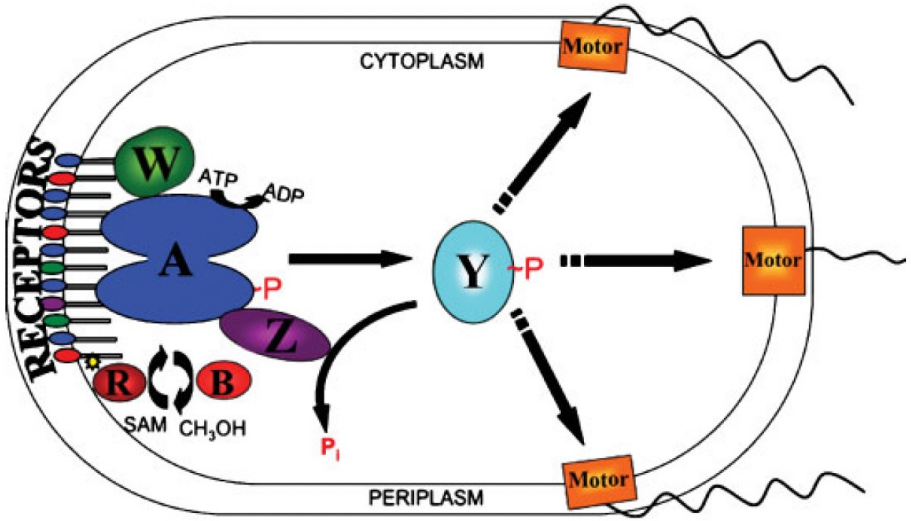
Two Models for Minimal Minds

Peter Godfrey-Smith
University of Sydney

Erice 2024



"Signal transduction in bacterial chemotaxis"
Melinda Baker et al. *BioEssays,* 2006

Pam Lyon, "The cognitive cell: bacterial behavior reconsidered", *Frontiers in Microbio*, 2015

We often think of the origin of life as fundamentally a problem of the origin of template replication. That certainly is a central property of all living things, and there is no way life could have evolved without it. It has been elegantly pointed out by Dyson (1999) that replication of itself is not sufficient and that metabolism is another important property that was essential for life right from the beginning. Here I would like to add a third element that must have been equally important in distinguishing the living from the inert. It is the invention of a stimulus-response system. Ultimately, this system became the basis of how organisms respond to the environment, and how parts of an organism and, at the highest level, whole organisms communicate with one another.

John Bonner, *First Signals,* 2000

Elaborations:

Boolean operations (*and*, *or*..),
And other kinds of integration –
Spatial and temporal.
Flexibility on an ontogenetic scale – learning,
Recurrent nets,
Decoupled representations (Sterelny),
Offline processing, model-based learning…

PROCEEDINGS B

royalsocietypublishing.org/journal/rspb

Review

Cite this article: Barron AB, Halina M, Klein C. 2023 Transitions in cognitive evolution. *Proc. R. Soc. B* **290**: 20230671. https://doi.org/10.1098/rspb.2023.0671

Transitions in cognitive evolution

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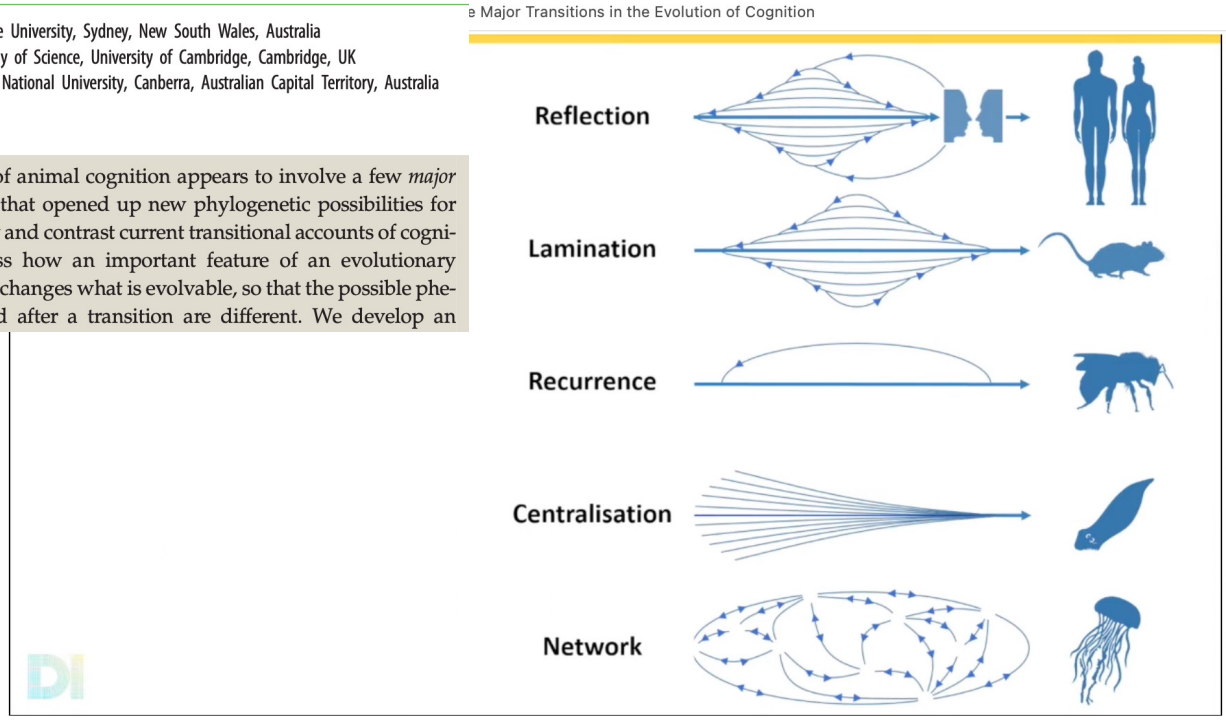
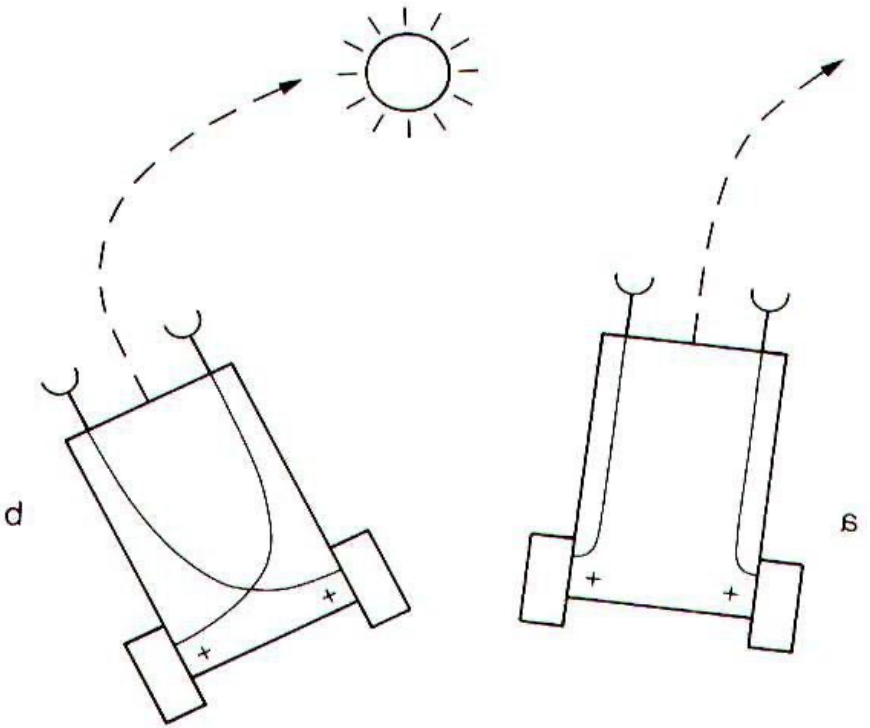
The evolutionary history of animal cognition appears to involve a few *major transitions:* major changes that opened up new phylogenetic possibilities for cognition. Here, we review and contrast current transitional accounts of cognitive evolution. We discuss how an important feature of an evolutionary transition should be that it changes what is evolvable, so that the possible phenotypic spaces before and after a transition are different. We develop an



The image is from a 2021 talk.

One highly important principle of my monism seems to me to be, that I regard *all* matter as *ensouled*, that is to say as endowed with *feeling* (pleasure and pain) and with *motion*, or, better, with the power of motion. As elementary (atomistic) attraction and repulsion these powers are asserted in every simplest chemical process, and on them is based also every other phenomenon, consequently also the highest-developed soul-activity of man. For the comprehension

From Haeckel, "Our Monism," 1892



Braitenberg, *Vehicles*, 1984

*PRIMITIVE NERVOUS SYSTEMS**

By L. M. Passano

DEPARTMENT OF BIOLOGY, YALE UNIVERSITY

Communicated by G. E. Hutchinson, June 17, 1963

For nearly fifty years the dominant and accepted theory of the evolution of the nervous system has been that of G. H. Parker, developed over the course of the decade from 1909 to 1919 and summarized in his now classic book *The Elementary Nervous System.*[1] Like many successful theories, it was an oversimplification of contemporary knowledge presented in a forceful and stimulating manner. In essence, Parker viewed the initial evolution of the nervous system as involving three successive phylogenetic stages. At first there were only "independent effectors,"

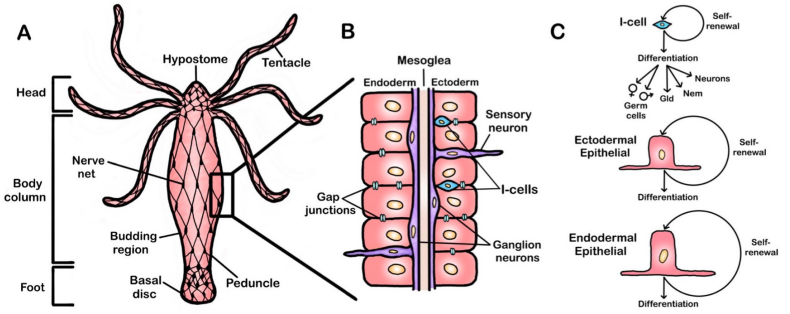
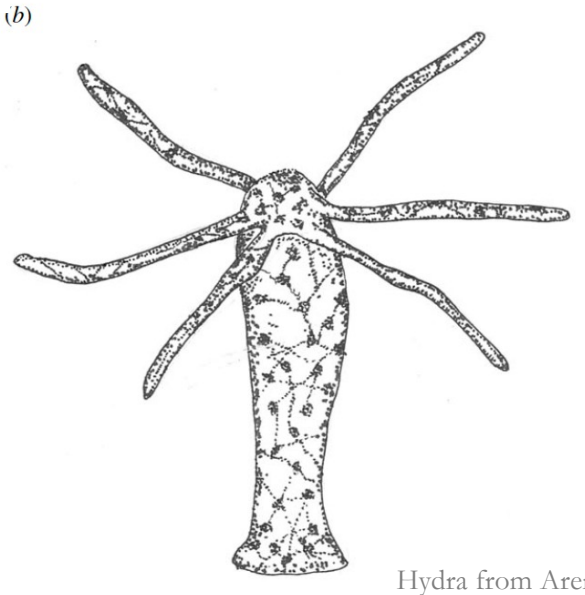


Fig. 1 *Hydra* anatomy. **A** The basic body plan of *Hydra*. **B** The two tissue layers of *Hydra* are depicted with endodermal epithelial cells on the interior, ectodermal epithelial cells on the exterior, and an acellular mesoglea in between. Ganglion neurons are found at the base of the epitheliomuscular cells while sensory neurons protrude from both the endoderm and ectoderm. Interstitial-cells (I-cells) are located between ectodermal epithelial cells. Not shown are gap junctions between extensions of the endodermal and ectodermal epithelial cells within the mesoglea. **C** The three stem cell lineages of *Hydra* are shown with the unipotent endodermal and ectodermal epithelial cells and multi-potent I-cells that produce four cell types: germ cells, gland cells (Gld), nematocytes (Nem), and neurons



Hydra from Arendt, "Elementary Nervous Systems"

Hanson, "On being a *Hydra* with, and without, a nervous system: what do neurons add?", *Animal Cog.*, 2023

Animal Cognition (2023) 26:1783–1797
https://doi.org/10.1007/s10071-023-01782-1

REVIEW

Thoughts from the forest floor: a review of cognition in the slime mould *Physarum polycephalum*

Chris R. Reid[1]

Received: 8 February 2023 / Revised: 27 April 2023 / Accepted: 28 April 2023 / Published online: 11 May 2023

Abstract
Sensing, communication, navigation, decision-making, memory and learning are key cor
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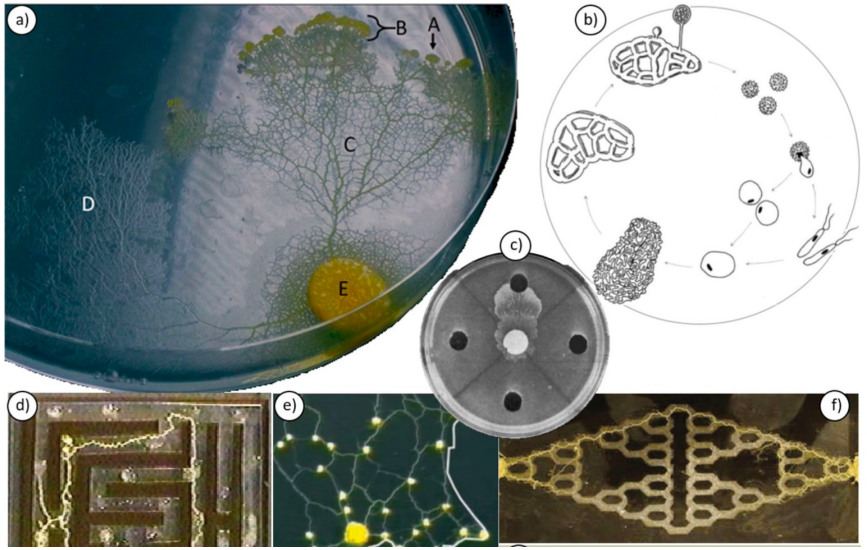

When cell surface receptors detect attractants such as food and moisture, oscillation frequency increases in the local area, which decreases cell surface tension, making the plasmodium more fluid... This causes protoplasm to flow towards the stimulus area, and directs the movement of the entire cell. Repellents such as light and certain salts induce the opposite response, increasing the local stiffness of the cell and restricting further flow into the area.

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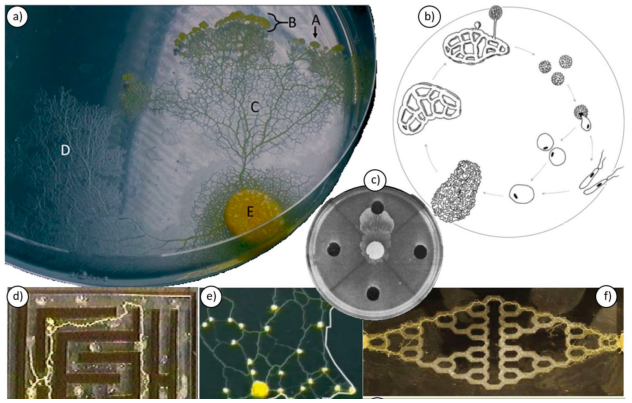


Animal Cognition (2023) 26:73–85
https://doi.org/10.1007/s10071-022-01677-7

REVIEW

From representations to servomechanisms to oscillators: my journey in the study of cognition

Ken Cheng[1]

Received: 11 May 2022 / Revised: 20 July 2022 / Accepted: 9 August 2022 / Published online: 27 August 2022

More from Reid – "Much of the cognitive behaviour observed in Physarum is fundamentally a consequence of communication between the myriad contractile units. While each unit senses and responds to the environment around it, physical coupling between adjacent oscillators entrains them to each other's frequencies (Nakagaki et al. 1999). This means they can respond to and influence the behaviour of their neighbours, and transfer information about the quality of local environments to distant parts of the cell."

Cognitive motifs:

Bonner's IO structures

Send-receive structures

Negative feedback

Gallistel's read-write structures

...

Network motifs: theory and experimental approaches

Uri Alon

Abstract | Transcription regulation networks control the expression of genes. The transcription networks of well-studied microorganisms appear to be made up of a small set of recurring regulation patterns, called network motifs. The same network motifs have recently been found in diverse organisms from bacteria to humans, suggesting that they serve as basic building blocks of transcription networks. Here I review network motifs and their functions, with an emphasis on experimental studies. Network motifs in other biological networks are also mentioned, including signalling and neuronal networks.

Nature Reviews Genetics, 2007

BOTANY

Glutamate triggers long-distance, calcium-based plant defense signaling

Masatsugu Toyota[1,2,3]*, Dirk Spencer[2]†, Satoe Sawai-Toyota[2]‡, Wang Jiaqi[1], Tong Zhang[4,5]§, Abraham J. Koo[4,5], Gregg A. Howe[6,7], Simon Gilroy[2]*

Animals require rapid, long-range molecular signaling networks to integrate sensing and response throughout their bodies. The amino acid glutamate acts as an excitatory neurotransmitter in the vertebrate central nervous system, facilitating long-range information exchange via activation of glutamate receptor channels. Similarly, plants sense local signals, such as herbivore attack, and transmit this information throughout the plant body to rapidly activate defense responses in undamaged parts. Here we show that glutamate is a wound sig[illegible] *LIKE* family act as sensors that convert t[illegible] concentration that propagates to distan[illegible]

Toyota et al., *Science* 2018.

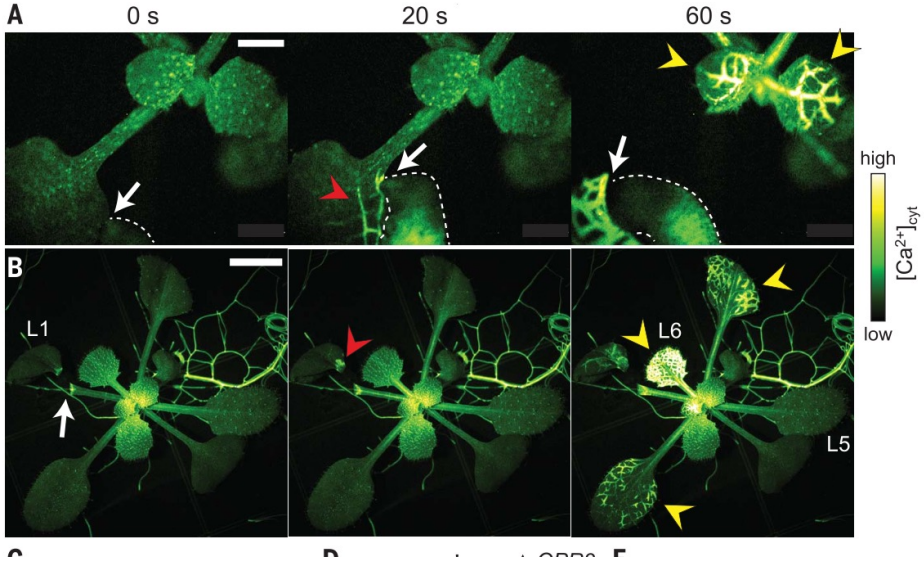
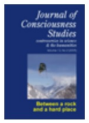


Fig. 1. Wounding triggers long-distance transmission of $[Ca^{2+}]_{cyt}$ increases and systemic defense responses. (**A**) Caterpillar (dashed outline) feeding (white arrow) caused local $[Ca^{2+}]_{cyt}$ increases (red arrowhead) that propagated toward younger leaves (yellow arrowheads). (**B**) Cutting leaf 1 (L1, white arrow, 0 s) caused a local $[Ca^{2+}]_{cyt}$ increase (red arrowhead) that propagated toward target distal leaves (yellow arrowheads), e.g., leaf 6 (L6), but not to nontarget leaves such as L5. (**C** to **E**) $[Ca^{2+}]_{cyt}$ signature (C), defense gene induction (D), and JA and JA-Ile accumulation (E). *N* = 10 (C), *N* = 6 (D), and *N* = 3 (E) separate experiments. Error bars, mean ± SE. **P* < 0.05 leaf 6 versus 5. Scale bars, 1 mm (A) or 5 mm (B).

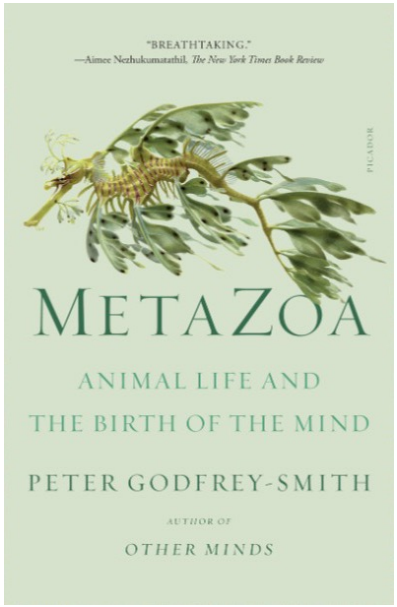
Model 1: Cognition is built from the concatenation and elaboration of cognitive motifs, which are basically local.

Model 2: Cognition is created through the modulation of large-scale endogenous patterns of activity in whole systems.



Could All Life Be Sentient?

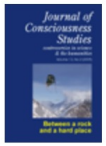
Author: Thompson, Evan
Source: Journal of Consciousness Studies, Volume 29, Numbers 3-4, March 2022,



'Minimal cognition is, after all, present in bacteria, and when you look at what they do and how they do it, feeling just seems to not be part of the picture' (p. 278). [quoting me]

In the end, what decides the matter is a kind of seeing-as, or rather the absence of a kind of seeing-as. Looking at bacteria, Godfrey-Smith says he does not see them as sentient. The decisive reason turns out to be a kind of interpretive perception, the perception of bacteria as not conforming to a certain mode of being, the sentient mode. Coupled to this perception are background convictions about the importance of the nervous system (the book is about animals) and about how widespread we should take consciousness to be. So we are very much within the epistemological circle mentioned above.

Speaking for myself, when I look at videos of what bacteria do and hear biologists talk about how they do it, I have no difficulty seeing feeling as part of the picture.



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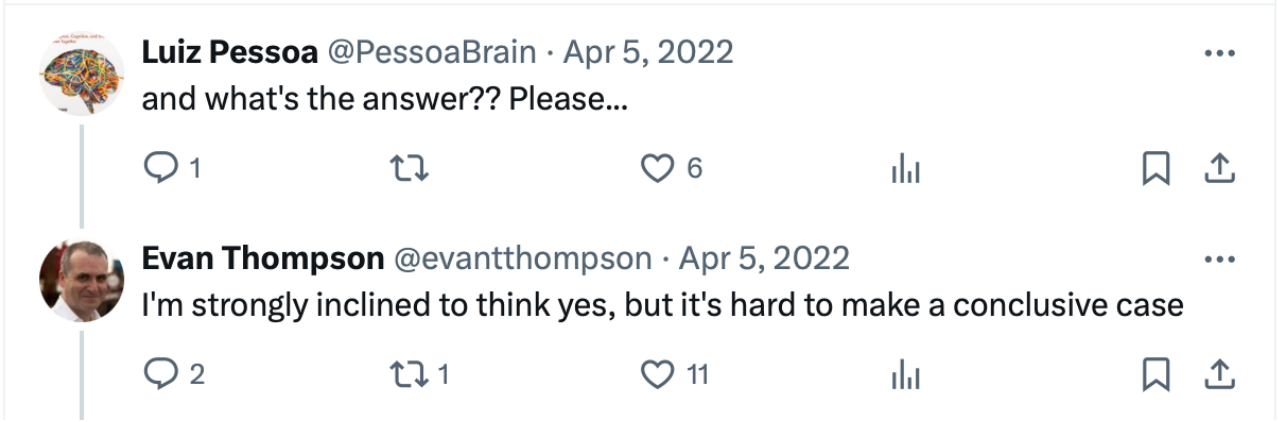

First road:

Subjectivity is the bridging concept.
Minimal subjectivity accompanies some kinds (not all) of minimal cognition.
Subjectivity exhibits graded presence – no "lights on" moment.
Nervous systems are important in the way they enable the focusing of subjectivity on a macroscopic scale.

Second road:

An essential role for nervous systems or for some other means of enabling Model 2 processes – large-scale activity with modulation.
The form of integration that those processes enable is essential to felt experience (sentience, consciousness in a minimal sense).

1. Two Models

2. Cognitive Motifs

3. Minimal Cognition and Sentience

4. One Path to Maximal Minds

Unitary versus *modular* body plans.

Modular: many cnidarians, bryzoans, some ascidians, plants..

Unitary: humans, octopuses, ants..

The role of a recurring body form in the evolution of complex behavior.

Keijzer and Arnellos, "The animal sensorimotor organization: a challenge for the environmental complexity thesis," *Bio and Phil*, 2017

My "Individuality, subjectivity, and minimal cognition," *Bio and Phil*, 2016

Thanks to Gaspar Jekely, Fred Keijzer, Andy Barron.