Towards an enactive origin of life

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The central point

• Enactivism - “life is mind-like, mind is life-like”

  or even “life = mind”

• If we take this seriously, we need an “embodied, embedded, enactive, extended” approach to life, not just mind

• And therefore also to the origin of life

• I believe this is possible, and indeed it gives us insights into both life and mind
Overview [TENTATIVE]

• Background on autopoiesis (my own perspective)

• Extended autopoiesis

• Intro to dissipative structures

• The importance of death ("precariousness")

• Dissipative structures as "model organisms"

• The origin of individuals
Part 1

Autopoiesis and extended autopoiesis
Autopoiesis

TERMINOLOGY CLASH ALERT! “autopoiesis”

Humberto Maturana
Francisco Varela
Autopoiesis

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“An autopoietic machine is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components that produces the components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in the space in which they (the components) exist by specifying the topological domain of its realization as such a network.”
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• Note: no reference to evolution - it’s a reaction against that

Humberto Maturana
Francisco Varela
What is a process?

• Maturana and Varela don’t give examples! But for me, these are some:

  • “metabolic” chemical reaction, e.g. a step in the Krebs cycle

  • transcription of RNA into a protein

  • transport of ions across a membrane

  • reacting to a stimulus

  • learning to walk

  • growing a liver
Autopoiesis: the organism *is* the network
What is a process?

• On my reading, at least:
  • Chemical reactions
  • Transport across membranes
  • But also: motion, reacting to stimulus, learning, ...

• These all form *one* network
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“metabolism”
What is a process?

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What is a process?

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“cognition”
Autopoiesis and the Origins of Life

- There are a few groups and individuals working on models of autopoiesis in a pre-biological context

- Some examples follow...
Modelling autopoiesis

• Eran Agmon (with Gates, Beer)

• Spatial model of concentration dynamics supports emergence of “minimal protocells”

• “Network of possible ontogenies” mapped by exposing to perturbations

• Analysis reveals how perturbations change response to future perturbations
Example - self-propelled oil droplets
Example - self-propelled oil droplets
• Matthew Egebert - protocell with dynamical “metabolism-based behaviour”
Also

• Kepa Ruiz-Mirazo (+ Ben Shirt-Ediss) at San Sebastian
  • philosophy and systems chemistry modelling

• Pierre Luigi Luisi
  • experimental work, but using a very different definition of autopoiesis

• Plus plenty of work on protocells
Extended life?
Physical Boundary ≠ Operational Limits
Another example (development)
Extended life?
Extended life?

• “...an autopoietic machine is an homeostatic (or rather relationstatic) system which has its own organization (defining network of relations) as the fundamental variable which it maintains constant.” (Maturana and Varela, 1978)
Extended life?

• “If one says that there is a [homeostatic] machine M, in which there is a feedback loop through the environment so that the effects of its output affect its input, one is in fact talking about a larger machine M' which includes the environment and the feedback loop in its defining organization.” (Maturana and Varela, 1978)
A richer tapestry

- There are many processes (or sets of processes) that contribute in some way without being necessary (e.g. my hobbies)

- Others are detrimental (e.g. smoking)

- Barandiaran has written about *habits* as autonomous in their own right

- One may also consider viruses - not autopoietic but part of the tapestry of life

- Also society, man-made objects, etc.

- So I think the “enactive world” is best thought of not as a collection of individuals but as a rich tapestry in which individuals sometimes emerge
Part 2

Precarious, individuated dissipative structures
An autopoietic machine is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components that produces the components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in the space in which they (the components) exist by specifying the topological domain of its realization as such a network.
Is this a problem?

• Confronted with such examples, Maturana and Varela changed their definition to try and exclude them.

• They focused on the cell’s membrane as a dividing line between “inside” and “outside”.

• But I think this was a mistake!

• It’s far more interesting to think about what typhoons share with cells than how they differ.
The view from physics

- Things like typhoons are called “dissipative structures” (Prigogine)

- They all have the property of **being maintained by a dynamical balance of processes** rather than just being solid

- They persist by consuming free energy from their environment (“producing entropy”)

- And they have the “ship of Theseus” property - persists despite every atom being replaced

- Let’s look at some other examples
Dissipative structures - examples
Some non-dissipative structures
Dissipative structures
Dissipative structures
Precariousness

• Important idea in enactive literature

• Implies the possibility of death - some things can be bad for the organism

  • My definition: \textit{conditions for formation} \neq \textit{conditions for maintenance}

• Not “all or nothing” property, but a variable one

• Very common in dissipative structures
Dissipative structures

Precarious
Dissipative structures

Precarious
Dissipative structures

Precarious
Precariousness

• Precariousness: \textit{conditions for formation} \neq \textit{conditions for maintenance}

• conditions for formation can be a lot more specific than conditions for maintenance (e.g. human), or just a little.
Individuation

• Another common life-like property: the formation of distinct, similar, spatially separated ‘individuals’

• distinct individuals have distinct life-histories

• almost ubiquitous in living systems (counterexamples)

• can occur on multiple levels (cells, organisms, colonies)

• not about genetics (clones, chimeras)

• not all-or-nothing...
unindividuated, individuated and ambiguous dunes on Earth and Mars
Individuation

• This version of individuation does not imply a “hard” separation between an individual and its environment

• This is really important! Even in the case of a living cell, molecules continually move across the membrane, and the membrane can break and re-form

• Thus the question of whether something is “inside” or “outside” the cell is ill-defined on the molecular level.

• This is why “extended autopoiesis” is the appropriate notion here
Dissipative structures

Precarious
Dissipative structures

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Individuated
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Precarious, individuated dissipative structures

Precarious

Individuated
Precarious, individuated dissipative structures

These all have analogues of...
Dissipative structures

Precarious, individuated dissipative structures

These all have analogues of Metabolism
Precarious, individuated dissipative structures

These all have analogues of

Metabolism
Anatomy
Precarious, individuated dissipative structures

These all have analogues of

Metabolism
Anatomy
Behaviour
Precarious, individuated dissipative structures

These all have analogues of

Metabolism
Anatomy
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Similar to early version of autopoiesis (constitution of a unity)
Dissipative structures

Precarious

Individuated

Membrane-producing
Dissipative structures

Precarious

Individuated

Membrane-producing

With genetic material
Dissipative structures

Precarious

Individuated

Membrane-producing

With genetic material

Life
Dissipative structures

Precarious

Individuated

Membrane-producing

With genetic material

Life

Cells
Life, mind and dissipative structures

• The point is that we can *readily observe and create* systems that
  • are constituted as individuals by self-producing networks of processes (you can decide if this is autopoiesis)
  • homeostatically maintain their organisation
  • can “die”
  • can respond to their environment (see next)
  • can accumulate adaptations (see later)
Reaction-Diffusion Systems

- Implemented like a cellular automaton, except that each “cell” contains a continuously variable amount of several chemicals.

- Within each cell, chemicals react and can enter or leave system from outside (reaction).

- Chemicals slowly leak between cells (diffusion).
Reaction-Diffusion Systems

• Gray-Scott system based on autocatalysis: \( U + 2V \rightarrow 3V \)

• In addition, \( U \) fed into each cell, and \( V \) decays, leaving system

• Can form spots, lines, chaotic patterns, depending on parameters
Three patterns formed by different parameter ranges in the Gray-Scott system (colours are arbitrary)
Anatomy of a Spot

Food U

Autocatalyst V

Space
Anatomy of a Spot

\[ U + 2V \rightarrow 3V \]
Anatomy of a Spot

\[ U + 2V \rightarrow 3V \]
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\[ U + 2V \rightarrow 3V \]
Anatomy of a Spot

\[ U + 2V \rightarrow 3V \]
“Metabolism” of a spot

\[ U + 2V \rightarrow 3V \]

Inward diffusion of \( U \) and outward diffusion of \( V \).
“Metabolism” of a spot

\[ U + 2V \rightarrow 3V \]

U in inward diffusion of U

outward diffusion of V

V \rightarrow P
Cognition?

• Reaction-diffusion spots are maintained by a balance in the rates of several processes

• A perturbation will cause an imbalance

• Large perturbations will destroy the spot (boundary of viability)

• But we would never observe spots if they weren’t stable to small perturbations

• Crucially, a small perturbation may return the spot to a different stable configuration (e.g. moving it to a different place) - “cognitive domain”

• See demo
Adding a permanent perturbation

• What if there was another autocatalyst that could “feed on” the first?

• $U + 2V \rightarrow 3V$ and $V + 2W \rightarrow 3W$

• With the right parameter settings, a stable spot of $V$ continuously moves away from a “tail” of $W$

• The direct effect of the tail is purely negative, but it can enable survival in new environments...
Adaptations and precariousness

- The tail is “metabolically costly”, but can provide greater “fitness” through modulation of behaviour
  - (compare with brain)

- The environment changes to one where only “spot-with-tail” can survive

- These structures have a more non-trivial precariousness - now you need quite specific conditions to create them (both red and blue)
Processes across levels

• Earlier I said that chemical-level and behaviour-level processes form a single operationally closed network

• Here we have a nice example:
Part 3

Wrapping up
The role of information

- I didn’t really mention the debates about mental representations

- Or about the role of genetic information in biology

- But I think these are deeply related, and a rich seam of possible future ideas
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“representation”

**TERMINOLOGY CLASH ALERT!**

“information”
Origins of life

• Many approaches to origins of life (even some of the autopoiesis based ones) strike me as not very “lively”

• People imagine that the environment must do a lot of work to produce the first organism
  
  • e.g. just exactly the right chemistry to produce RNA, or catalyse the citric acid cycle, or produce a protocell

• But we’ve seen that there is plenty of liveliness in physics already!

• Can this lead to a research programme that helps us understand life’s origins?
Origins of life

• I think “yes”, but there are many questions to be answered:

• The simulations I showed are quite limited - only a few processes can occur

• Biology is more “open-ended” - huge range of things proteins can catalyse

• How to really capture this in theory / simulation?

• ...and how to observe it in the lab?
Questions for discussion

• What is the relationship between life and mind?
  • Are they similar to each other? Do they overlap? Are they the same?
  • Did life come first and then mind, or the other way around?

• What about other complex, self-perpetuating systems?
  • e.g. economic systems, smoking...?

• What is the role of information in all this?
Thank you