

Dynamic organizational structures

David I. Spivak



NASA Prebiotic Chemistry and Evolution on the Early Earth (PCE3)
2022 October 20

Outline

1 Introduction

- Why am I here?
- Accounting systems
- Toward PCE3
- Plan for the talk

2 Dynamical systems and interaction patterns

3 Dynamic organizational structures

4 Conclusion

Why am I here?

The question of what has brought us to this moment is always relevant.

- There are many lenses for the question “why am I here?”
- Physically, why have our atoms assembled here?
- Culturally, why are we allowed (invited / funded) to be here?
- Personally, what is our motivation for being here?

Why am I here?

The question of what has brought us to this moment is always relevant.

- There are many lenses for the question “why am I here?”
- Physically, why have our atoms assembled here?
- Culturally, why are we allowed (invited / funded) to be here?
- Personally, what is our motivation for being here?

To me, the origin of life question can give a clue to all of these.

- My understanding of PCE3 is very limited; mainly Eric Smith videos:
- Proto-life was the minimally complex “lab” that could perform...
- ...certain exothermic reactions (e.g. $CO_2 + 2H_2O \rightarrow CH_4 + 2O_2$).
- Life develops and maintains equipment for dissipating free energy.
- We're here to collect “materials” (knowledge) for such a purpose.
- Our “funding” works like a siphon for dissipating free energy.

Why am I here?

The question of what has brought us to this moment is always relevant.

- There are many lenses for the question “why am I here?”
- Physically, why have our atoms assembled here?
- Culturally, why are we allowed (invited / funded) to be here?
- Personally, what is our motivation for being here?

To me, the origin of life question can give a clue to all of these.

- My understanding of PCE3 is very limited; mainly Eric Smith videos:
- Proto-life was the minimally complex “lab” that could perform...
- ...certain exothermic reactions (e.g. $CO_2 + 2H_2O \rightarrow CH_4 + 2O_2$).
- Life develops and maintains equipment for dissipating free energy.
- We're here to collect “materials” (knowledge) for such a purpose.
- Our “funding” works like a siphon for dissipating free energy.

I'm fascinated by nature's capacity to develop understanders like us.

- Our prebiotic origin gives clues as to how this development occurs.
- I would like to make such ideas formal and systematic.

Mathematical fields as accounting systems

I think of mathematical fields as [accounting systems](#).

- Arithmetic accounts for the flow of quantities, as in finance.
- Hilbert spaces account for the states of elementary particles, as in QM.
- Probability distributions account for likelihoods, as in game theory.

Mathematical fields as accounting systems

I think of mathematical fields as [accounting systems](#).

- Arithmetic accounts for the flow of quantities, as in finance.
- Hilbert spaces account for the states of elementary particles, as in QM.
- Probability distributions account for likelihoods, as in game theory.

An account of phenomena needs to be written in high-fidelity language.

- To understand the phenomena requires that certain aspects be tracked.
- The language must articulate the relevant type-differences ...
- ... and provide operations that correspond with their interactions.

Mathematical fields as accounting systems

I think of mathematical fields as [accounting systems](#).

- Arithmetic accounts for the flow of quantities, as in finance.
- Hilbert spaces account for the states of elementary particles, as in QM.
- Probability distributions account for likelihoods, as in game theory.

An account of phenomena needs to be written in high-fidelity language.

- To understand the phenomena requires that certain aspects be tracked.
- The language must articulate the relevant type-differences ...
- ... and provide operations that correspond with their interactions.
 - In finance, we have the types **dollar (\$)** and **quantity (#)**.
 - We can add and multiply #'s by #'s: 5 boxes $\times$ 10 widgets = 50.
 - We can multiply \$'s by #'s: 100 * \$3 = \$300.
 - But we cannot multiply \$'s by \$'s. Consider it: \$5 * \$3?

Mathematical fields as accounting systems

I think of mathematical fields as [accounting systems](#).

- Arithmetic accounts for the flow of quantities, as in finance.
- Hilbert spaces account for the states of elementary particles, as in QM.
- Probability distributions account for likelihoods, as in game theory.

An account of phenomena needs to be written in high-fidelity language.

- To understand the phenomena requires that certain aspects be tracked.
- The language must articulate the relevant type-differences ...
- ... and provide operations that correspond with their interactions.
 - In finance, we have the types **dollar (\$)** and **quantity (#)**.
 - We can add and multiply #'s by #'s: 5 boxes $\times$ 10 widgets = 50.
 - We can multiply \$'s by #'s: 100 * \$3 = \$300.
 - But we cannot multiply \$'s by \$'s. Consider it: \$5 * \$3?

Category theory is the accounting system for coherent structures.

- It makes analogies—similarities of structure—into formal objects.
- It's been useful in math, CS, physics, materials science, linguistics, etc
- What sort of system accounts for PCE3?

My understanding of PCE3

Again, please excuse my ignorance of PCE3; here's how I naively see it.

- Our concept of the early earth is that life formed from chemistry.
- We see a repeated pattern regarding concentration of power.
- X's *power* is its capacity to quickly catalyze a change in conditions.
 - In physics, it is work divided by time. But more colloquially also:
 - Birthing a child is a 9-month catalysis: zygote + food → baby.
 - Detonating a bomb is quickly catalyzing a change in conditions.

My understanding of PCE3

Again, please excuse my ignorance of PCE3; here's how I naively see it.

- Our concept of the early earth is that life formed from chemistry.
- We see a repeated pattern regarding concentration of power.
- X's *power* is its capacity to quickly catalyze a change in conditions.
 - In physics, it is work divided by time. But more colloquially also:
 - Birthing a child is a 9-month catalysis: zygote + food → baby.
 - Detonating a bomb is quickly catalyzing a change in conditions.
- Life catalyzed certain chemical reactions on the early earth.
- To catalyze and not be dissipated during those reactions is “survival”.

My understanding of PCE3

Again, please excuse my ignorance of PCE3; here's how I naively see it.

- Our concept of the early earth is that life formed from chemistry.
- We see a repeated pattern regarding concentration of power.
- X's *power* is its capacity to quickly catalyze a change in conditions.
 - In physics, it is work divided by time. But more colloquially also:
 - Birthing a child is a 9-month catalysis: zygote + food → baby.
 - Detonating a bomb is quickly catalyzing a change in conditions.
- Life catalyzed certain chemical reactions on the early earth.
- To catalyze and not be dissipated during those reactions is “survival”.
- We're interested in a formal account of power.
 - By what mechanism does it so consistently concentrate?
 - Is there a theme to the sorts of changes that life catalyzes?
 - In what respects are material conditions on the EE relevant?

Dynamic organizational structures

Concentration of power comes from organization, not elementary makeup.

- Spider silk is stronger—pound for pound—than steel.
- But it is made only from the flies that the spider eats.
- Its strength comes from hierarchical organization of protein materials.

Dynamic organizational structures

Concentration of power comes from organization, not elementary makeup.

- Spider silk is stronger—pound for pound—than steel.
- But it is made only from the flies that the spider eats.
- Its strength comes from hierarchical organization of protein materials.

Any life-form is a collective, a dynamic organization of smaller parts.

- The organization provides an interaction pattern for the parts.
- The RNA will interact with the nucleus and the ribosome, etc.
- What occurs during these interactions can change the organization.
- As an extreme example, death will allow the system to disintegrate.
- A CEO may see what's occurring and change the company org-chart.

Dynamic organizational structures

Concentration of power comes from organization, not elementary makeup.

- Spider silk is stronger—pound for pound—than steel.
- But it is made only from the flies that the spider eats.
- Its strength comes from hierarchical organization of protein materials.

Any life-form is a collective, a dynamic organization of smaller parts.

- The organization provides an interaction pattern for the parts.
- The RNA will interact with the nucleus and the ribosome, etc.
- What occurs during these interactions can change the organization.
- As an extreme example, death will allow the system to disintegrate.
- A CEO may see what's occurring and change the company org-chart.

So what I would like to provide is an accounting system for the above idea.

- Open dynamical systems that interact with each other...
- ...according to some pattern: the type of signals/materials that flow.
- The interaction pattern itself can change based on what flows.

Dynamic organizational structures

Concentration of power comes from organization, not elementary makeup.

- Spider silk is stronger—pound for pound—than steel.
- But it is made only from the flies that the spider eats.
- Its strength comes from hierarchical organization of protein materials.

Any life-form is a collective, a dynamic organization of smaller parts.

- The organization provides an interaction pattern for the parts.
- The RNA will interact with the nucleus and the ribosome, etc.
- What occurs during these interactions can change the organization.
- As an extreme example, death will allow the system to disintegrate.
- A CEO may see what's occurring and change the company org-chart.

So what I would like to provide is an accounting system for the above idea.

- Open dynamical systems that interact with each other...
- ...according to some pattern: the type of signals/materials that flow.
- The interaction pattern itself can change based on what flows.

I have a category-theoretic accounting system for such things.

Plan for the talk

During the remainder of the talk I will:

- discuss open dynamical systems and interaction patterns,
- explain dynamic organizational structures, and
- conclude with a summary.

Outline

1 Introduction

2 **Dynamical systems and interaction patterns**

- Open dynamical systems
- Interaction patterns

3 Dynamic organizational structures

4 Conclusion

Open dynamical systems

An **open dynamical system (ODS)** is a kind of “worker”.

- It can interact with the outside world through a specified interface.
- This interface displays its position, attitude, various signals, and...
- ...can receive forces, materials, signals, etc.
- The ODS has an internal state, which dictates its position, etc., and...
- ...this state can change based on the forces, etc., that it receives.

Open dynamical systems

An **open dynamical system (ODS)** is a kind of “worker”.

- It can interact with the outside world through a specified interface.
- This interface displays its position, attitude, various signals, and...
- ...can receive forces, materials, signals, etc.
- The ODS has an internal state, which dictates its position, etc., and...
- ...this state can change based on the forces, etc., that it receives.

We can consider either continuous or discrete ODS's.

- In both cases, the outputs are given by a function of the state.
- In a cont'ous ODS, the state evolves according to a system of ODEs...
- ...and the inputs provide time-varying parameters to the ODEs.
- In a discrete ODS, the state is updated discretely based on input.

Open dynamical systems

An **open dynamical system (ODS)** is a kind of “worker”.

- It can interact with the outside world through a specified interface.
- This interface displays its position, attitude, various signals, and...
- ...can receive forces, materials, signals, etc.
- The ODS has an internal state, which dictates its position, etc., and...
- ...this state can change based on the forces, etc., that it receives.

We can consider either continuous or discrete ODS's.

- In both cases, the outputs are given by a function of the state.
- In a continuous ODS, the state evolves according to a system of ODEs...
- ...and the inputs provide time-varying parameters to the ODEs.
- In a discrete ODS, the state is updated discretely based on input.

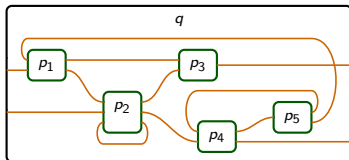
How can you visualize the interface of an ODS (continuous or discrete)?

- The interface may change through time, but at any point it can...
- ...be drawn as a box with inputs/outputs on the left/right: 

Wiring diagrams and interaction patterns

Open dynamical systems connect with each other in [interaction patterns](#).

- The easiest sort of interaction pattern to visualize is a wiring diagram.

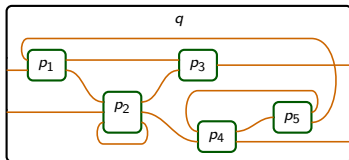


- This one interconnects interfaces $p_1, \dots, p_5$ inside a boundary q .
- Let's denote the wiring diagram as $\varphi: (p_1, \dots, p_5) \rightarrow q$.
- It gives rise to a formula: given an ODS in each p_i , we get one in q .

Wiring diagrams and interaction patterns

Open dynamical systems connect with each other in **interaction patterns**.

- The easiest sort of interaction pattern to visualize is a wiring diagram.



- This one interconnects interfaces $p_1, \dots, p_5$ inside a boundary q .
- Let's denote the wiring diagram as $\varphi: (p_1, \dots, p_5) \rightarrow q$.
- It gives rise to a formula: given an ODS in each p_i , we get one in q .

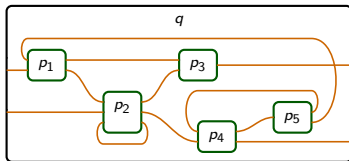
In category theory, φ is called a morphism, a formal object.

- It's not just a drawing; it has unambiguous semantics in the theory.
- In particular, WDs are implemented in software (AlgebraicDynamics.jl)

Wiring diagrams and interaction patterns

Open dynamical systems connect with each other in [interaction patterns](#).

- The easiest sort of interaction pattern to visualize is a wiring diagram.



- This one interconnects interfaces $p_1, \dots, p_5$ inside a boundary q .
- Let's denote the wiring diagram as $\varphi: (p_1, \dots, p_5) \rightarrow q$.
- It gives rise to a formula: given an ODS in each p_i , we get one in q .

In category theory, φ is called a morphism, a formal object.

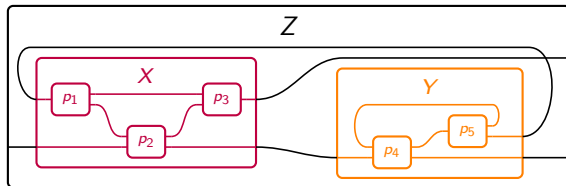
- It's not just a drawing; it has unambiguous semantics in the theory.
- In particular, WDs are implemented in software (AlgebraicDynamics.jl)

Interaction patterns can be more general, e.g. weighted, dynamic, prob'istic.

- It's harder to draw, but the unambiguous CT syntax generalizes easily.

Nesting

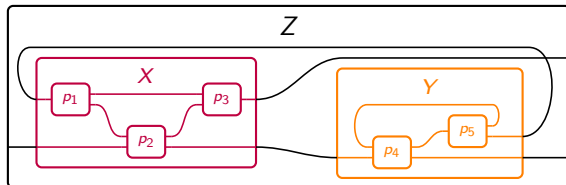
Interaction patterns can be nested.



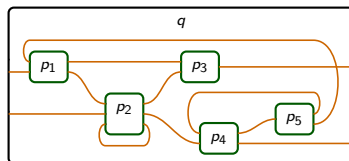
- Here we see eight interfaces and three interaction patterns. Check!

Nesting

Interaction patterns can be nested.

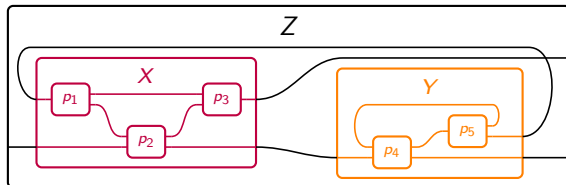


- Here we see eight interfaces and three interaction patterns. Check!
- We can **compose** these interaction patterns to get this one:

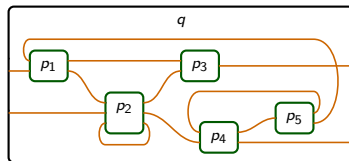


Nesting

Interaction patterns can be nested.



- Here we see eight interfaces and three interaction patterns. Check!
- We can **compose** these interaction patterns to get this one:



You can abstract an interacting population of ODS's as an ODS.

- The semantics of zooming or regrouping is *compositional* wrt nesting.

Outline

- 1 Introduction
- 2 Dynamical systems and interaction patterns
- 3 Dynamic organizational structures**
 - Mode dependent interaction
 - Continuity with respect to boundary
 - Applications to PCE3
- 4 Conclusion

Mode dependent interaction

In the above pictures, the interaction pattern appeared to be fixed.

- This works great for integrated circuits, but not for real life.
- Even computers have “plug and play”: the wiring pattern can change.
- We’re talking now, but later we’ll disconnect.
- Cells can swim around: the interaction pattern changes through time.

Mode dependent interaction

In the above pictures, the interaction pattern appeared to be fixed.

- This works great for integrated circuits, but not for real life.
- Even computers have “plug and play”: the wiring pattern can change.
- We’re talking now, but later we’ll disconnect.
- Cells can swim around: the interaction pattern changes through time.

Moreover, the interface of each ODS can change through time.

- Sometimes your eyes are open, and your input type is larger.
- Sometimes your car is in a tunnel and can’t receive GPS.
- The system’s interface depends on its mode: “mode dependence”.

Mode dependent interaction

In the above pictures, the interaction pattern appeared to be fixed.

- This works great for integrated circuits, but not for real life.
- Even computers have “plug and play”: the wiring pattern can change.
- We’re talking now, but later we’ll disconnect.
- Cells can swim around: the interaction pattern changes through time.

Moreover, the interface of each ODS can change through time.

- Sometimes your eyes are open, and your input type is larger.
- Sometimes your car is in a tunnel and can’t receive GPS.
- The system’s interface depends on its mode: “mode dependence”.

The CT accounting system I’ve been alluding to can handle all this.

- The formal system is called [polynomial functors](#); it accounts for...
- ...ODS’s in time-varying interfaces with time-varying inter’n patterns.

Dynamic organizational structures

A **dynamic organizational structure**¹ is a systematized version of the above.

- It's like a presentation of the laws of nature or the rules of a game.
- It tells you rules for how parts are allowed to form into wholes...
- ...where these laws/rules are required to be a compositional.

¹Perhaps we should call these “Multi-Scale Dynamic Organizational Structures”.

Dynamic organizational structures

A **dynamic organizational structure**¹ is a systematized version of the above.

- It's like a presentation of the laws of nature or the rules of a game.
- It tells you rules for how parts are allowed to form into wholes...
- ...where these laws/rules are required to be a compositional.

We know of a zoo of simple examples, but only four interesting ones:

- Deep learning,
- Hebbian learning (spike-time dependent plasticity),
- Prediction markets, and
- Non-cooperative strategic games.

¹Perhaps we should call these “Multi-Scale Dynamic Organizational Structures”.

Dynamic organizational structures

A **dynamic organizational structure**¹ is a systematized version of the above.

- It's like a presentation of the laws of nature or the rules of a game.
- It tells you rules for how parts are allowed to form into wholes...
- ...where these laws/rules are required to be a compositional.

We know of a zoo of simple examples, but only four interesting ones:

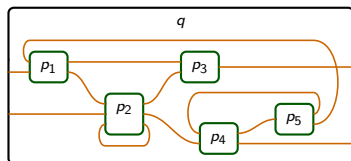
- Deep learning,
- Hebbian learning (spike-time dependent plasticity),
- Prediction markets, and
- Non-cooperative strategic games.

In each case: a systematized dynamic for how parts form wholes.

¹Perhaps we should call these “Multi-Scale Dynamic Organizational Structures”.

More detail on dynamic organizational structures

Recall this picture, where parts form wholes.

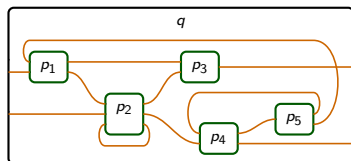


Several things are different for a dynamic organizational structure.

- The interaction pattern is generalized, e.g. weighted sums.
- The inter'n pattern is dynamic, changing based on what flows.
- The dynamic inter'n pattern is formulaic and compositional.

More detail on dynamic organizational structures

Recall this picture, where parts form wholes.



Several things are different for a dynamic organizational structure.

- The interaction pattern is generalized, e.g. weighted sums.
- The inter'n pattern is dynamic, changing based on what flows.
- The dynamic inter'n pattern is formulaic and compositional.

This “formulaic and compositional” aspect shows up in our examples.

- Deep learning formula: gradient descent.
 - A population of gradient descenders forms a gradient descender.
- Prediction markets formula: update wealths based on Bayes rule.
 - A population of predictors with varying wealths forms a predictor.

Applications to PCE3

In Darwinian evolution, the individual is metaphysically primary.

- People thus need to argue about whether groups can be selected for.
- An organism learning or adapting is not seen as internal selection.
- These discontinuities in the theory offer an avenue for improvement.

Applications to PCE3

In Darwinian evolution, the individual is metaphysically primary.

- People thus need to argue about whether groups can be selected for.
- An organism learning or adapting is not seen as internal selection.
- These discontinuities in the theory offer an avenue for improvement.

In prebiotic chemistry, I imagine boundaries are much more fluid.

- The theoretician needs to be able to change boundary lines.
- Low-latency feedback loops may better define individuality...
- ...than any case-by-case notion of membrane, skin, envelope.
- The theory should be “continuous” with respect to boundary-drawing.

Applications to PCE3

In Darwinian evolution, the individual is metaphysically primary.

- People thus need to argue about whether groups can be selected for.
- An organism learning or adapting is not seen as internal selection.
- These discontinuities in the theory offer an avenue for improvement.

In prebiotic chemistry, I imagine boundaries are much more fluid.

- The theoretician needs to be able to change boundary lines.
- Low-latency feedback loops may better define individuality...
- ...than any case-by-case notion of membrane, skin, envelope.
- The theory should be “continuous” with respect to boundary-drawing.

The above gives an accounting system for ODS's inhabiting interfaces.

- It is compositional: continuous with respect to boundary-drawing.
- Individuality is a derived concept rather than metaphysically primary.
- Parts connect or disconnect based on what occurs during interaction.

Outline

- 1 Introduction
- 2 Dynamical systems and interaction patterns
- 3 Dynamic organizational structures
- 4 **Conclusion**
 - Summary

Summary

Category theory is an accounting system for coherent structures.

- It helps you structure what you're trying to think about.
- Rather than quantities, it focuses on relationships.
- Its operating principle is compositionality.

Summary

Category theory is an accounting system for coherent structures.

- It helps you structure what you're trying to think about.
- Rather than quantities, it focuses on relationships.
- Its operating principle is compositionality.

Dynamic organizational structures are CT accounts of interacting ODS's.

- Open dynamical systems interact with others.
- They do so by sending and receiving information/material.
- Interacting parts form wholes, and the pattern changes through time.

Summary

Category theory is an accounting system for coherent structures.

- It helps you structure what you're trying to think about.
- Rather than quantities, it focuses on relationships.
- Its operating principle is compositionality.

Dynamic organizational structures are CT accounts of interacting ODS's.

- Open dynamical systems interact with others.
- They do so by sending and receiving information/material.
- Interacting parts form wholes, and the pattern changes through time.

Only four known interesting examples, but PCE3 may offer another one.

- We'd need to find a system for how identity-flexible evolution works.
- The math gives guardrails (compositionality) that ensure integrity.
- Email david@topos.institute if you'd like to explore a collaboration.

Thanks! Comments and questions welcome...