Week 3 Slides

2x4+1 minutes
4 minute Pres.
1 minute Q/Connection
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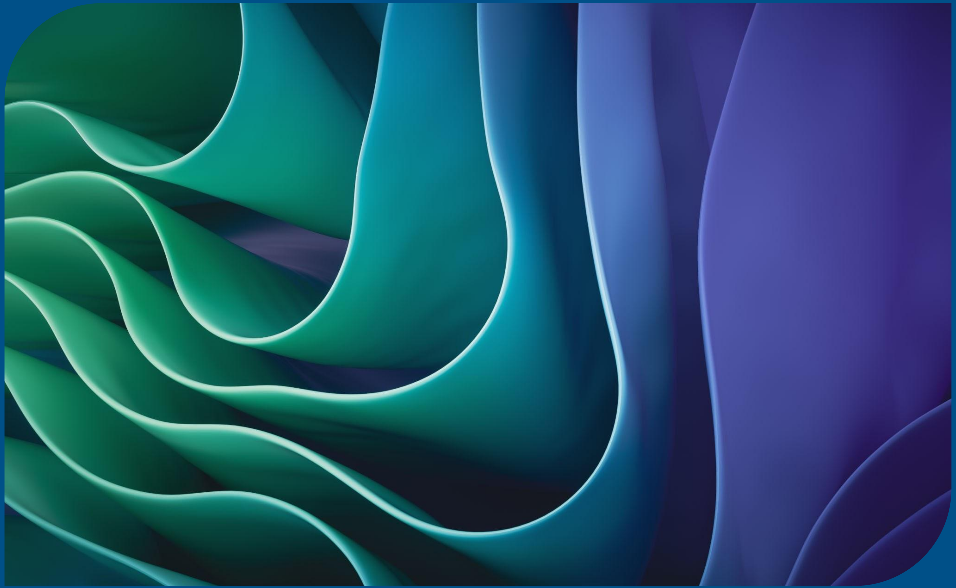
10 minutes for logistics, feedback

Origins of Life & Artificial Chemistry

Collaboratively learning about collective efforts to learn from this past week's material.

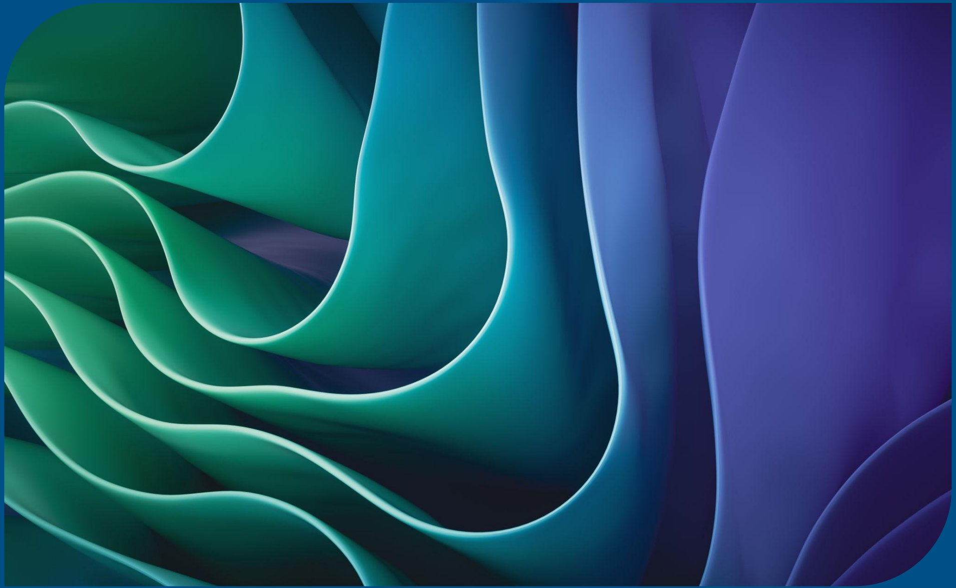


1. **Will: Structural Cellular Hash Chem**
2. **Steven: Assembly Theory**
3. **DEF: _____**
4. **JKL: _____**
5. **Group Activity**

Will

Plan

- Introduce Hash Chemistry / Why It Is Appealing (4 minutes)
- Discuss Connections/Ideas (2 minutes)
- Introduce Structural Cellular Hash Chemistry (4 minutes)
- Brief Discussion on SCHC (2 minutes)



What Hash Chemistry?

- An AChem system proposed by (as far as I have found) Hiroki Sayama in 2019
- Definition
  - $S \subseteq \mathbb{N}$ (e.g. {1 .. 1000})
  - A := the current state in some data structure
    - Might encode locality
  - F(A) => A' where F is some function that applies hashing

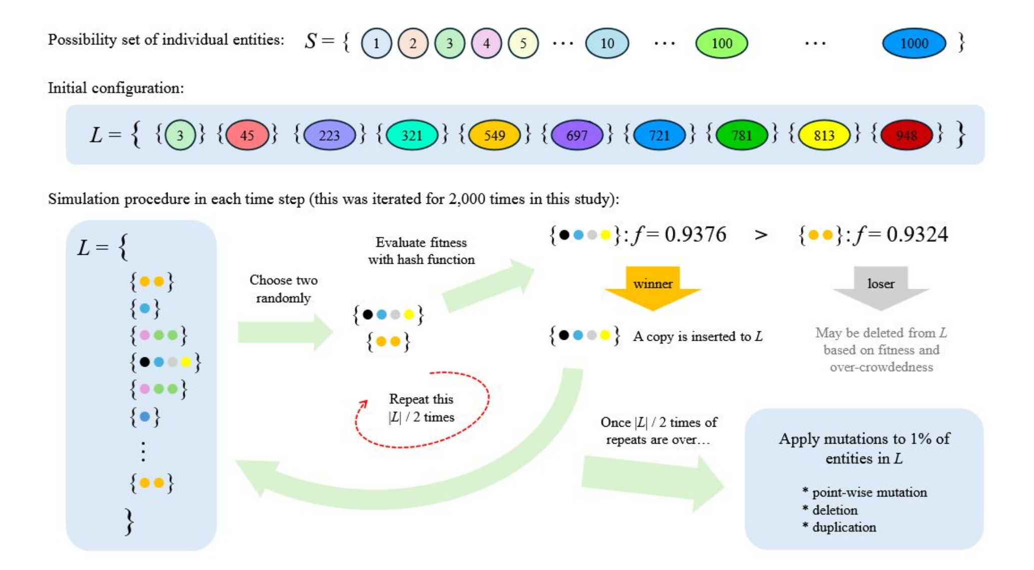


Fig. 1. Schematic illustration of the outline of the proposed non-spatial Hash Chemistry model. See the main text for details.

Why Hash Chemistry?

<u>Potential Answer to the search for open endedness</u>

“As a **promising mechanism to facilitate open-endedness** in artificial evolutionary systems, we previously argued the importance of a ‘cardinality leap’ of possibility spaces and demonstrated its effectiveness using Hash Chemistry, a simple artificial chemistry” (Sayama, 2024) in reference to (Sayama 2019).

- Linear relationship between iterations and number of new entities
- Extremely fast, when coupled with the above, extremely efficient
- New method of AChem (many possibilities)

Cardinality Leap

- In reference to the set of possible states. In theory, need many for complexity to arise.
- Hash chem is promising because $S \subseteq \mathbb{N}$

Slide for Discussion/Questions before P2

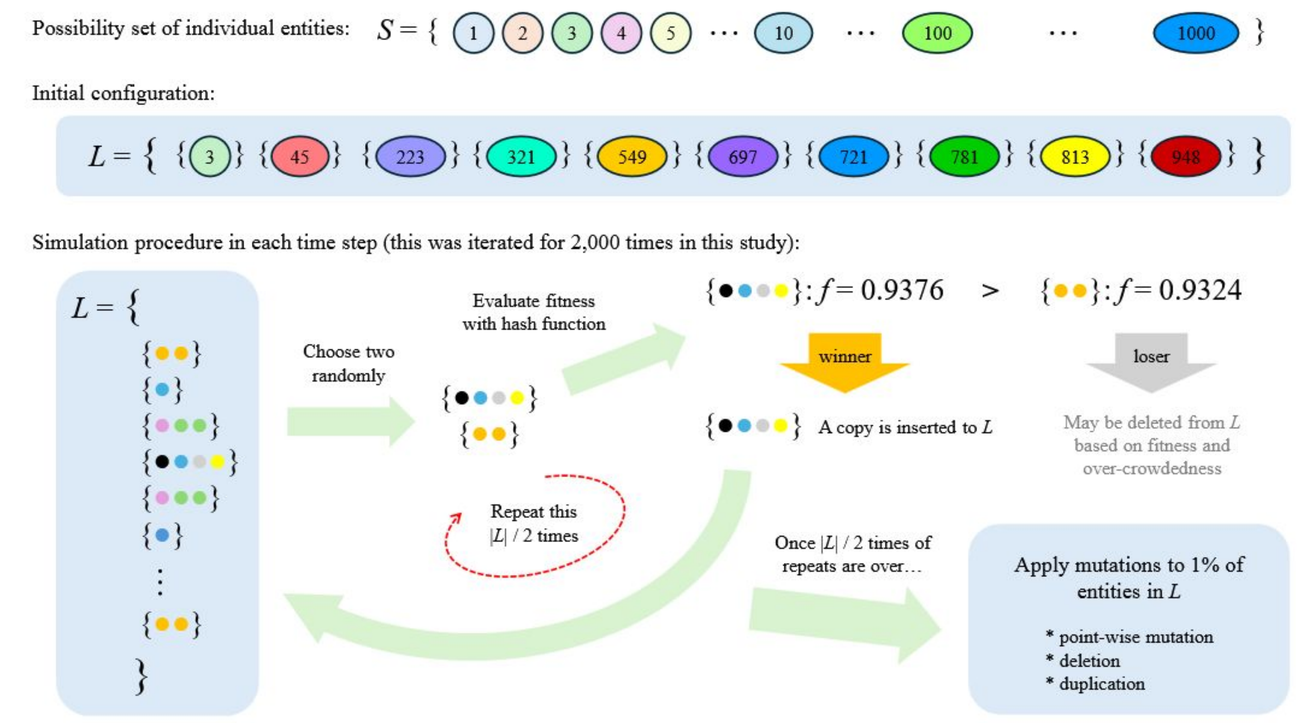


Fig. 1. Schematic illustration of the outline of the proposed non-spatial Hash Chemistry model. See the main text for details.

Evolution of HChem

First Paper

- Fully encoded space in 2D, each entity a point natural number
- Slow, but showed the promising linearity of new states
- Bounded to prevent “data explosion” (Sayama, 2019)

Second Paper

- Proposed set locality (sets expressing proximity, with only members of the same set being considered interactable)
- Much faster, promising results when compared to the first paper (same metrics were maximized (fitness of entities, # unique entities)
- Failed to show “ecological interactions” between entities

Fourth Paper

- Attempt to combine the best of all prior attempts
- Structural Cellular Hash Chemistry

Structural Cellular Hash Chemistry

- Structural - Meaning spatial, locality is preserved on a grid
- Cellular - In reference to cellular automata, as that is the base structure which is being iterated based on the hash fitness function
- Hash Chemistry - Hash fitness function

"SCHC's computational cost was significantly reduced compared to the original version and even to the non-spatial version, achieving all of the desired properties (continuous adaptation, unbounded growth of complexity, spatial ecological interactions among self-replicating entities, diversity of populations, and computational efficiency) within a single model framework." (Sayama, 2024)

- In summary, it managed to express evolution towards fitness, increasing individuality, and ecological interactions in less computational time.

Structural Cellular Hash Chemistry

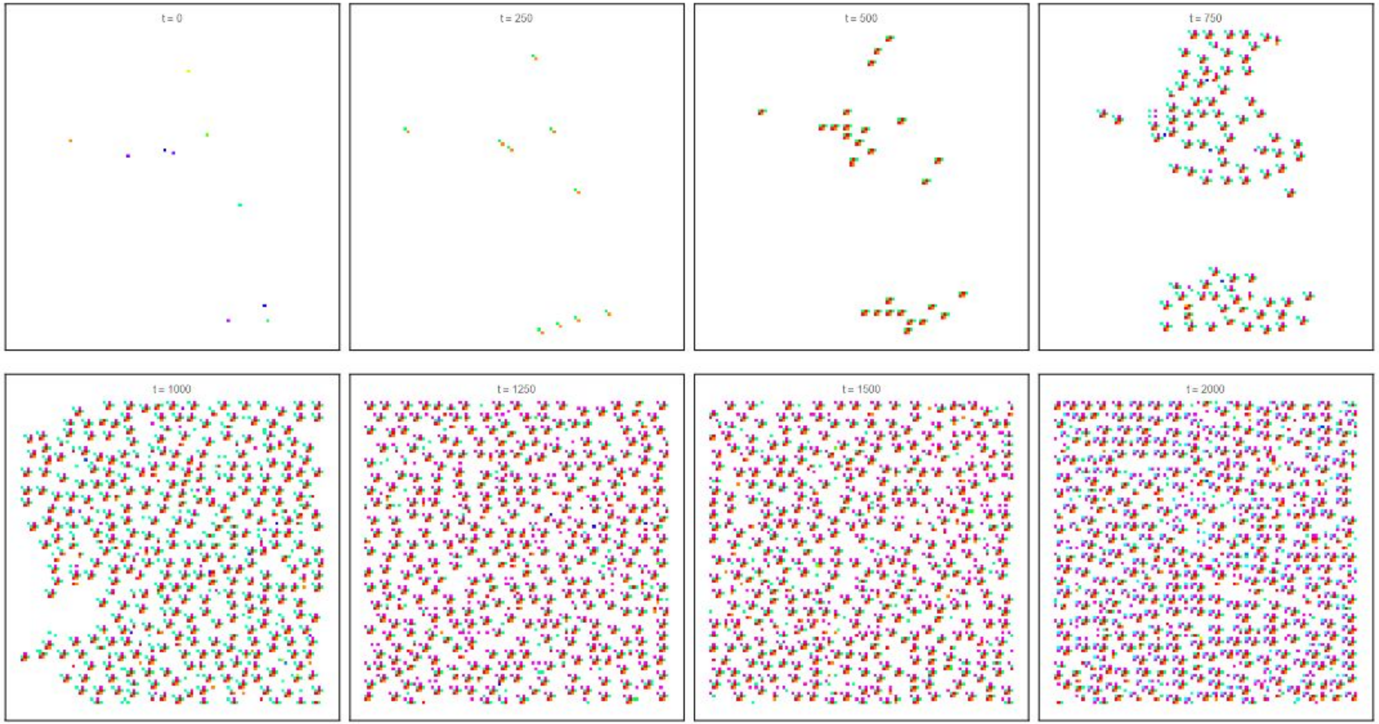
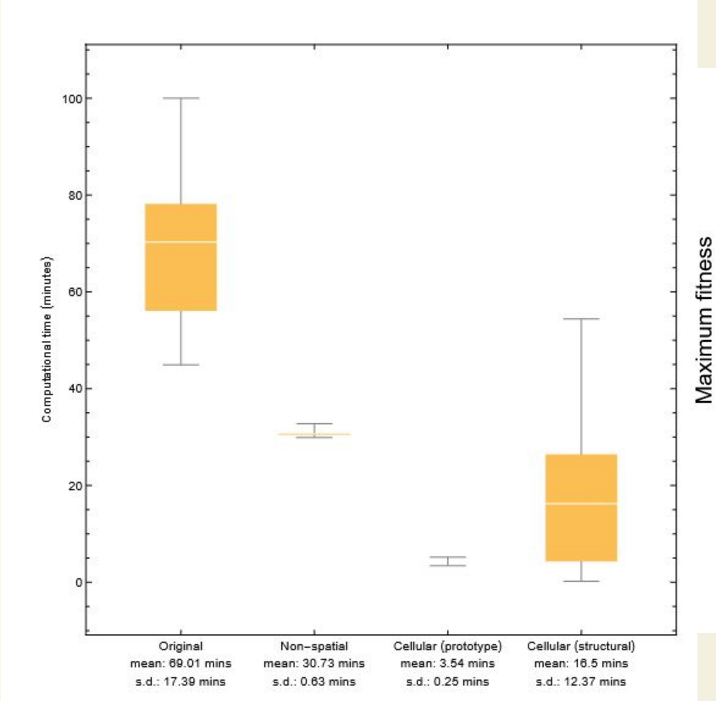
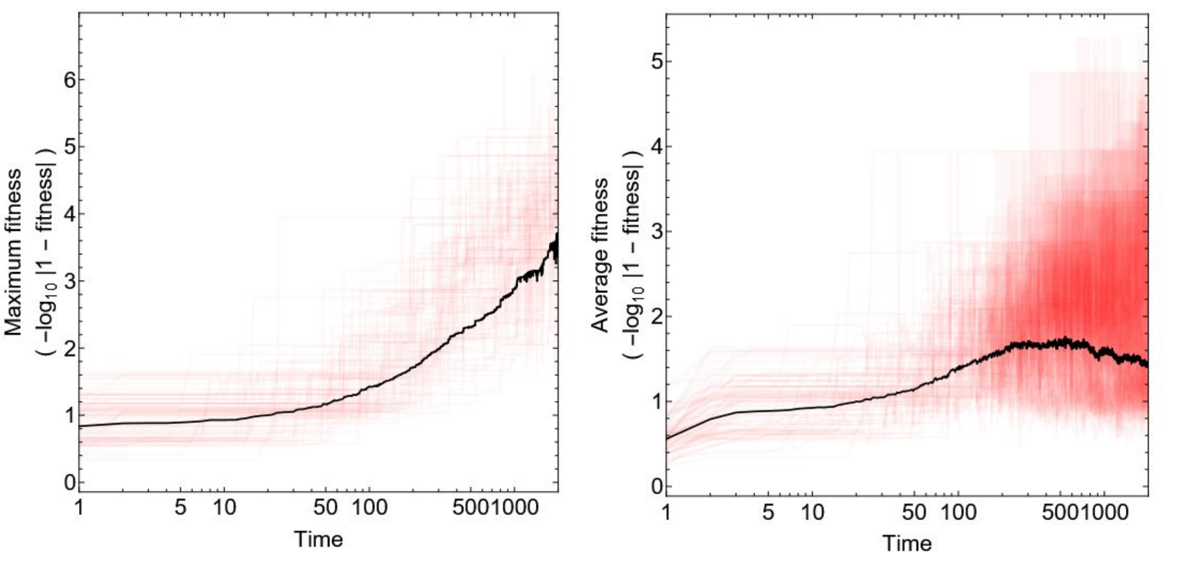


Fig. 1. A sample simulation run of Structural Cellular Hash Chemistry. Snapshots of system configurations are arranged temporally from left to right and then top to bottom ($t = 0, 250, 500, 750, 1000, 1250, 1500, 2000$). Colors represent different element types, and blank (white) spaces represent empty cells. It is observed in these visualizations that the self-replicating patterns gradually proliferate and evolved to larger forms with more complex nontrivial structures (also see Fig. 2).

Structural Cellular Hash Chemistry





Structural Cellular Hash Chemistry

TABLE II
COMPARISON OF FOUR HASH CHEMISTRY MODELS

Attributes	Original [10]	Non-spatial [11]	Cellular (prototype) [12]	SCHC (this study)
Selection mechanism	Individual evaluation	Pairwise competition	Four-way competition	Pairwise competition
Unbounded possibilities by cardinality leap	✓	✓	✓	✓
Computational efficiency		✓	✓	✓
Multiscale ecological interactions	✓		✓	✓
Adaptive behavior	?	✓		✓
Continuous exploration of possibility space	✓	?	✓	✓
Unbounded complexity growth	?	✓		✓

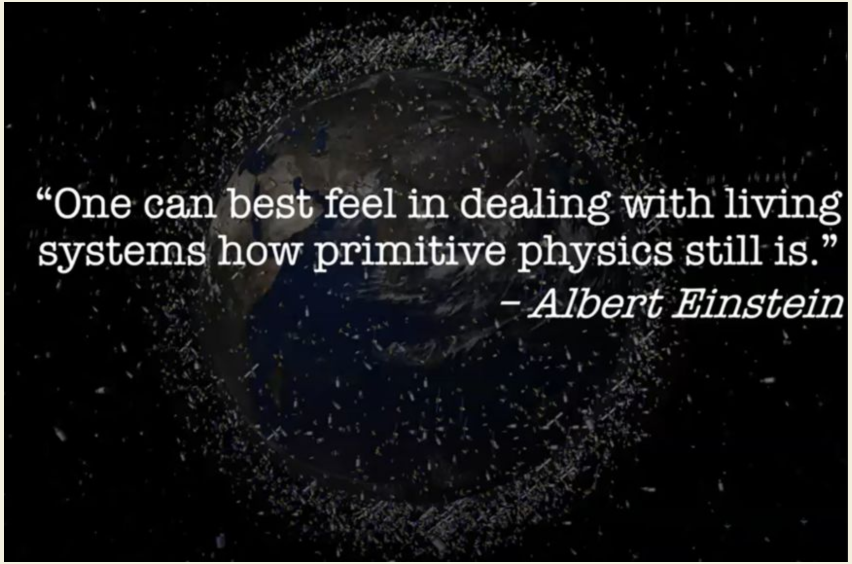
Steven

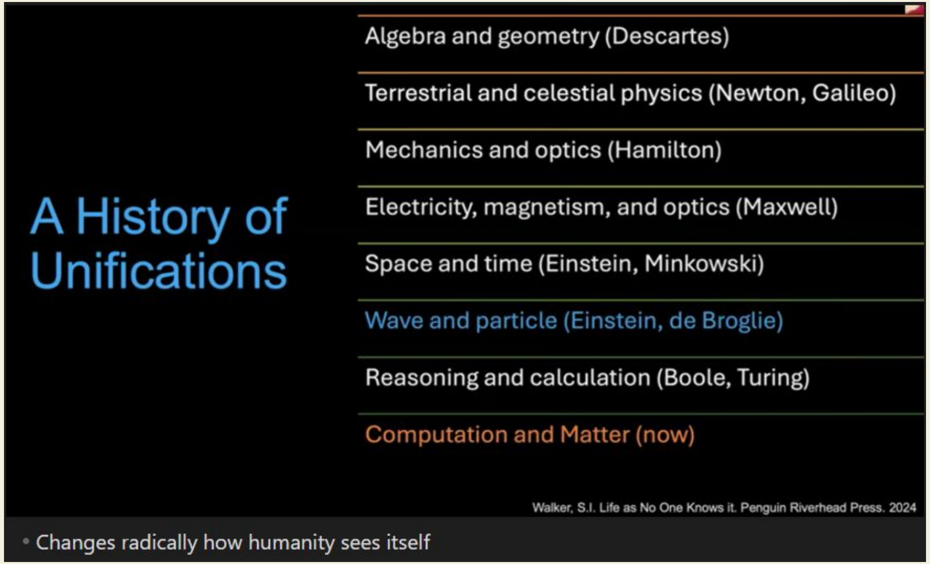
Plan

Introduce Assembly Theory
Discuss Question/Scenario/Etc.

"But as a classically trained theoretical physicist I did not think the ideas would be testable in my lifetime. Lee aimed to prove me wrong. Early in our collaboration he pushed me to **ground my thinking in what we can measure, and this exercise has made all the difference in the reality I now see written in the story of life**." pg. 89-90

Steven – Assembly Theory





"Assembly theory represents a new possible kind of unification: that of matter and computation" pg. 130

"In order for life to exist as a natural kind, we need a new concept of time as material." pg. 136

Steven - Assembly Theory

Selection is NOT just a passive filter we've traditionally thought about but it's actually constructed by objects constraining other objects to be able to allow certain things to exist and not others (paraphrased from video)

"We cannot look at DNA on its own as an object and say what its meaning is. But we can measure the minimal path to make DNA, independent of what built it or were we find it." pg. 103

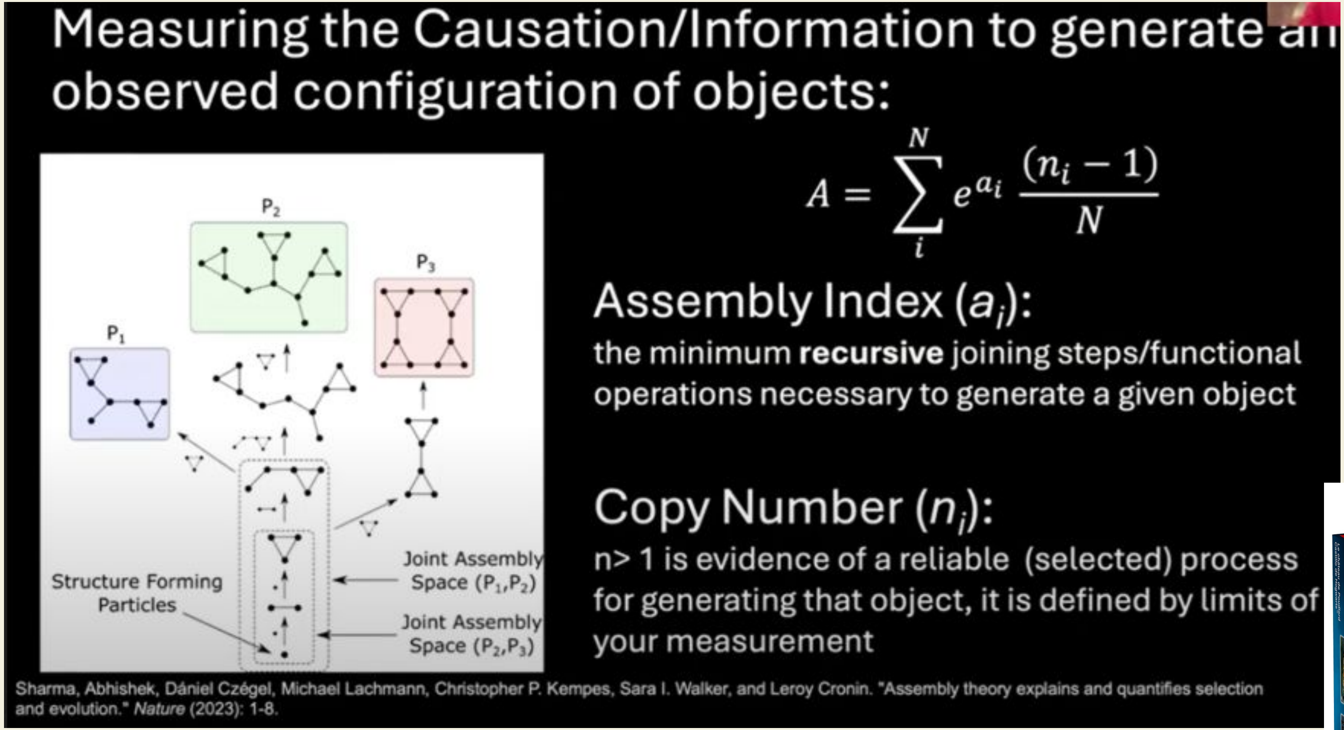
- "The set of steps you would have taken (or maybe did take, if you made your own LEGO version) is what we call an assembly pathway." pg. 98

- "The assembly space we care about in assembly theory is the one with the shortest number of steps: this assembly space minimally captures the amount of causation necessary to make the object." pg. 98

Mentioned several times

Pg. 99

Steven - Assembly Theory



"The shortest path would be quite long (I have not personally calculated the assembly index of LEGO Hogwarts)."" pg. 100

Steven - Assembly Theory

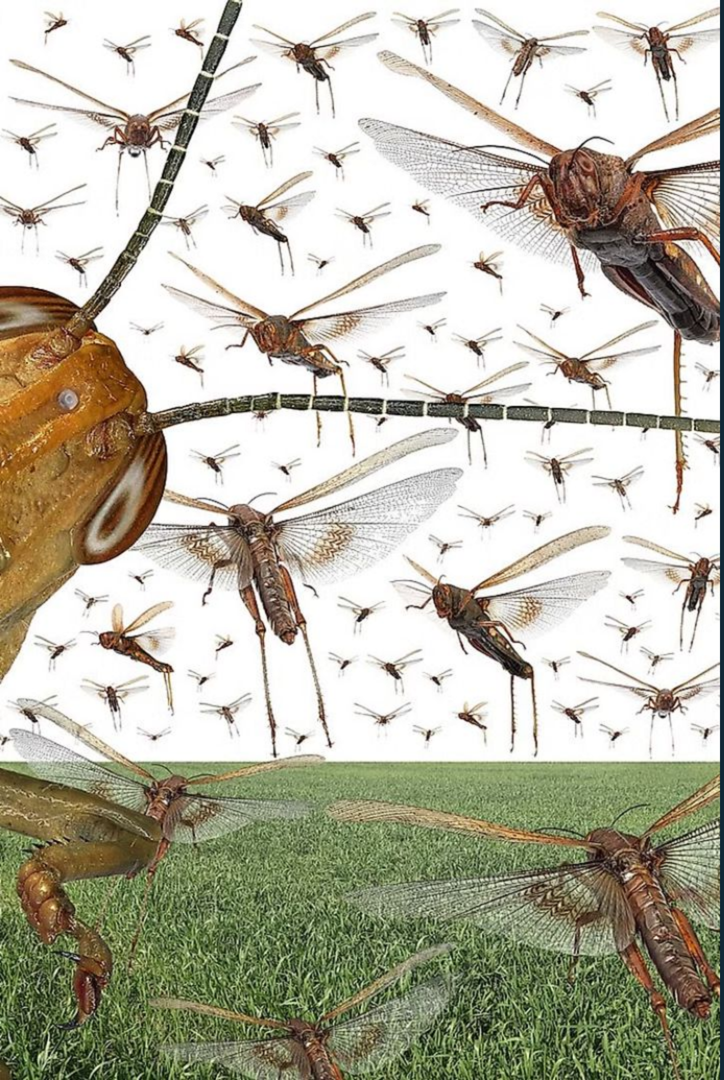
"All objects that require information to specify their existence constitute "life." Life is the high-dimensional combinatorial space of what is possible for our universe to build that can be selected to exist as finite, distinguishable physical objects."
"Being "alive," by contrast, is the trajectories traced through that possibility space. The objects that life is made of and that it constructs exist along causal chains extended in time; these lineages of information propagating through matter are what it is to be "alive."" pg. 141

"**The fundamental unit of life is not the cell, nor the individual, but the lineage of information propagating across space and time.** The branching pattern at the tips of this structure is what is alive now, and it is what is constructing the future on this planet." pg. 143

Swarm Systems as a Platform for Open-Ended Evolutionary Dynamics

Sayama et al. 2024

Presented by Dominic Reilly



Swarm Systems

System of individual agents that each operate on local instructions

Often capable of complex tasks that could not be achieved on their own

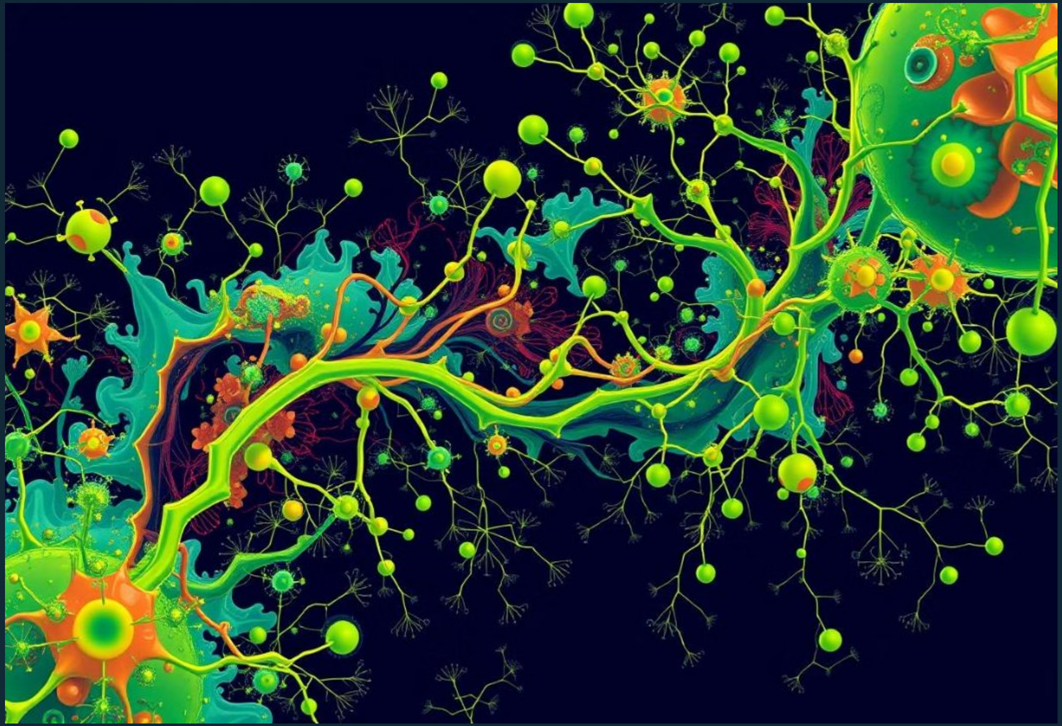
- Whole is greater than the sum of the parts

Traditionally aim for a specific objective

Open-Ended Evolution

Evolutionary system that evolves without a specific objective

- Often seeking novelty or unique outcomes
- Has a human cultivator that adjusts hyperparameters and searches for fascinating outcomes



Swarm Systems as a Medium for OEE

Heterogenous swarms

Different agents have different roles

Interactive Evolutionary Computation

Human input as the fitness function

Emergent Behaviors

Visually rich

Robust to environment or dimension changes (2D → 3D)

Useful in studying human design behavior

Original Swarm Chemistry

Inspired by Boids (1986)

Simulates individual bird behavior

Follow 3 Simple Rules

Flocking, swarming, splitting/merging, and obstacle avoidance

Recipe

How a swarm is represented

Set of particle types with corresponding behavioral parameters

Morphogenetic Swarm Chemistry

Dynamic Re-differentiation

Ability for an individual to change type and alter its recipe

Information Sharing

Can send recipes or observations to local neighbors

Incrementally Added:

Homogeneity, Heterogeneity, Dynamic re-differentiation, Local information sharing

Observed Behaviors

Self-assembly, growth, and self-repair with enhanced diversity in emergent behaviors

Evolutionary Swarm Chemistry

Recipe Transmission

Recipes are exchanged during collision

Less effective in 3D due to decreased collisions

Competitive functions

Govern which recipe will be chosen between two colliding particles

Recipes mutate during transfer

Majority function is the best

Favors particles surrounded by similar types

Encourages local homogeneity and global heterogeneity

Behaviors

- Organism-like swarm patterns
- Predation, self-replication

Applications

Science

Cellular behavior, asymmetric swarm dynamics, artificial chemistries

Art

Interactive art, music, performances

Swarm generate dynamic sound/visual patterns

Explored in games and VR

Engineering

Recipes evolve into robotic swarm coordination mechanisms

Inspired Particle Lenia

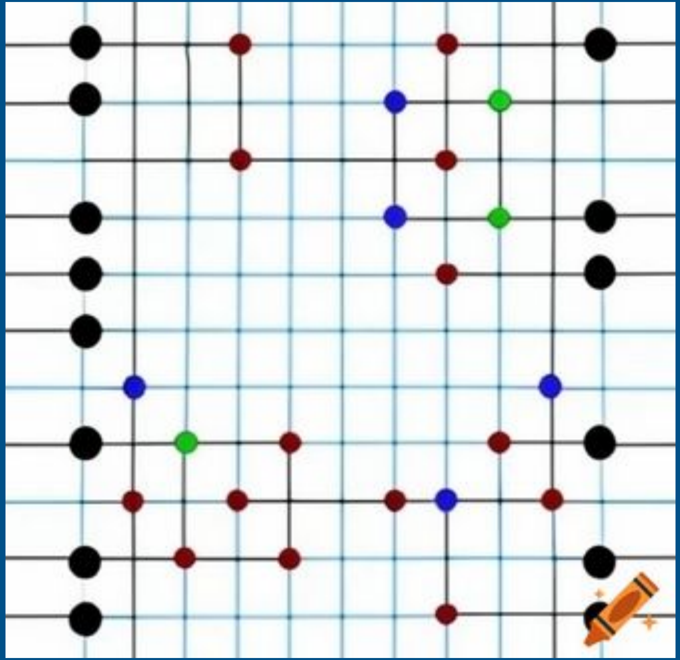
Sub-symbolic Artificial Chemistries
Alex Brickley

2 min -Main ideas

2 min - Moving Between Levels in Artificial Chemistries

2 min - RBN-World: The Hunt for a Rich AChem

Discussion



1. **Reactions should be emergent**

2. **Small number of powerful rules should work**

3. **Marcoscorpic-unbounded molecular size-COM**

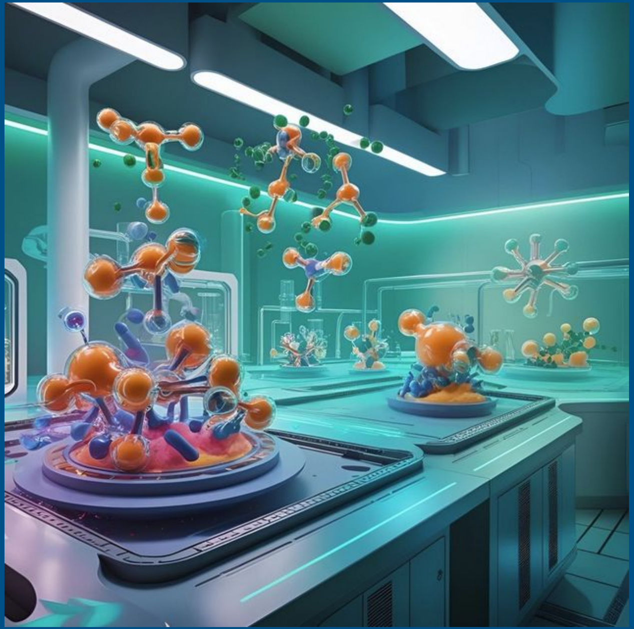
4. **Microscopic- synthesis - self-synthesis-decomposition**

Automatically Moving Between Levels in Artificial Chemistries

Moving from higher to lower or vise versa causes different issues

To move upwards, the low level system must be left to run to see what structures form.

While all major pieces are wanted, intermediate stages from lower stages may not always be appropriate for high level components.



- Synthesis - bonds are possible but not trivial/universal

- Self-Synthesis - bonds between identical atoms

- Decomposition - breakdown of bonds should be possible but not universal

- Substitution - not inherently import but implies relationships between multiple molecules

- Catalysis - a seris of reactions that don't consume the catalyst but allow for more/faster reactions