



MINDS



**MINIMAL MINDS**

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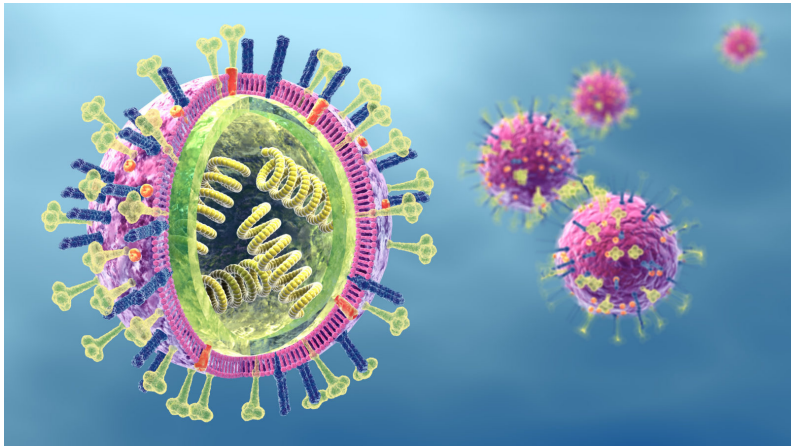
> All the virus wants to do is break inside a healthy cell, steal its genetic machinery, and start profiting from the intrusion. To stop a thief, you need to throw a monkey wrench—or several—into his plans. That's exactly what anti-HIV drugs, known as antiretrovirals (ARVs) are designed to do.[1]

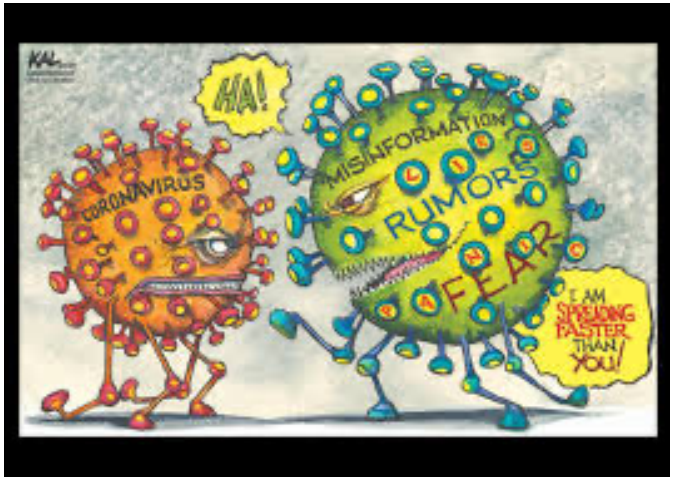
We sometimes speak, in a "loose and popular" way, as though viruses have human-like beliefs and desires. It comes as no surprise when such intentional idioms occur in the hyperbolic prose of the mainstream media. However, it is more surprising when scientific discourse relies on anthropomorphizing claims when discussing the nature of viruses. In recent papers, it has been suggested that if the HIV "virus wants to resist AZT, it needs to make a specific mutation at codon 215 and at another position, such as position 41"[2] and that the Hepatitis C virus must try to coexist with its host by reducing its visibility.[3] Yet, philosophical reflection suggests that although we *can* use intentional idioms whenever we find an entity that exhibits robust and systematic patterns of behavior, a plausible theory of mentality should not treat viruses as even minimally minded. After all, viruses are nothing more than packets of RNA (or sometimes DNA) encased in protein. So, although they are likely to be mechanical and complex, the type of complexity that we find in viruses is unlikely to implement the computational and representational capacities that are necessary for being in cognitive states or carrying out cognitive processes. Viruses are not the kind of entities that can *want* to threaten our wellbeing; they do not *make plans* and *adopt deceptive strategies* for navigating our immune systems; and they have not *learned* to outsmart our best anti-virals. Although many viruses exhibit systematic and predictable patterns of behavior, we can and should treat them as complex biological robots.[4] However, difficult theoretical issues arise in providing a more general strategy for distinguishing genuine mentality from witless mechanical behavior.

In this chapter, my goal is to establish the *minimal conditions* that must be satisfied for an entity to be in cognitive states or carry out cognitive processes. I begin with an examination of the philosophical assumptions that underlie the Cartesian assertion that linguistic capacities are necessary for genuine mentality. I argue that the explanatory resources provided by contemporary cognitive science undercut the force of these assumptions and provide compelling reasons for thinking that even invertebrates (e.g., crickets, cockroaches, termites, and honeybees) possess genuine cognitive capacities. While this claim may seem familiar, I extend the arguments for treating invertebrates as possessing *minimal minds* in two ways. First, I argue that minimal mindedness is likely to be realized by computations that operate over non-linguistic representations; thus, minimal cognitive states and processes are unlikely to be beliefs or desires. Second, I argue that the theoretical and empirical evidence that supports treating invertebrates as minimally minded also warrants the more intriguing conclusion that some sorts of *collective behavior* are best explained in terms of collective mental states and processes;

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[1] Alice Park, "Beefing Up the Arsenal Against AIDS," *Time Magazine* (2007), http://www.time.com/time/health/article/0,8599,1595377,00.html (accessed August 9, 2010)
[2] David Ho, "Therapy of HIV Infections: Problems and Prospects," Bulletin of the New York. Academy of Medicine, 73 (1996), pp. 37.
[3] Vito Racanelli and Barbara Reherman, "Hepatitis C Virus: Infection When Silence is Deception," *Trends in Immunology* 24 (2003): 456-64.
[4] Cf. Daniel C. Dennett, *Kinds of Minds* (New York: Basic Books, 1996), pp. 21ff.

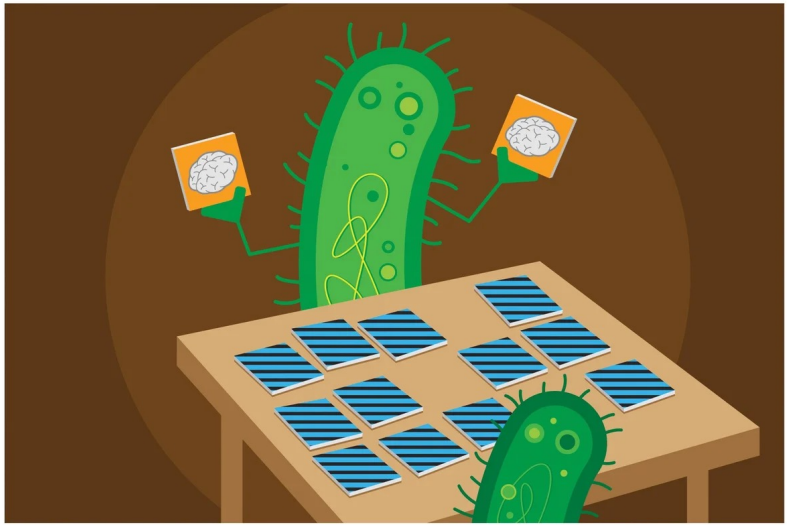





Viruses are often described as having intentionality – “The virus “**wants**” to invade a host cell, hijack its machinery, and reproduce”.

It lacks the **representational** and **computational** machinery needed for genuine cognition

A virus’s actions are fully determined by its genetic design, **with no flexibility or adaptation based on environmental feedback**.



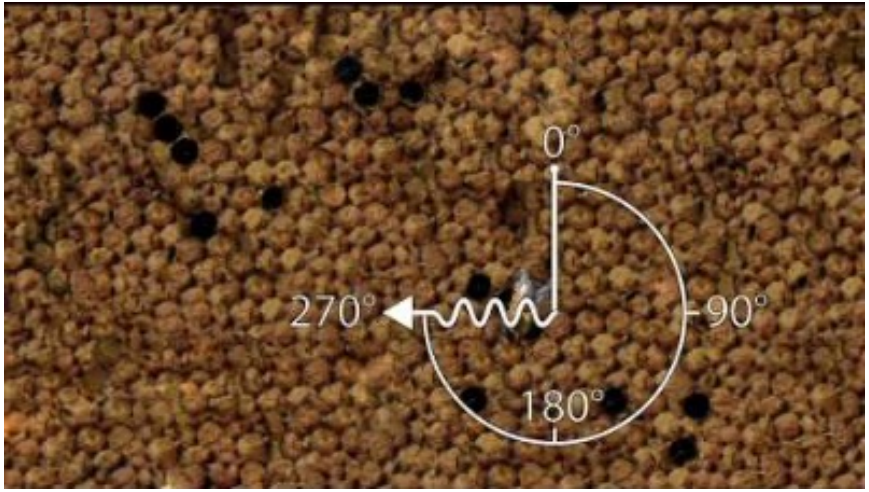


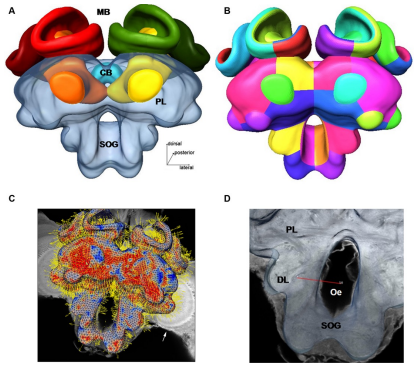
Bacteria have shown themselves capable of semi-autonomous functional **reorganization** in **response** to environmental stressors

The bacteria are **not internally complex enough** to **store** and **redeploy** skills from past experiences in novel situations. Every time bacteria face a challenge, they have to attempt functional reorganization afresh

However, there is **no system for generalizing past learning to new contexts**, and they **lack anything like the sophisticated neural circuits** seen in animals that allow for robust representational capacities… **Or can they?**

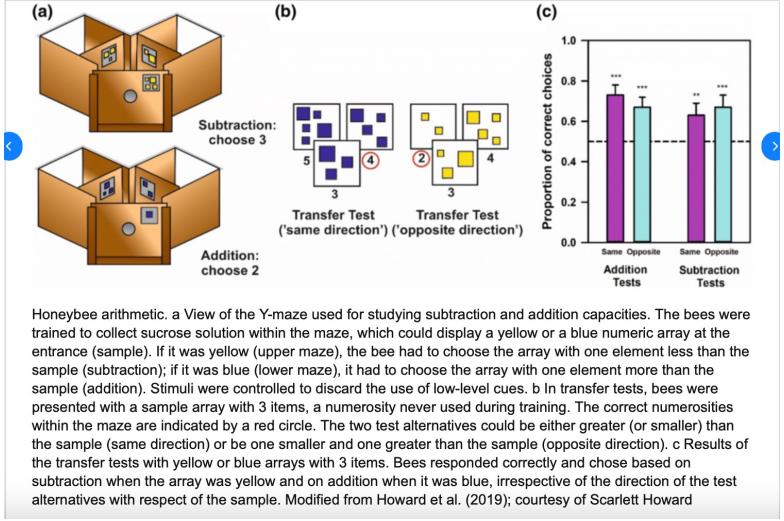




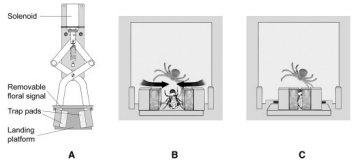

**Honeybees exhibit behaviors that suggest they possess a rudimentary capacity for representing their environment**. They use the famous **waggle dance to communicate** not just the presence of food, but its distance and direction relative to the hive

Bees can **construct cognitive maps** that encode **spatial relationships** and rely on geometric **representations of space**. Honeybees can also **recalibrate their internal maps** using landmark information encountered during their travels.




Honeybee arithmetic. a View of the Y-maze used for studying subtraction and addition capacities. The bees were trained to collect sucrose solution within the maze, which could display a yellow or a blue numeric array at the entrance (sample). If it was yellow (upper maze), the bee had to choose the array with one element less than the sample (subtraction); if it was blue (lower maze), it had to choose the array with one element more than the sample (addition). Stimuli were controlled to discard the use of low-level cues. b In transfer tests, bees were presented with a sample array with 3 items, a numerosity never used during training. The correct numerosities within the maze are indicated by a red circle. The two test alternatives could be either greater (or smaller) than the sample (same direction) or be one smaller and one greater than the sample (opposite direction). c Results of the transfer tests with yellow or blue arrays with 3 items. Bees responded correctly and chose based on subtraction when the array was yellow and on addition when it was blue, irrespective of the direction of the test alternatives with respect of the sample. Modified from Howard et al. (2019); courtesy of Scarlett Howard






This ability to **learn from past experiences** and **apply that learning in novel contexts** points to the existence of an **internal representational system**

This **decision-making process** shows that the bees were engaging in **a form of cognitive evaluation** that required **integrating multiple sources of information** about their environment

However, these representations are still **tightly coupled to their sensory inputs**—they don't form abstract, decoupled representations in the way humans do.

**A minimal mind requires that an entity:**

**1.Possess internal states** and processes that have the function of **adjusting the entity's behavior** in ways that allow it to cope with features of its environment in ways that are **not fully determined by the design of the system**;

2.These states and processes must be **capable of standing-in for various features of the environment** that are significant for the system, and they must be capable of doing so even **in the absence of immediate environmental stimuli**;

3.These states and processes must be **part of a larger representational scheme** that allows for a variety of possible contents to be represented (in a systematic way) by a corresponding variety of possible representations; and,

4.There **must be norms governing** the proper production, maintenance, and use of these representations under various environmental conditions.



A minimal mind requires that an entity:

1. Possess internal states and processes that have the function of adjusting the entity's behavior in ways that allow it to cope with features of its environment in ways that are not fully determined by the design of the system;

Honey bees exhibit flexible foraging strategies, **adjusting their behavior based on factors such as the availability of food sources, weather conditions**, and the needs of the hive.

They use internal processes to modulate their activities, such as choosing when to forage or stay in the hive, in a way that **isn't strictly determined by genetic programming or their immediate sensory input.**

Their decision-making in foraging can be **influenced by past experiences**, such as learning which flowers offer the best nectar, rather than being purely reactive.



A minimal mind requires that an entity:

2. These states and processes must be capable of standing-in for various features of the environment that are significant for the system, and they must be capable of doing so even in the absence of immediate environmental stimuli;

Honey bees **use waggle dances** to communicate the location of food sources to other bees in the hive.

Waggle dance **encodes information about direction, distance, and quality of a food source**, allowing bees to understand and act on this information even when the food source is **not immediately present**.

This dance serves as an **internal representation that stands in for various features of the environment**, helping the hive collectively navigate toward resources without immediate sensory input.



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**Structured Communication**: The **waggle dance is a systematic form of representation** where the angle of the dance relative to the hive represents the direction of the food source in relation to the sun, and the length of the waggle indicates distance.

**Variety of Representations**: This scheme allows honey bees to convey a range of information about multiple potential food sources, indicating that their **representational system can accommodate a variety of contents**.



A minimal mind requires that an entity:

4. There must be norms governing the proper production, maintenance, and use of these representations under various environmental conditions.

**Proper Production and Use of Representations**: There are **norms governing how the waggle dance** is performed and interpreted within the hive. For example, the **precision and accuracy of the dance** are crucial to its effectiveness in guiding other bees to food sources.

**Adaptive Adjustments**: Bees **adjust their dance** based on environmental conditions like the **position of the sun or wind patterns**, showing that they have norms for when to modify their communication based on changing circumstances.

**Error Detection and Correction**: Bees can also **update their internal maps** and foraging patterns **if the environmental cues they relied upon change**, indicating a capacity for maintaining and adapting their representational schemes.



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Peter Carruthers argues, bees can hold representational states like "There is nectar 100 meters east of the hive" and "There is pollen 50 meters west of the hive." However, it's unlikely that they can combine these representations into more complex propositions like "The nectar is further east than the pollen."




**Distributed Decision-Making**: In honeybee colonies, **decision-making does not depend on a single leader or central authority**. Instead, it **emerges** from the interactions of thousands of individual bees, each contributing their behavior and information to the group's actions.

Multiple bees might **perform different waggle** dances for different food sources, providing a variety of potential foraging options to the colony.

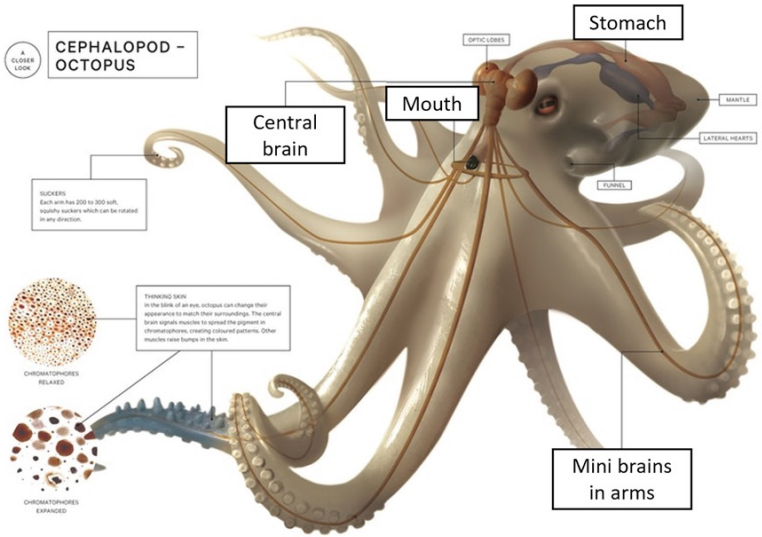
The hive's decision on where to forage next **emerges from the collective evaluation of these dances**.

Deborah Gordon have compared the behavior of insect colonies to the **distributed architecture of the human brain**. Just as **neurons in the brain process information** locally and communicate with each other to generate thought and action, bees in a colony interact in ways that **produce intelligent collective behavior**.

The **individual bees function like neurons**, responding to local stimuli (such as the waggle dance or pheromone signals) and altering their behavior accordingly. **The colony as a whole, then, operates like a neural network** where the overall behavior is much more complex than the sum of its parts.


ANY
QUESTIONS?


OTHER MINDS
THE OCTOPUS, THE SEA, and THE DEEP ORIGINS of CONSCIOUSNESS
PETER GODFREY-SMITH




Octopuses have an incredibly complex nervous system, containing about **500 million neurons**, which puts them **on par with some vertebrates**, like dogs.

But their nervous system is structured very differently from ours or most animals, in that it is **highly distributed** across several regions, notably the brain, optic lobes, and arms.

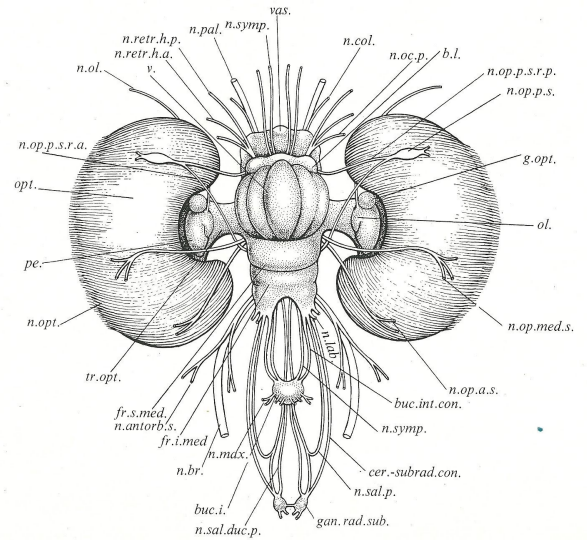



FIG. 1.6. Diagrammatic drawing of central nervous system of *Octopus* as seen from above (modified from Young 1964*b*).

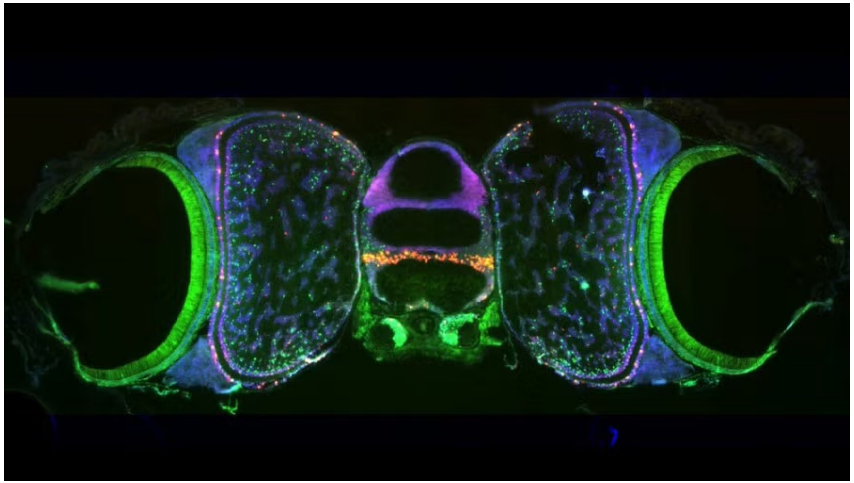
The octopus brain contains about **45-50 million neurons** and is responsible for high-level cognitive functions such as **decision-making, motor coordination, and learning**.

What's surprising is that even though the brain initiates many behaviors, much of the actual **motor and sensory processing happens in the arms**, **not the brain**.

The brain contains **basal lobes**, which are involved in complex motor functions such as **walking, swimming**, and **changing skin color**.

Another important part of the brain is the **vertical lobe**, which plays a key role in **visual memory** and the **cross-brain transfer** of learned information.

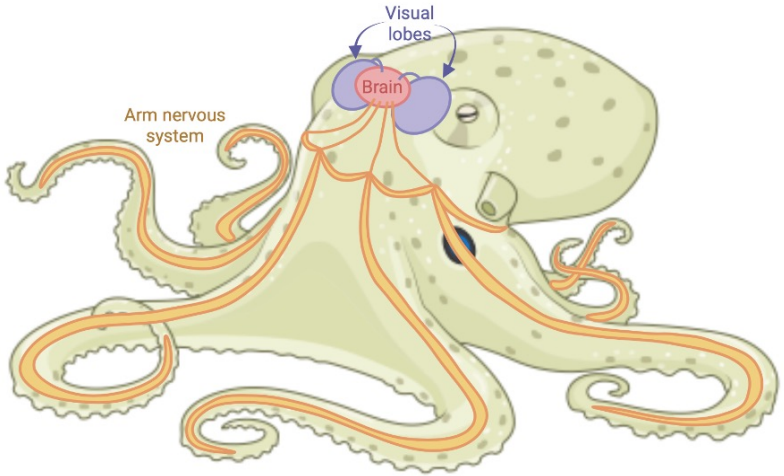
For example, if an octopus learns a task using one eye, it can later perform that task with the other eye, although not as efficiently. This **cross-brain transfer** highlights how the octopus brain processes memory across different parts of its nervous system.



The **optic lobes**, containing **120-180 million neurons**, handle **visual processing**.

Octopuses rely heavily on vision for **navigation** and **learning**.

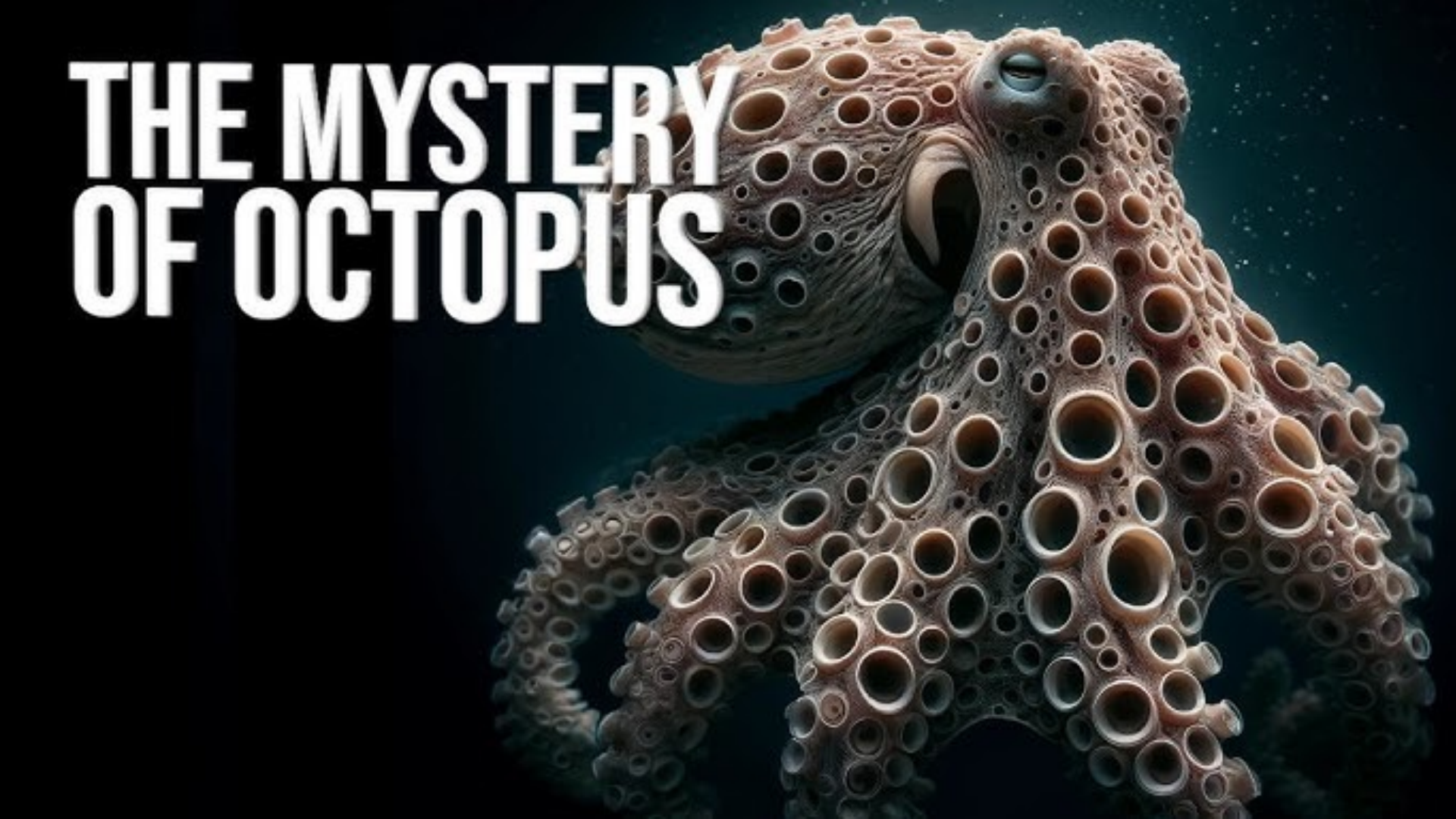
These optic lobes are responsible for receiving inputs from each **ipsilateral eye**, meaning each lobe processes the information from the eye on the same side of the body.

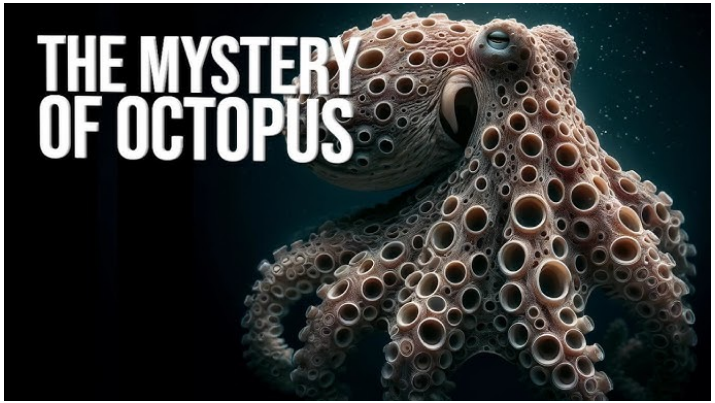



This is perhaps the most fascinating aspect of the octopus nervous system: the **arm nervous system**, containing **350 million neurons**, far more than in the brain itself.

Each arm operates with an extraordinary level of **autonomy**, equipped with **axial nerve cords, intramuscular nerve cords, sucker ganglia**, and sensory receptors that handle **chemical, tactile, mechanical**, and **proprioceptive stimuli**. These neurons allow each arm to function independently, processing sensory inputs and controlling movements **without direct involvement of the brain**.

Even when detached from the body, octopus arms continue to **grasp objects** and **withdraw from noxious stimuli** for hours. This suggests that **local control of suckers and movement** resides in the arm itself, highlighting the **decentralized nature of octopus cognition**.


THE MYSTERY
OF OCTOPUS

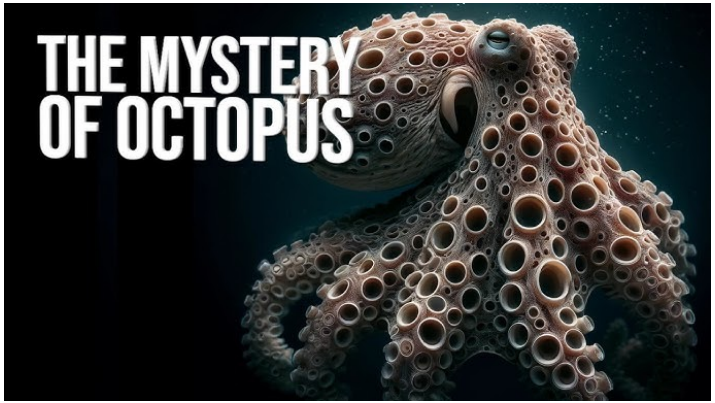



**Unique Features of the Octopus Nervous System**

First, there's **no somatotopic mapping** in the brain. In most animals, the brain maintains a one-to-one mapping of body parts, which allows for coordinated movements.

Experiments show that octopus brains **send global motor commands to all arms, rather than controlling each arm individually**. This means that instead of the brain mapping body parts, it **issues motor programs** that are **processed by the Peripheral Nervous System (PNS)**, where much of the control over movement occurs.

Second, the octopus **arm system is highly autonomous**. Each arm can **bend, twist, and elongate** without direct commands from the brain, making it incredibly flexible in its actions. This autonomy **is made possible by the arm's internal circuitry**, which processes movement and sensory inputs locally.




**Somatotopic Mapping in the Arms**

Even though the brain lacks somatotopic mapping, each arm appears to have its own form of mapping.

The arms **contain local brachial modules (LBMs)**, which process sensory inputs in a spatially ordered way. These modules **help the arms create a spatial map of objects they come into contact with**, allowing for **complex object manipulation and environmental exploration**.

Some researchers suggest that these arms may even store information for up to an hour, **enabling learning and adaptive movement based on recent sensory experiences**.

In humans, **myelinated fibers allow for fast information transfer**, which is crucial for coordinating complex cognitive tasks. Octopuses have **slower neural conduction due to unmyelinated fibers**, which may lead to different cognitive strategies and potentially **multiple 'minds'** instead of a unified consciousness.


Wait
for
it...
?


Waiting...
waiting...
Finally, when the
door opens.

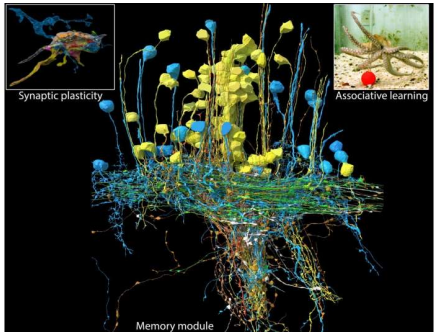


Octopuses demonstrate **domain-general cognition**, meaning they apply cognitive abilities across different contexts.

Their **learning** abilities include **trial-and-error problem-solving** when handling tough prey and **associative learning**, such as recognizing visual cues.

Octopuses can also discriminate between objects they've never encountered in the wild, suggesting that they are **capable of concept formation**.



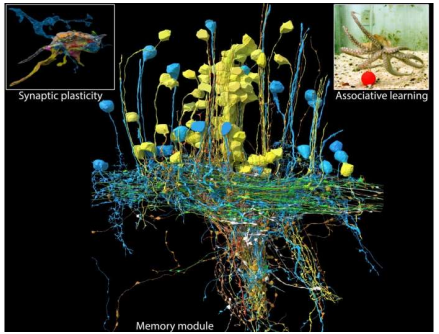



Octopuses also have **impressive memory**.

Their **denning behavior**, where they create homes and use environmental landmarks to navigate, suggests **they can form mental maps of their surroundings**.

They **don’t rely on fixed routes when traveling**, which further indicates the **presence of cognitive mapping and context-sensitive decision-making.**








**Mimicry and Self-Awareness**

Some octopus species, like the **mimic octopus**, are capable of remarkable **mimicry behaviors**.

They can imitate other species such as **flounders** or **lionfish** to avoid predators. This level of mimicry suggests that octopuses might possess a basic **third-person perspective**, as they seem aware of how their appearance affects others.

This could point to a rudimentary form of **self-awareness**.



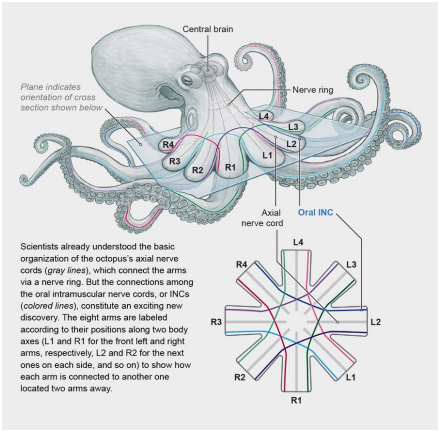
## Attributing Consciousness to Octopuses

The **Cambridge Declaration on Consciousness** recognized octopuses as candidates for consciousness based on their **neuroanatomy, neurochemistry**, and **neurophysiology**.

Several structures in the octopus brain resemble structures associated with consciousness in vertebrates - the **dorsal basal and sub-vertical lobes** may function similarly to the **thalamus** in vertebrates, which **relays sensory information to the cortex**.

This suggests that octopuses **could have central processing centers that integrate multimodal sensory inputs** and produce **conscious experience**.






## Arm-Based Consciousness: A Hypothesis

Studies by Rowell (1963) and Sumbre et al. (2001) have shown that **amputated octopus arms retain the ability to process sensory information** and execute movements independently.

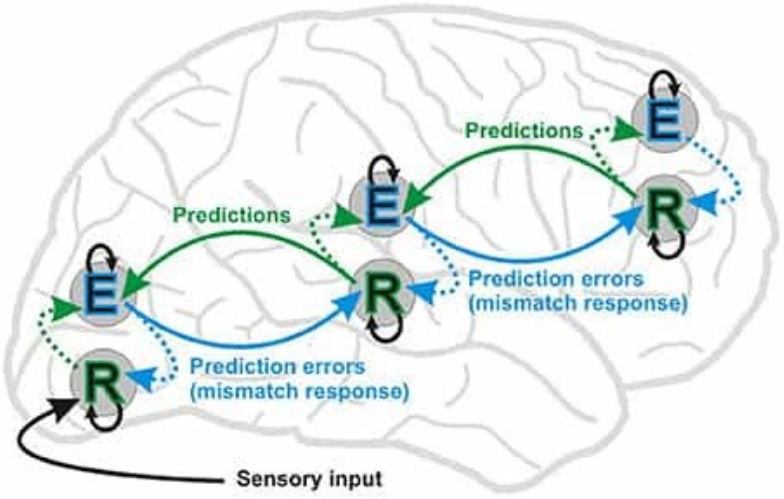
It raises the possibility that the **arm nervous system might generate local conscious fields**. These local fields could provide a form of **primary consciousness**, where the arms are directly aware of their environment and capable of independent action.

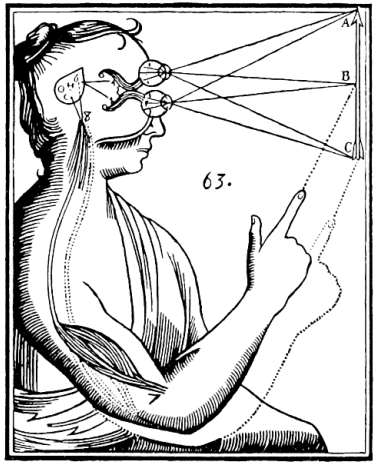
The idea of **decentralized consciousness** challenges our traditional models, which typically assume that **consciousness arises solely from the brain**.


ANY
QUESTIONS?

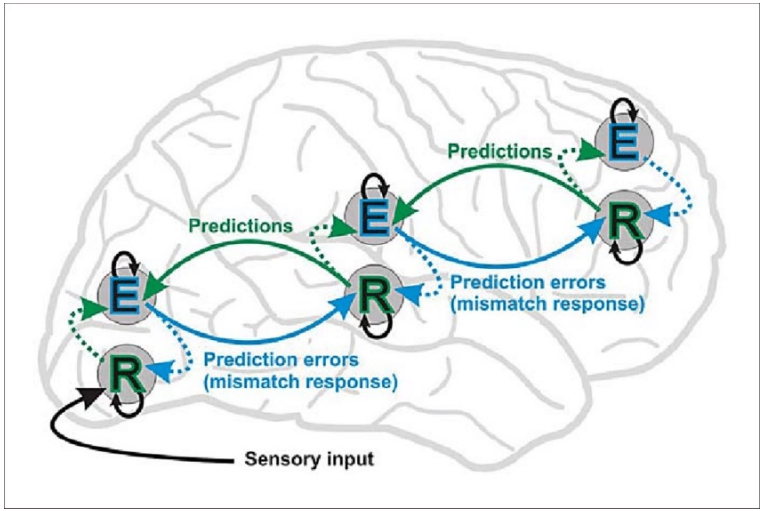




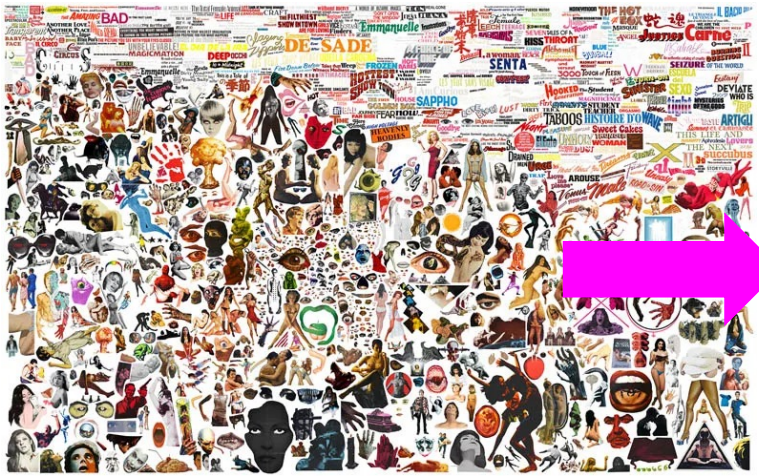

Predictions
Predictions
Prediction errors
(mismatch response)
Prediction errors
(mismatch response)
Sensory input


A
B
C
63.




Predictions
Predictions
Prediction errors
(mismatch response)
Prediction errors
(mismatch response)
Sensory input















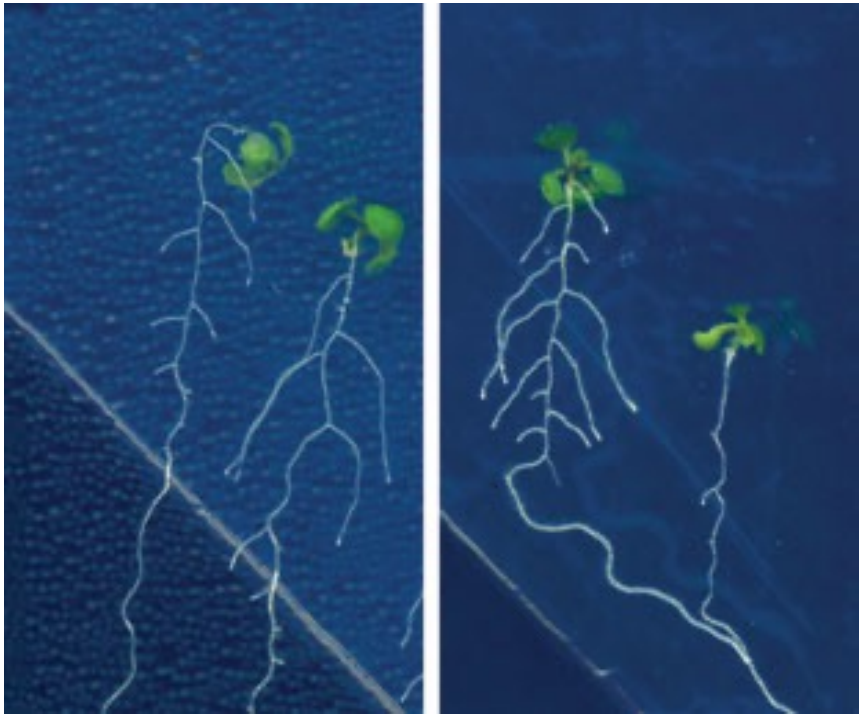



In PPP, plants are **proactive agents** rather than passive recipients

One illustrative example comes from research on **pea plants** exposed to fluctuating nutrient levels:

When **nutrient-rich patches** were compared to **nutrient-poor patches with increasing nutrient levels**, pea plants allocated more roots to the dynamic (but poorer) areas.

This indicates that plants **aren't merely reacting to absolute conditions**; instead, they **use predictive information** to anticipate which patches will yield better long-term results

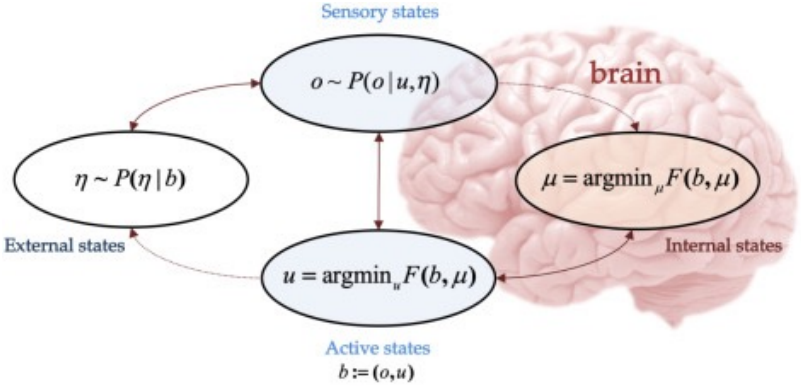


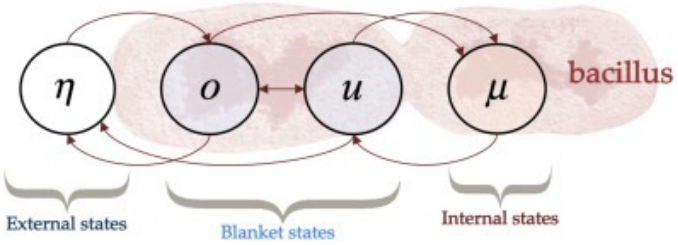
## Avoiding Salty Surprises: Halotropic Behavior

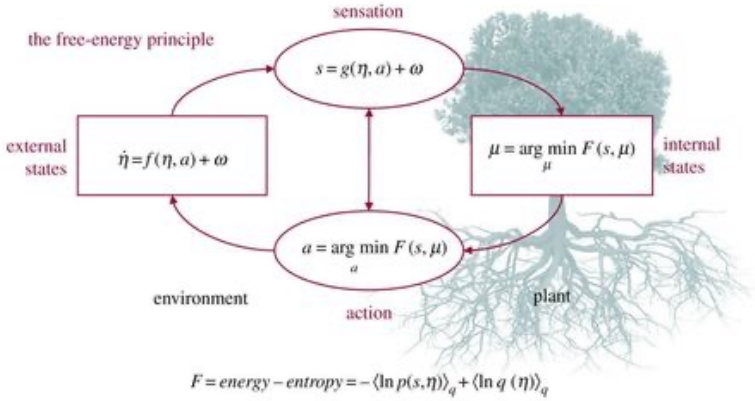
High salt levels can cause **osmotic and ionic stress**, disrupting essential processes like photosynthesis and protein synthesis.

When roots encounter salt, they can either **tolerate** it (in species that have adapted to salty environments like mangroves) or **actively avoid** it.

This **avoidance mechanism** is an example of plants **minimizing surprise** by using their sensory input to update their predictions about the environment.




action to minimize a bound on surprise

$F = \text{complexity} - \text{accuracy}$

$= D(q \| p(\eta)) - \langle \ln p(s(a) \mid \eta) \rangle_q$

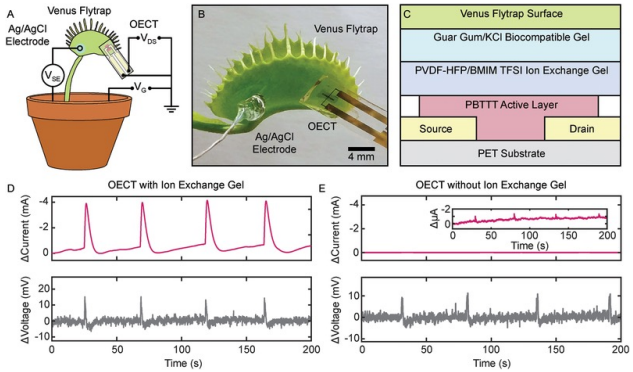
$a = \arg\max_{a} \text{accuracy}$

perception to optimize the bound

$F = \text{divergence} + \text{surprise}$

$= D(q(\eta : \mu) \| p(\eta \mid s)) - \ln p(s)$

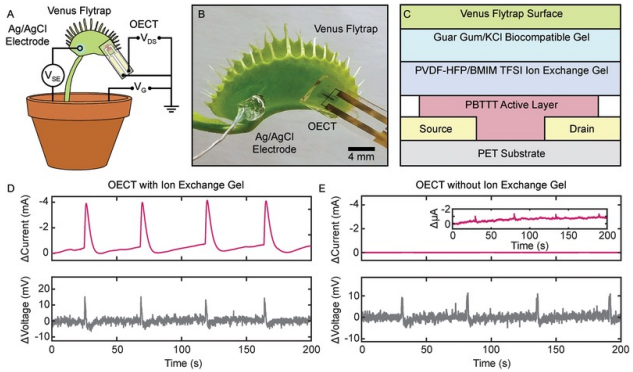
$\mu = \arg\min_{\mu} \text{divergence}$

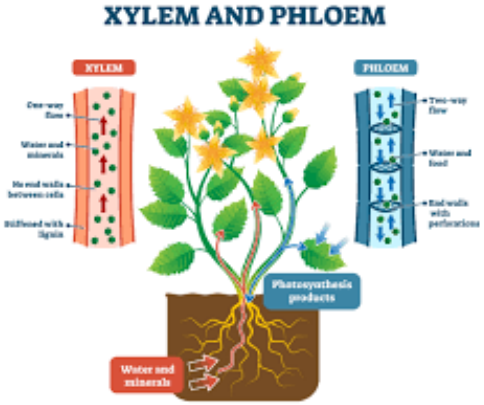



## Darwin's Analogy: Plant Roots as a "Brain"

**Charles Darwin** suggested that the **root tip of a plant** functions much like the **brain of lower animals**, directing the movements of the plant's body in response to sensory input.

For example, **Mimosa pudica**—the "sensitive plant"—demonstrates rapid leaf folding when touched, a behavior directed by **electrical signals moving through its tissues**. These signals resemble the **action potentials (APs)** seen in animals.



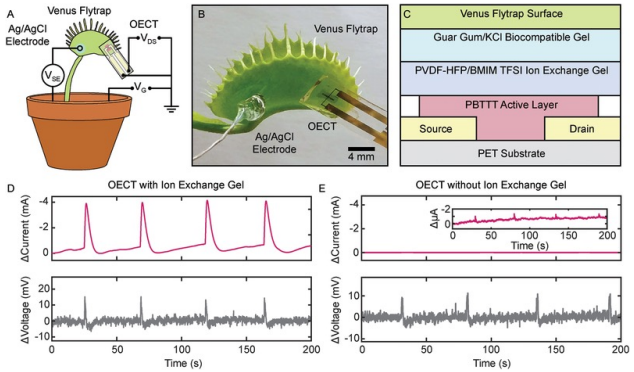



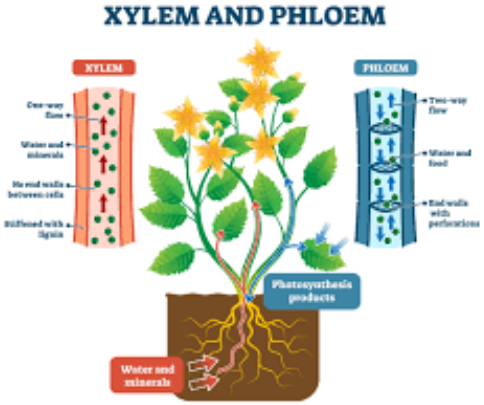

## Electric Signaling and Neurotransmitter-Like Chemicals

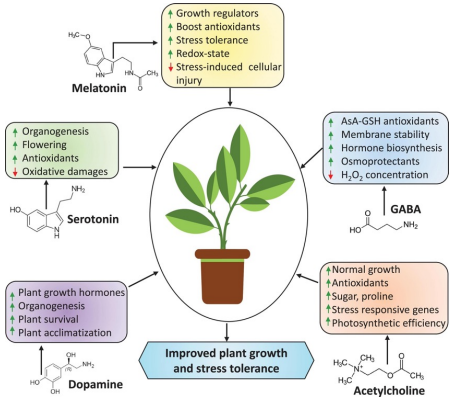
Plants may not have a nervous system, but **they do transmit electrical signals** over both short and long distances.

For example, **action potentials (APs)** and **variation potentials (VPs)**—also known as slow wave potentials (SWPs)—are crucial for **long-distance communication in plants**. These signals propagate through the **vascular system**, moving from the roots to the leaves via the **phloem** and **xylem**.

This allows plants to coordinate their responses to environmental stimuli, such as changes in light or mechanical stress, **in a fast and adaptive manner**.



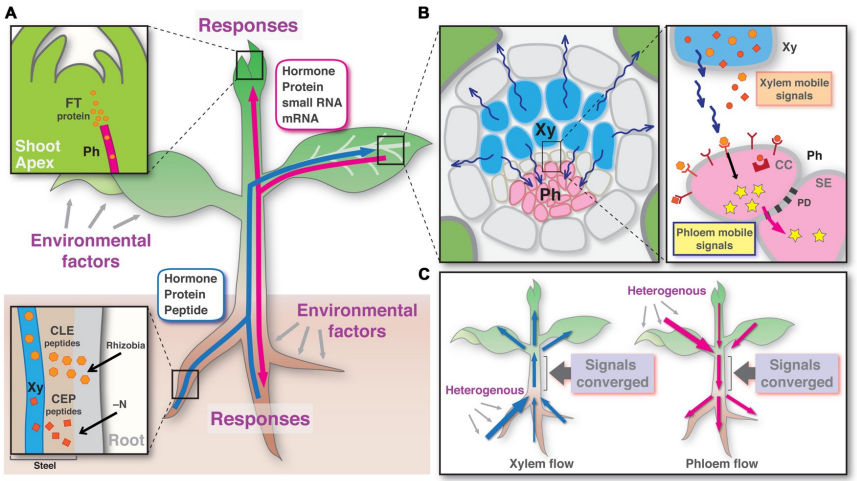




## Neurotransmitter Analogues in Plants

Plants also produce chemicals that act as **neurotransmitter-like substances**, further blurring the line between plant and animal communication systems.

Substances like **acetylcholine**, **dopamine**, and **serotonin** are found in plants and may modulate their responses to environmental stimuli, much like these neurotransmitters do in animals.

These chemicals **help plants manage prediction errors and adjust their internal states** to align with sensory input.

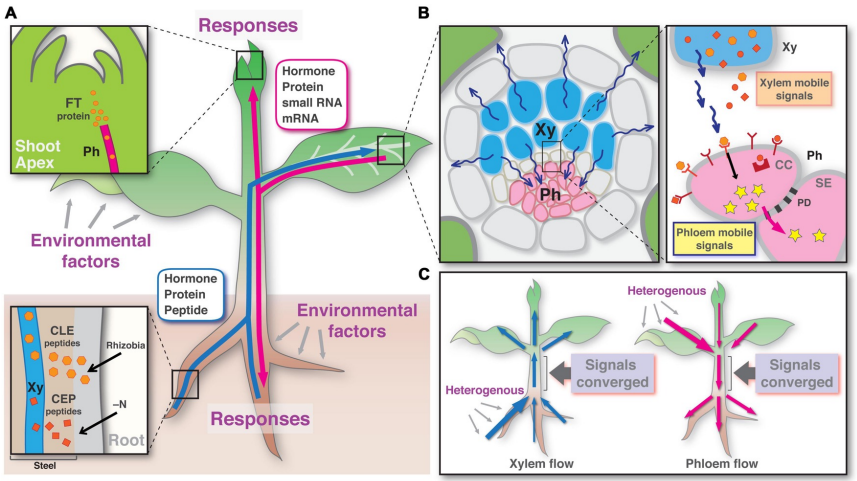



## Bidirectional and Asymmetric Message Passing

For plants to effectively minimize prediction errors, they must engage in **bidirectional** and **asymmetric message passing**—a fundamental requirement for predictive processing.

In animals, **top-down predictions** are sent to sensory receptors, and **bottom-up error signals** propagate back to update the system.

In plants, this is achieved through **electrical communication along the vascular system**, with **plasmodesmata** enabling lateral signaling over short distances.




## Layered Hierarchies in Plant Signal Processing

Plants have functionally equivalent systems for **hierarchical processing**, just as animals have neural hierarchies.

Signals may flow through different layers of the plant's **vascular tissues**, with **phloem cells** possibly encoding expected states of the world (predictions) and **apical cells** encoding errors (prediction errors).

These layers allow for a sophisticated, multi-level processing system that **mimics the hierarchical nature of animal brains**.




ANY
QUESTIONS?





MINDS



# Thanks

