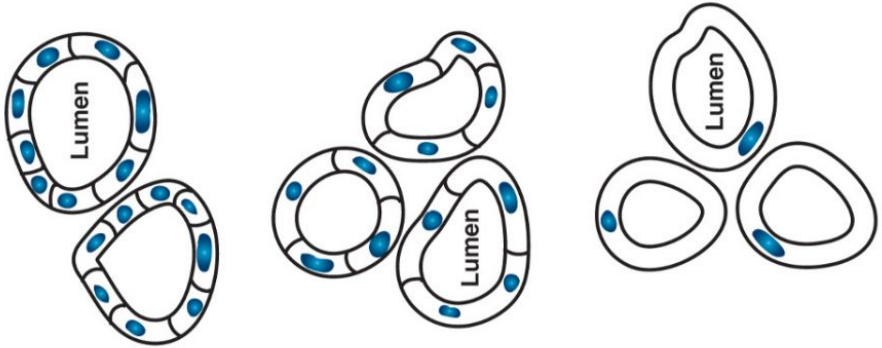
Basal cognition

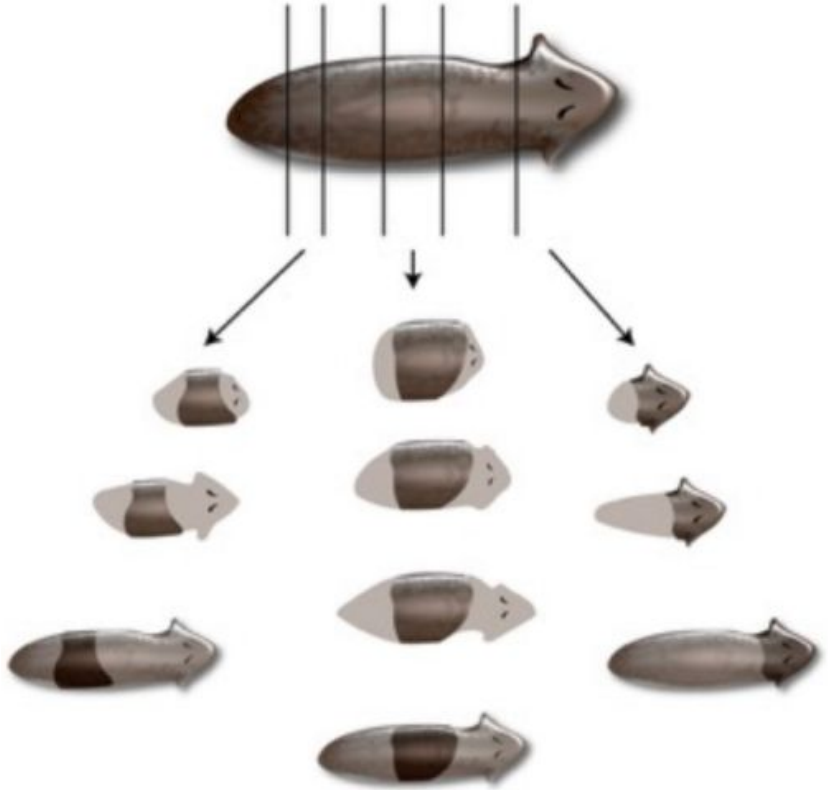
- There is an evolutionary history of learning and decision-making processes
- Nested selves within a body act intelligently



Selves Determined Through Communication

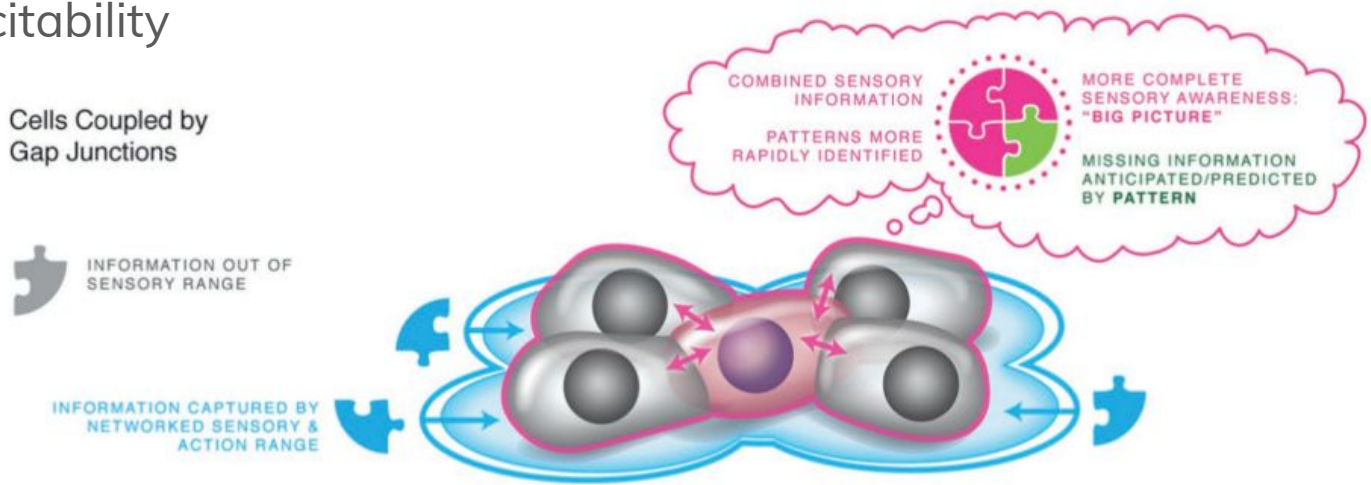
- Selves use their components to reach a desired state
- This state can be reached in different ways from different initial conditions
- The components do no know the larger scale goal





Bioelectrical Signaling

- Cells communicate using bioelectricity
- Resting potential changes can modify behavior
- Psychology evolved from membrane excitability



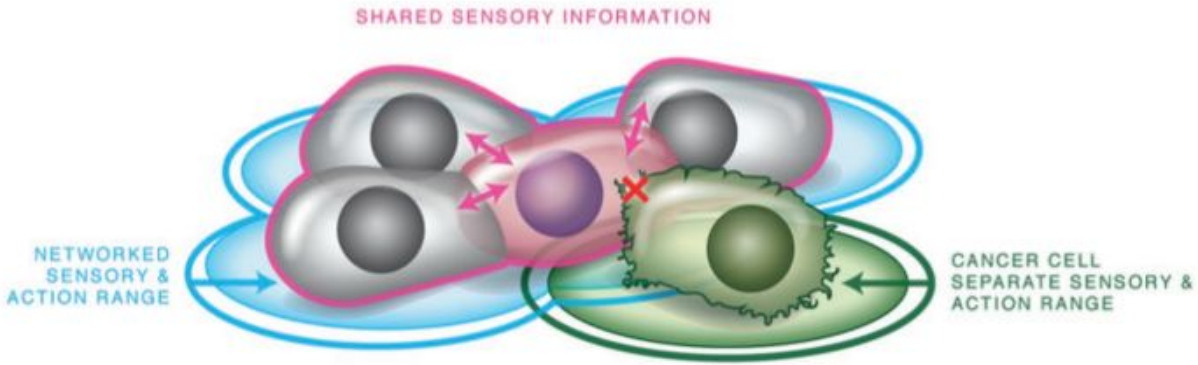
“What defines [a] Self is the boundary of information being able to pass between the subunits.”

- Michael Levin

Cancer Cells

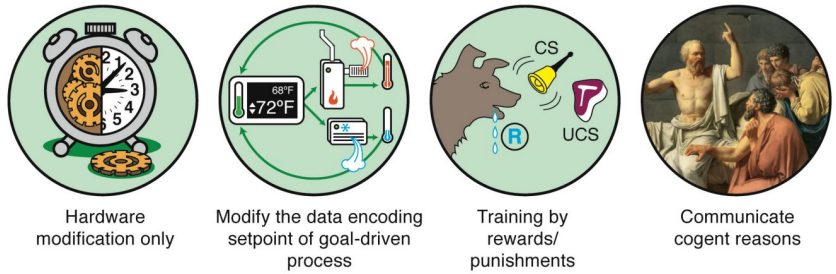
- Cancer cells can no longer communicate
- Cancer cells are isolated spatially and temporally
- Cancerous cells are no longer part of a larger individual

Cells Coupled by Gap Junctions, Disconnected Cancerous Cells



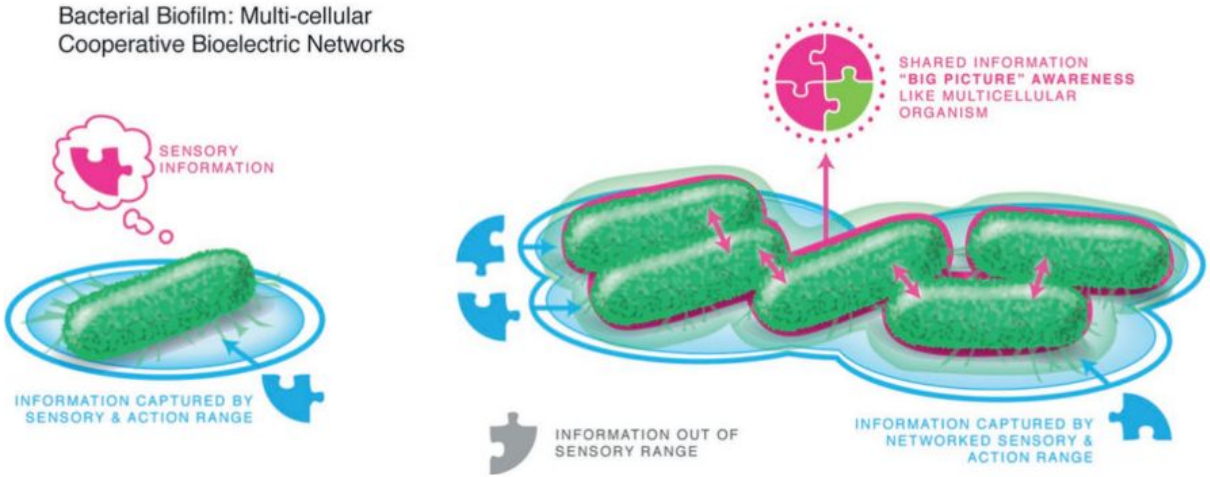
Selfish Selves

- Cells in a body are as selfish as unicellular organisms
- Nested selves cooperate and compete for their own benefits
- The best level or organization to work with is contextual



Variable Boundaries of Selves

- The scale a self exists at can change
- Selves exist at multiple levels of organization
- Shared information determines a self



What is an Individual? — Goals & Associative Learning

- Definition of **Individual**
  - The **scale & types of goals** a system can pursue **determines the boundaries AND content** of the “agent” (AKA, info-processing structure)
- What do we mean by goals?
  - Where do complex & multifaceted goals come from?
  - Counterfactuals & preferences
    - Reinforcement learning → explosion of computational possibilities
    - Homeostasis (more on this later!)
- Associative learning
  - Spatiotemporal → in space & time
  - Ex: Current state (neutral) → linked to future positive outcomes via past experience

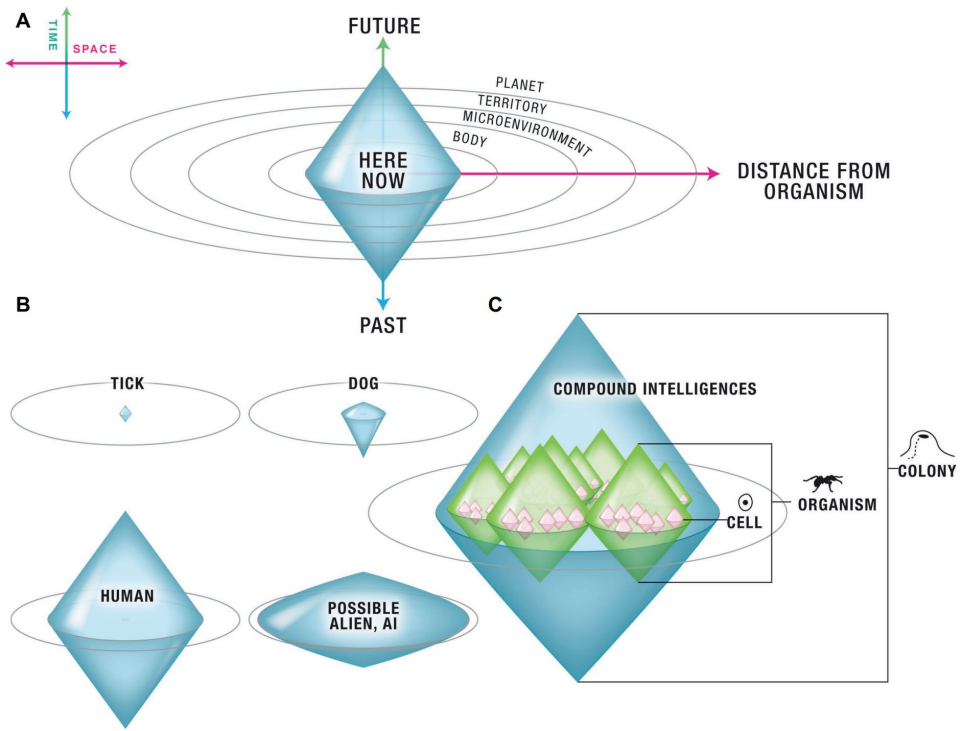
Counterfactuals
Future states that are not yet true, but can be brought about through specific actions.

Preferences
Certain states in the world are better for its welfare than others. Enables learning via **positive/negative reinforcement**.

DEFINING INDIVIDUATION FROM A COGNITIVE PERSPECTIVE

Cognitive Light Cone

FIGURE 2



How to compare examples in different material substrates?

Ex: biology vs. organic artificial life vs. AI vs. exobiology

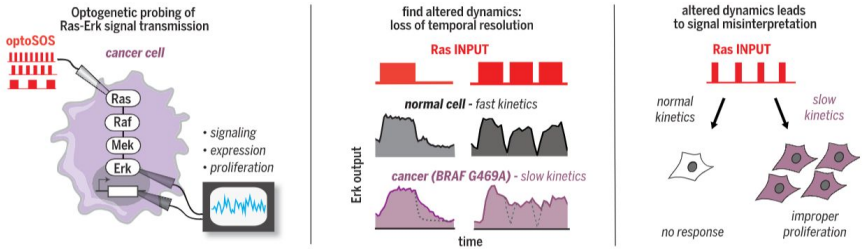
"Can highly diverse Selves, with **very different material structures** be compared with each other in any meaningful way?

A **universal rubric**, applicable regardless of the physical implementation, can be defined by focusing on the **information processing and goal-directed activity** of any given system."

THE AGENT'S EVOLUTIONARY BACKSTORY: SCALING OF INFORMATION BY BIOELECTRICITY

Homeostasis

- The "atom" of cognitive hierarchy → enabling cognitive boundaries to expand
    - Homeostatic persistence (maintain XYZ state) → origin of cognitive goals



Optogenetic profiling of cancer cells reveals perturbed signal transmission dynamics that can drive improper proliferation.

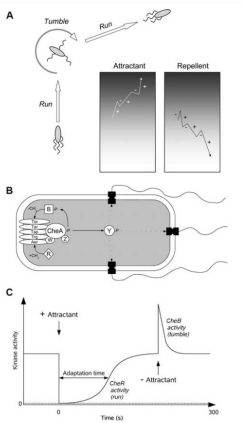
Bugaj et al., 2018;

Elements of the "simplest" homeostatic loop

1. Minimization of homeostatic stress
2. "Hidden layers" (AKA memory)
    a. Delay between I/O
    b. Feedback loops to maintain state after stimuli

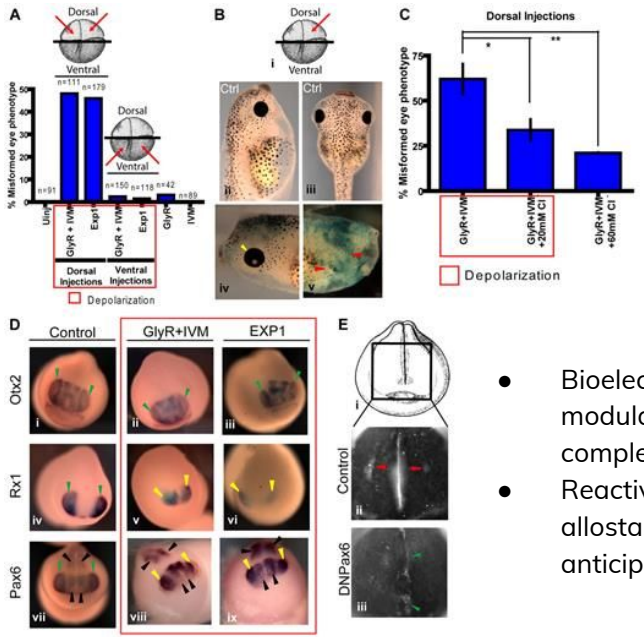
- Sense changes in chemical concentrations over short time periods
- Predictive movement to optimize nutrient intake
- Delayed response → "buffer" to overreacting

Vladimirov, N., and Sourjik, V. (2009)



Memory & Modularity

- Memory ⇒ beginning of modularity (collective intelligence)
  - Learning: Grouping diverse stimuli into compressed representations
  - Ex: Biophysical signals
  - Ex: Somatic control networks
- Modularity
  - Benefits for evolvability (expansion of cognitive boundaries)



- Bioelectric signaling → simple modular trigger sets off cascade of complex events
- Reactive homeostasis → predictive allostasis (use predictive signals to anticipate organ structures)

Local perturbation of Vmem disrupts endogenous eye development

Pai, V. P., Aw, S., Shomrat, T., Lemire, J. M., and Levin, M. (2012)

Sensing — Active Inference & Perceptual Control Theory

- Complex sensory machinery arises from hardware discovered by primitive bacteria
- Active inference — transcription/translational
  - Minimizing surprise & homeostasis
  - Data compression (Markov blanket & coarse-graining)
  - Progeny – the least surprising object in the world is a copy of yourself
    - Ex: queen bee & colony dynamics
- Perceptual control theory
  - Behaviour = control of perception

THE AGENT'S EVOLUTIONARY BACKSTORY: SCALING OF INFORMATION BY BIOELECTRICITY

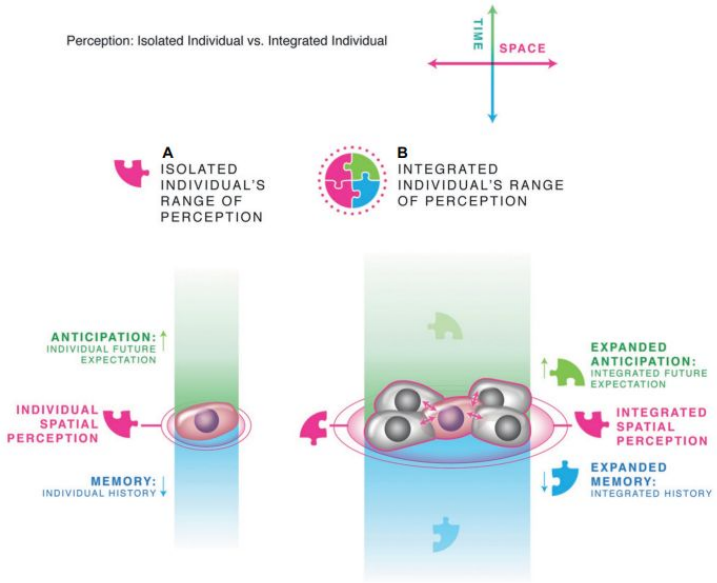
Scale-Up of Cognition

- Cell in center → gets filtered data about everything
  - All cells measure & detect events within the same boundary
    - Not just distinct/local environments
    - AKA limited internal models of the world
  - Spread of information → sharing of a "common reality" among them.

How collective individuals have higher problem-solving capacity than their members?

1. Support layered architecture w/ experience-dependent communication channels (synapses, broadly defined)
2. "Virtual governors" → control capacity (Dewan, 1976)
3. More complex state space → more attractors — can compute meta-system properties not accessible to the single agents (Hofstadter, 1979; Crutchfield et al., 1998; Cenek, 2011).

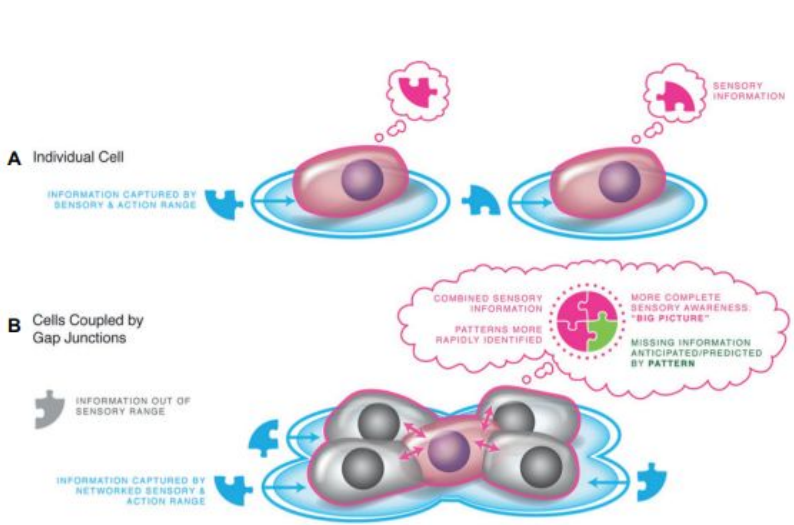
FIGURE 3

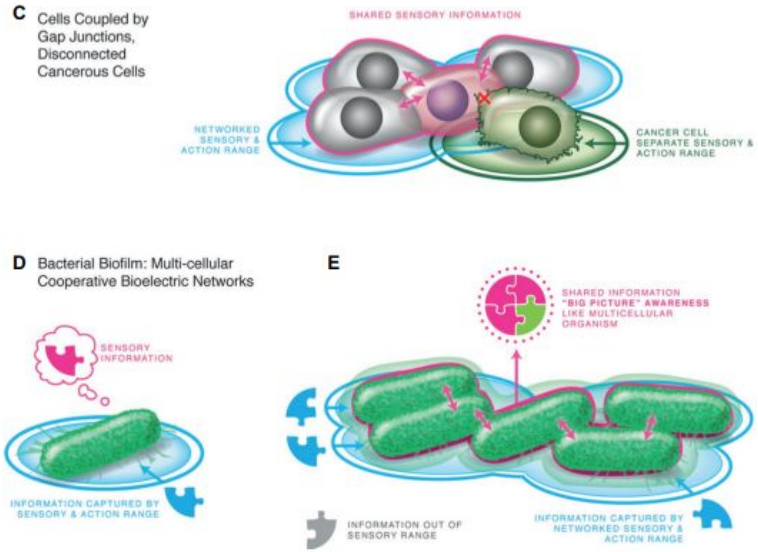


THE AGENT'S EVOLUTIONARY BACKSTORY: SCALING OF INFORMATION BY BIOELECTRICITY

Greedy Infotaxis

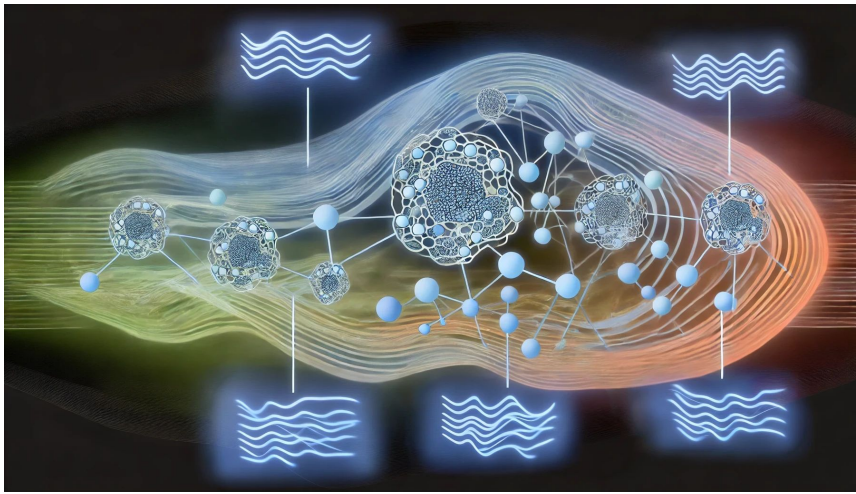
- Multicellularity → arises from **greedy infotaxis**
  - Collecting as much information as possible (as far away spatiotemporally as possible)
    - leads to morphological complexity
    - more connected to other cells = more processing capacity = bigger info processing horizon
  - What are underlying molecular mechanisms?





Predictions and Suggested Research: 1

1) Self-modeling in biological systems
2) In silico systems simulating homeostasis and infotaxis
3) The need to keep other cells nearby as the root of addictive opiates
4) The cost of decision-making



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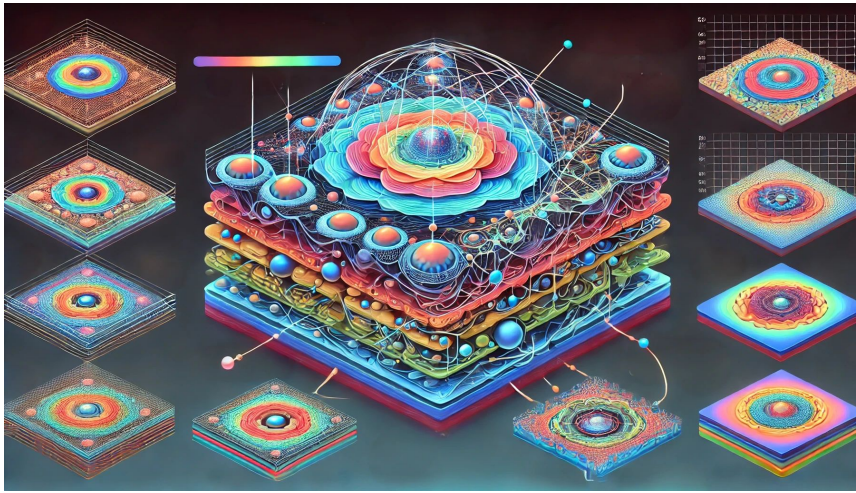

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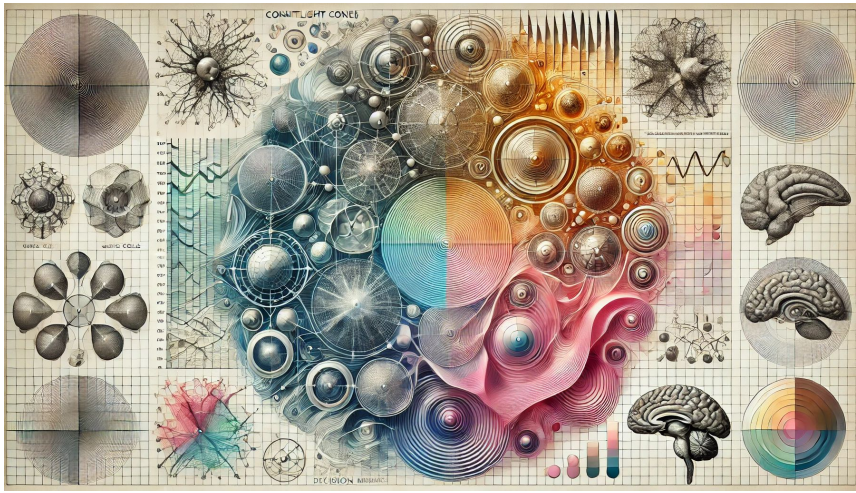
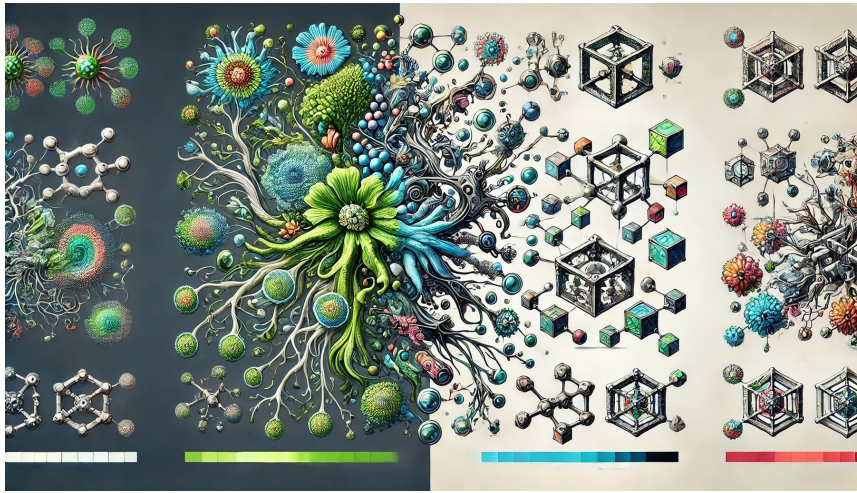


Predictions and Suggested Research: 5

5) Constructs must be made of goal-seeking components
6) Technology for cancer reprogramming
7) Formation and dissolution of metazoan bodies
8) Conservation of regeneration and neurotransmitter signalling



Predictions and Suggested Research: 6

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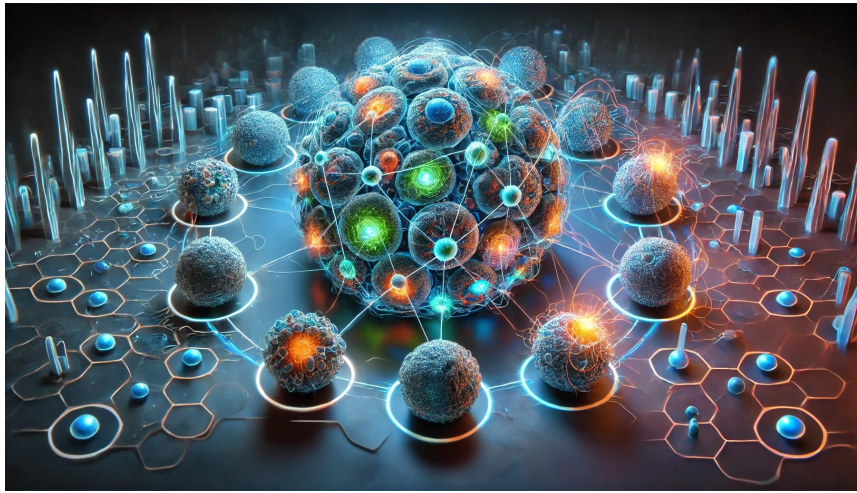

Predictions and Suggested Research: 7

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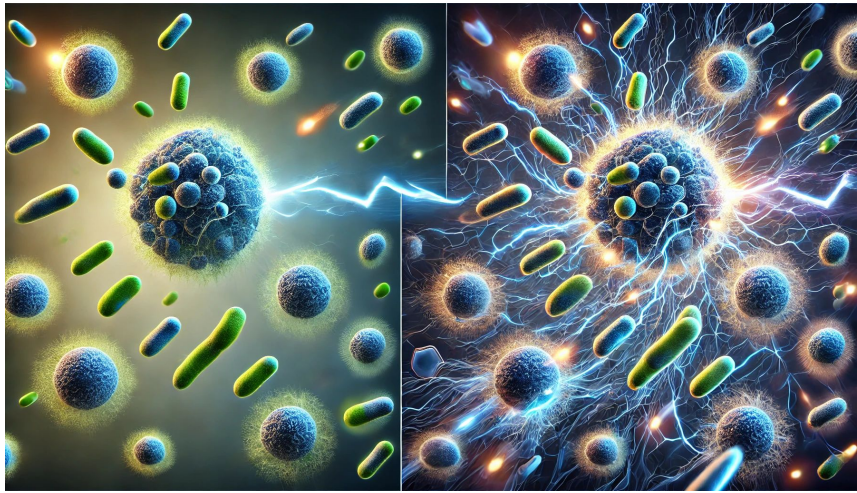

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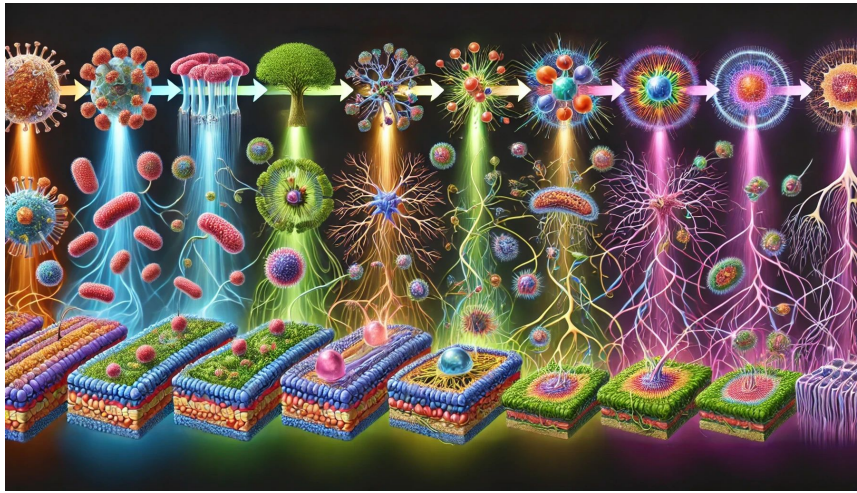
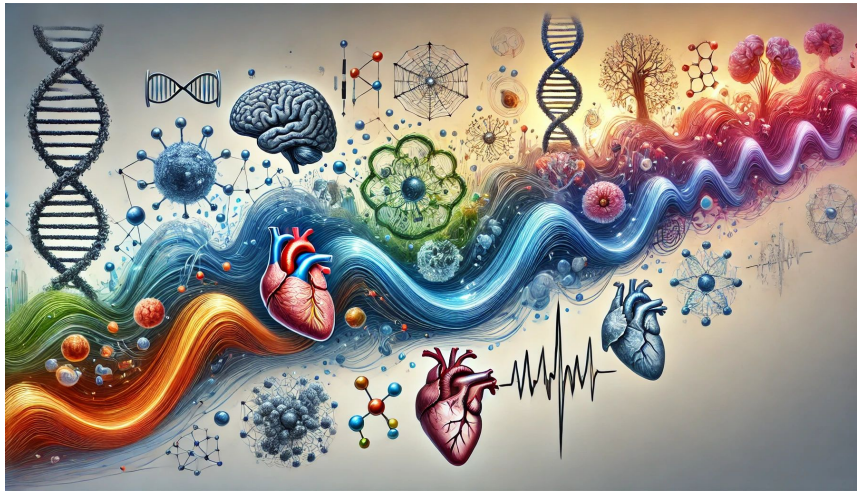


Predictions and Suggested Research: 9

9) Observation of signalling as cues for morphogenesis
10) Behavior shaping and training for regeneration
11) Train swarm organisms and human social groups
12) Communication through reinforcement



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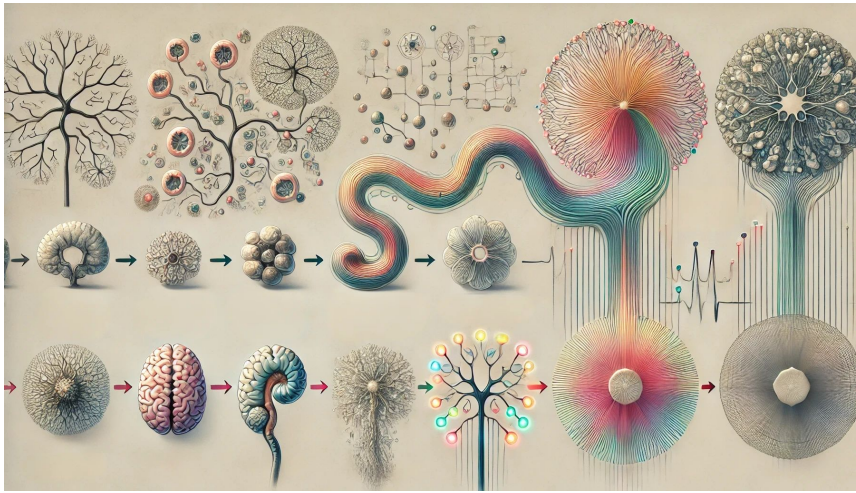

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Predictions and Suggested Research: 12

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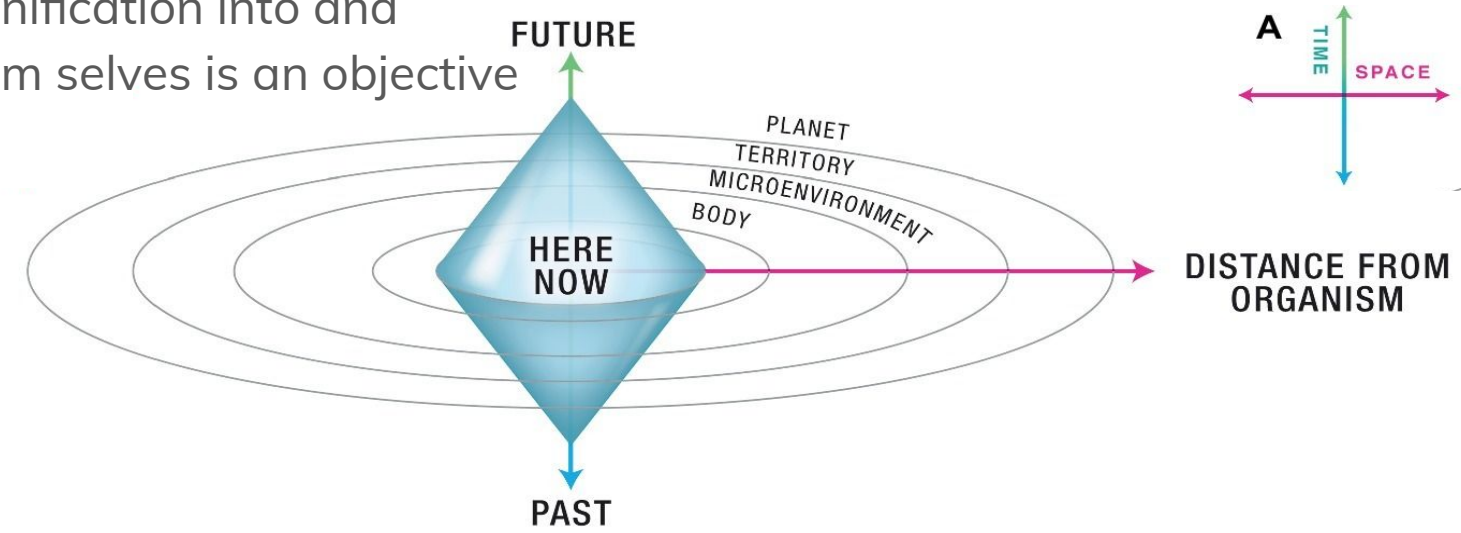
10) Behavior shaping and training for regeneration
11) Train swarm organisms and human social groups
12) Communication through reinforcement

The Potential for Panpsychism

- First person experiences may exist on a spectrum
- Successfully rejecting memories and expectations would dissolve a self
- Recreating unification into and liberation from selves is an objective



Any Questions?

- Do you have any questions?
- We will be bringing up discussion questions after answering.

Discussion Questions

1) If agents other than humans, such as a pancreas, experience some version of a first person experience, what do you believe it would feel to be a pancreas?
2) How can we apply the cognitive light cone to evaluate cognitive capabilities of various systems, both which do and do not yet exist in the present?
3) How do ideas in this paper compare/relate to other theories about cognition and intelligence (ex: Active Inference, Perceptual Control Theory, etc.)?
4) What applications of these theories are you most excited about (ex: regenerative medicine, robotics, etc.)?
5) Do you disagree with any aspects of the studies or theories presented in this paper?
6) Do you believe that the future of artificial intelligence will include nested intelligences?

Let us know if you have any other questions you would like to discuss!

Thank You!