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Artificial Life

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Alife and AI

- Artificial Life is a sister discipline for Artificial Intelligence
- Both take a functionalist approach to a mysterious subject:
  - AI: an artificial system can be *intelligent* if it is organised right
  - Alife: an artificial system can be *alive* if it is organised right
- Like AI, Alife combines a Strong project and a Weak project
  - Strong Alife: creating life inside a computer or in a robot
  - Weak Alife: understanding life by building life-like systems
    - Alife's pithy strapline: "The study of life-as-it-could-be"

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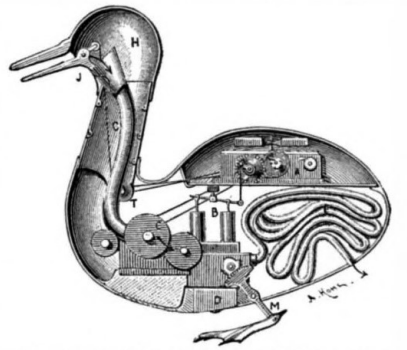
History

- Chris Langton named + founded Artificial Life in 1987
- But Alife has been going on for much longer than AI
  - Frankenstein, Golem, various ‘Automata’ and ‘Living Machines’:
  - Vaucanson’s Duck (1739): quacking, drinking eating, “excreting”
- The biggest names in CS were in fact Alifers…
  - Babbage: Evolutionary Models of Miracles
  - Turing: Models of Biological Morphogenesis
    - Von Neumann: Self-Reproducing Machines



INTERIOR OF VAUCANSON'S AUTOMATIC DUCK.
A, clockwork; *B*, pump; *C*, mill for grinding grain; *F*, intestinal tube; *J*, bill; *H*, head; *M*, feet.

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Self-Reproducing Machines

- How could a machine make a more complex copy of itself?
- This conundrum sounds impossible – paradoxical
- Von Neumann arrived at a two-part solution in 1948:
  1. Information encoding the structure of a machine …DNA
  2. Machinery that uses the information to make a new machine + a new copy of the information …cellular machinery
- In doing so, JVM predicted the contents of our cells…

…before the 1952 discovery of the DNA double helix.

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Universal Constructors

- But John Von Neumann went further than theorising and actually designed the first self-replicating machine!
- The first “Cellular Automaton” (CA):
  - A grid of cells, each containing a value
  - All values are updated according to a set of rules applied to each cell grid
    - Careful design of the rules plus the initial state of the grid, and…

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Conway's Game of Life

- You may be familiar with the most famous CA: Game of Life
- John Horton Conway (1937-2020) created the *Game of Life* in an effort to make a CA that had interesting behaviour:
  - Proliferating, repeating patterns; universal construction; etc.
- He settled on the following simple rules:
  - Each cell has a binary state – it can be alive or it can be dead
  - A live cell with >3 living neighbours or <2 living neighbours dies
    - A dead cell with three living neighbours becomes alive

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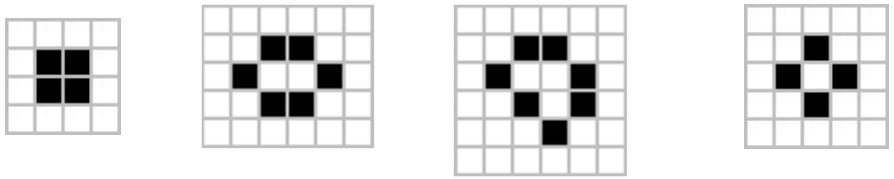
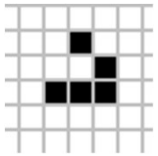
Conway's Game of Life

- Some configurations are static:



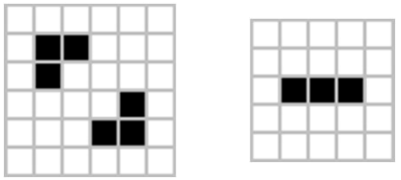
- Some oscillate on the move:



  - A "glider"

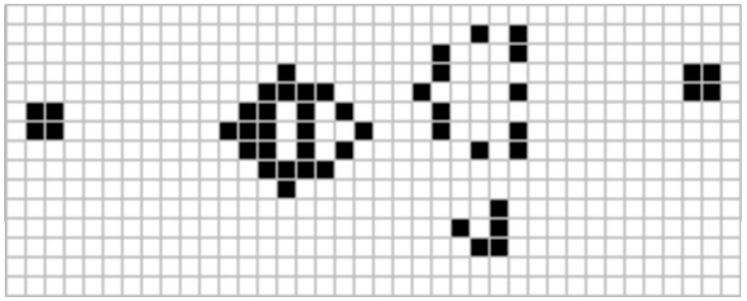
- Some destroy each other when they collide in the right way…

- Some oscillate in place:



  - A "beacon" and a "blinker"

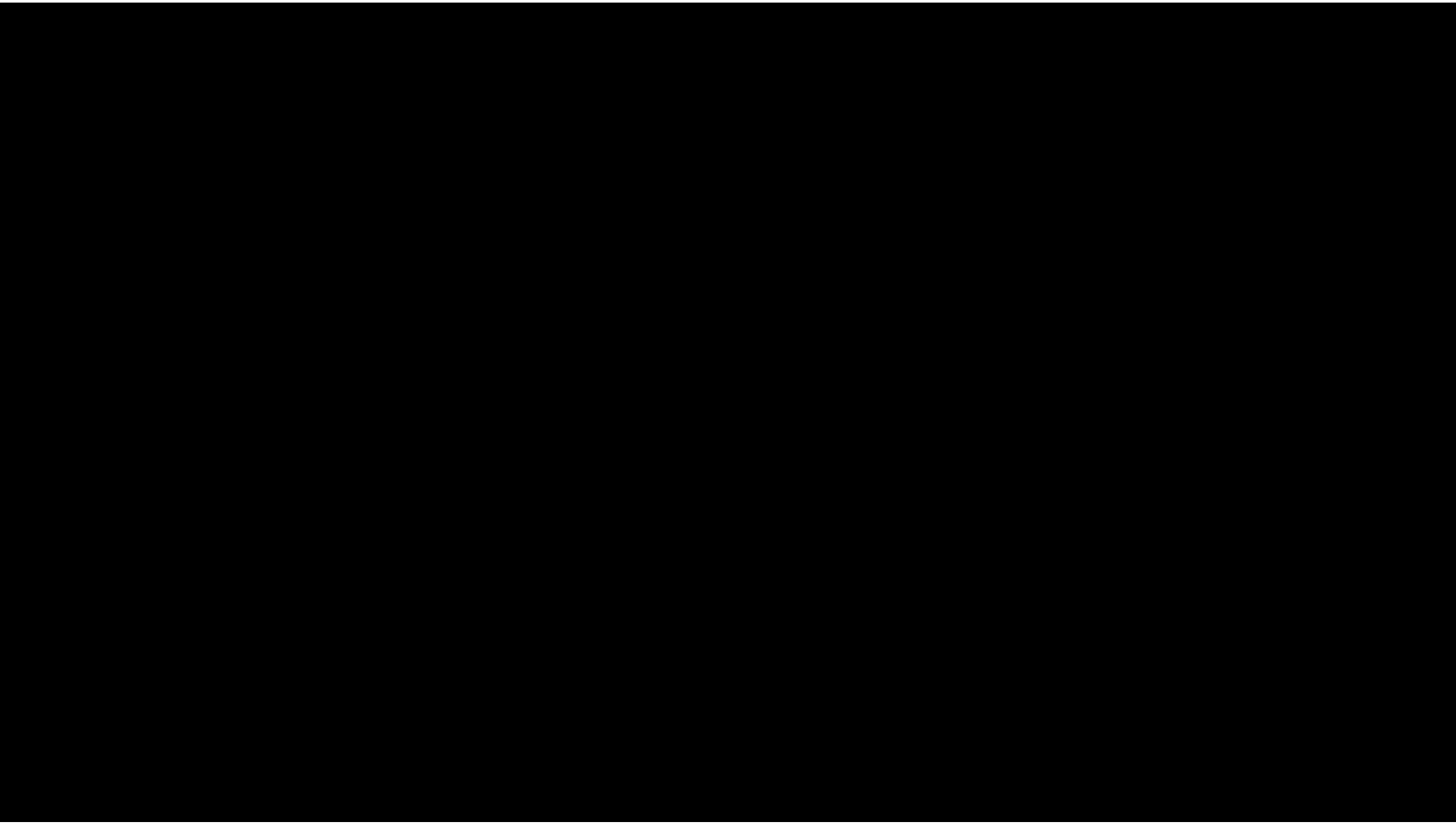
- Some *generate* other structures: e.g., a *glider gun*



  - Amazingly, the Game of Life is provably Turing Complete…

Life in Life

Phillip Bradbury
Roger Pincombe



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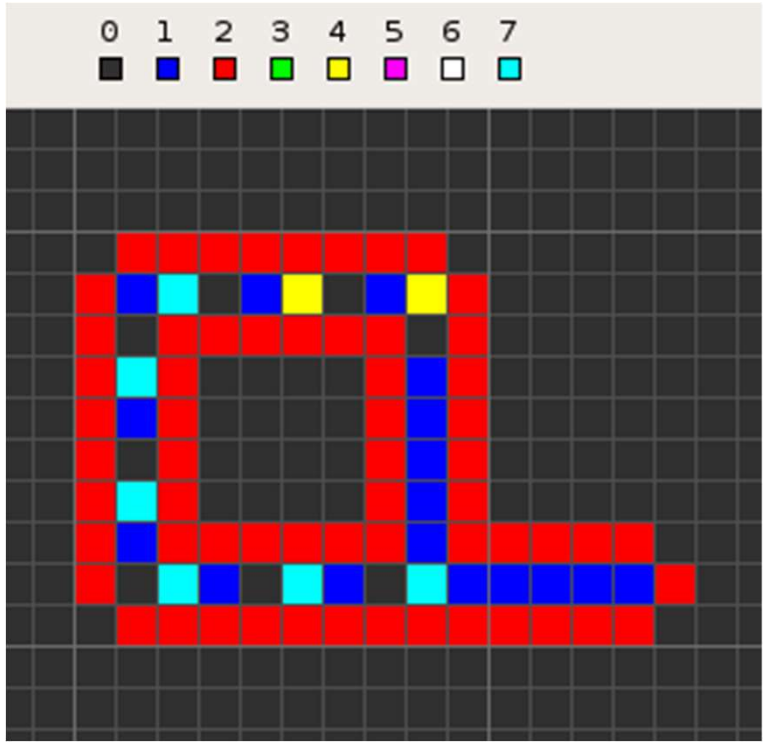
Langton's Loop

- Langton studied CAs + made a more simple self-replicator:

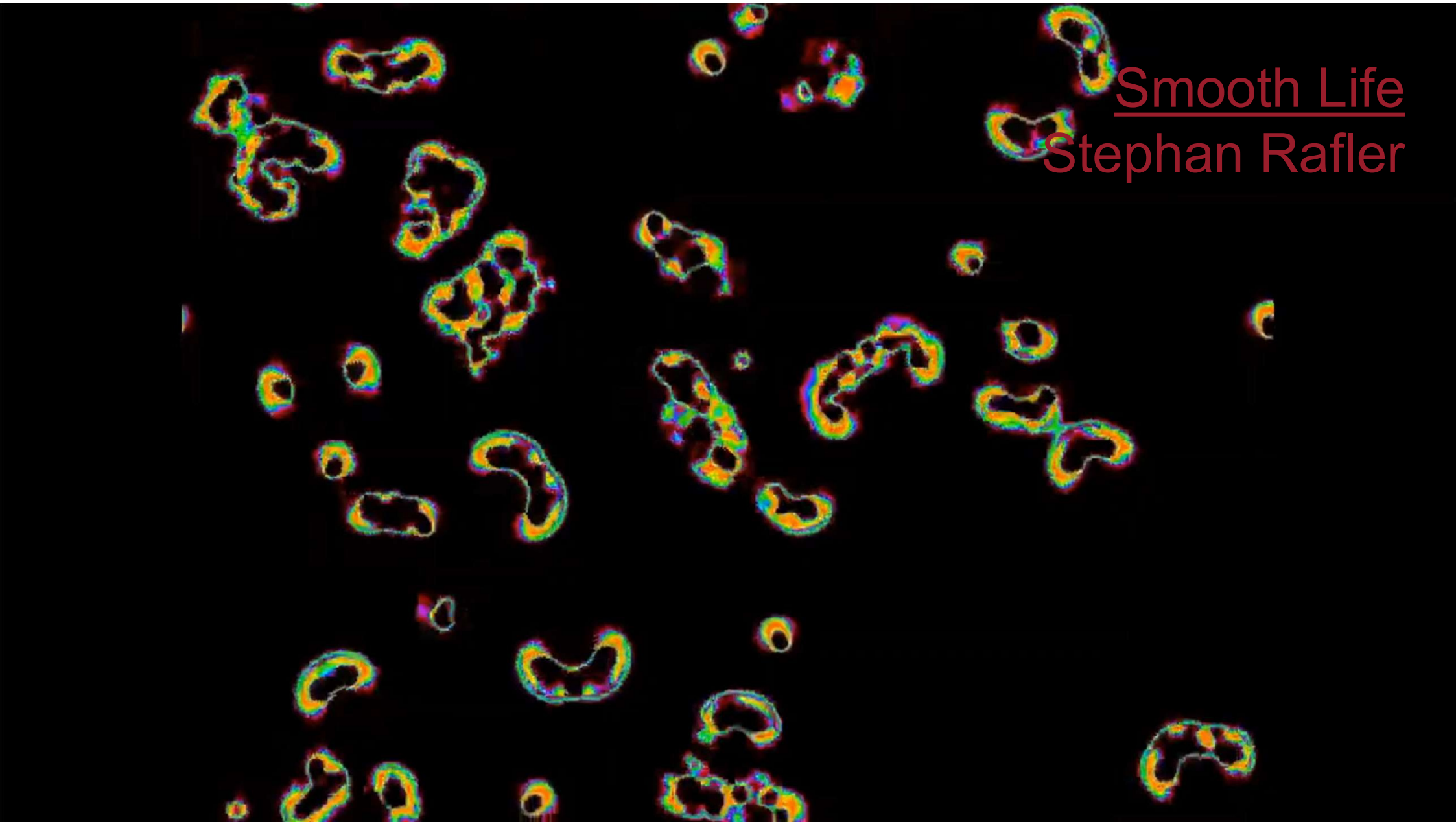


- Some CAs are boring, dead, inert, fixed;

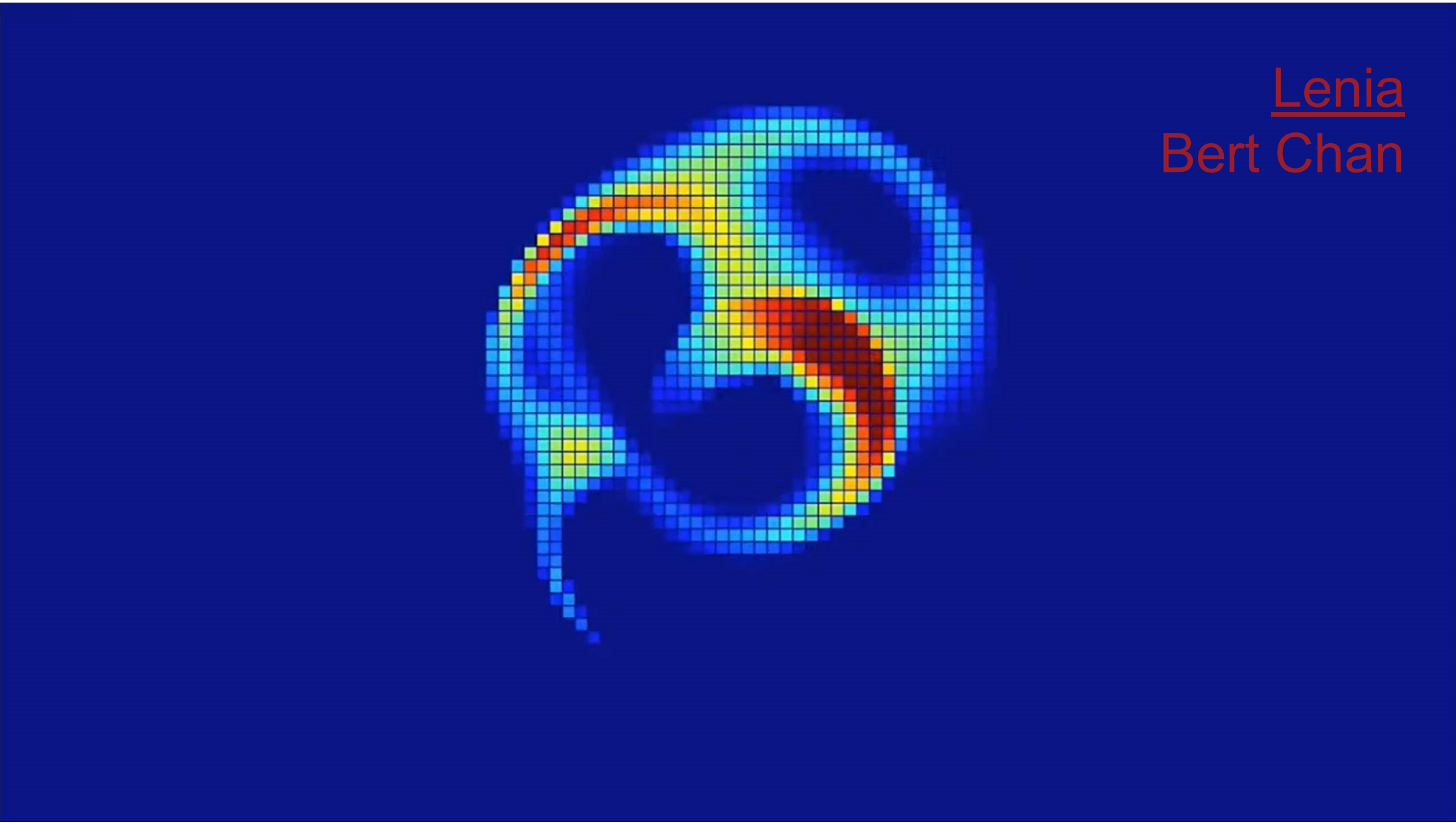
…some just repeat; some are messy chaos;

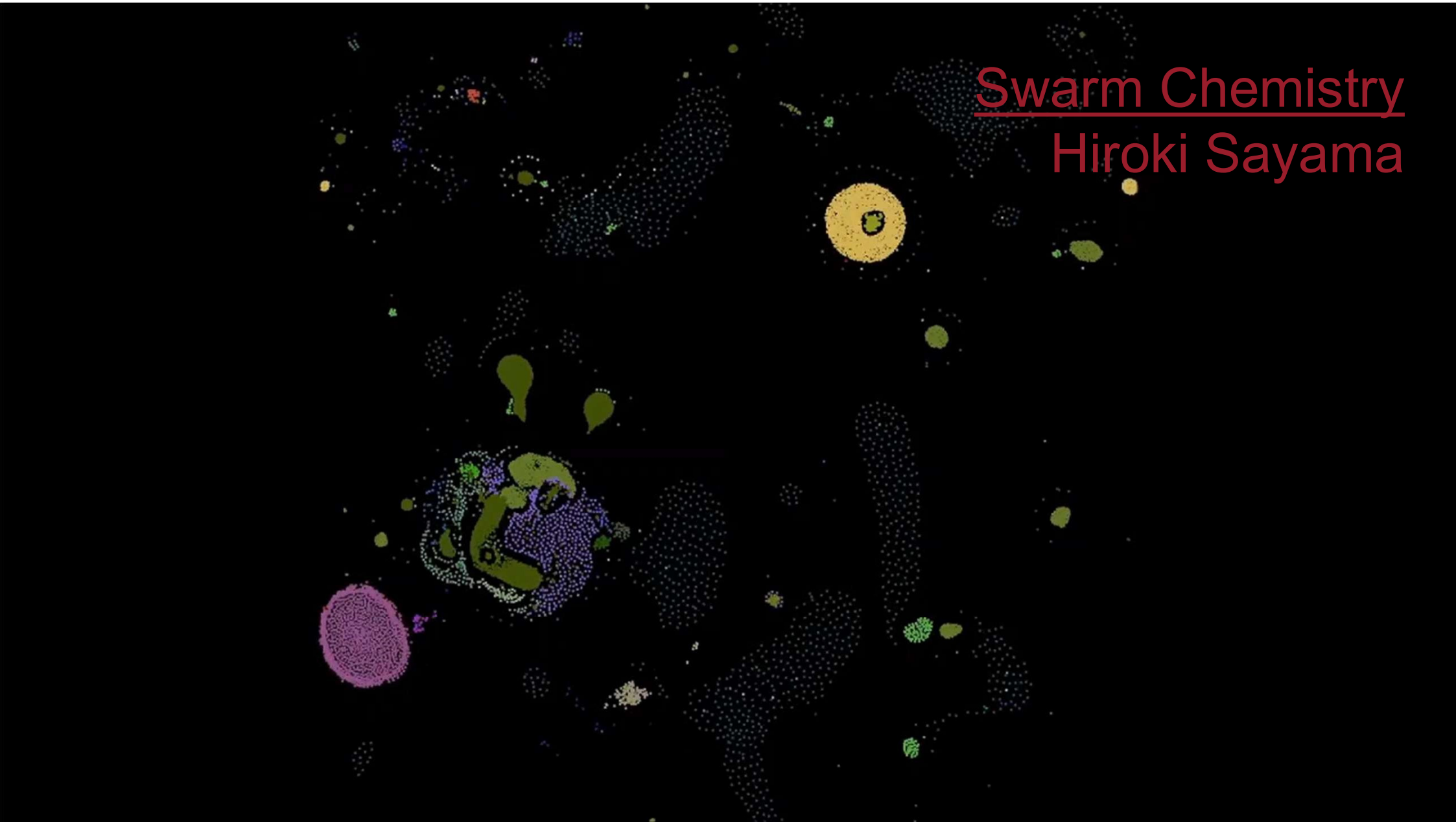
…and some are 'interesting' for a long time

- What is the physics of this complexity?
- Self-replicators + some kind of mutation = the possibility of *evolving replicators...*
- But how can truly 'open-ended evolution' be achieved in artificial systems?


Smooth Life
Stephan Rafler


Smooth LifeL
(Tim Hutton)


Lenia
Bert Chan


Swarm Chemistry
Hiroki Sayama

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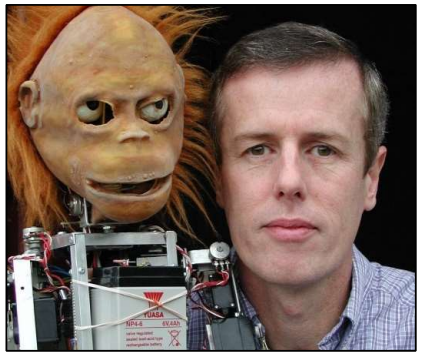
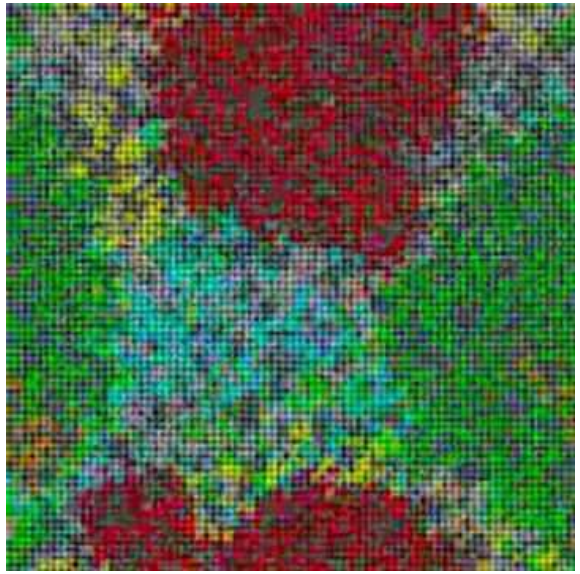
Tierra to Avida

- Other Alifers explored the evolution of “digital organisms”:
  - Tom Ray’s *Tierra*: from replicators to parasites to hyperparasites
  - Chris Adami’s *Avida*: a kind of digital evolutionary laboratory
  - Alastair Channon’s *Geb*; Yaeger’s *Polyworld*.
  - Steve Grand’s video game: *Creatures*





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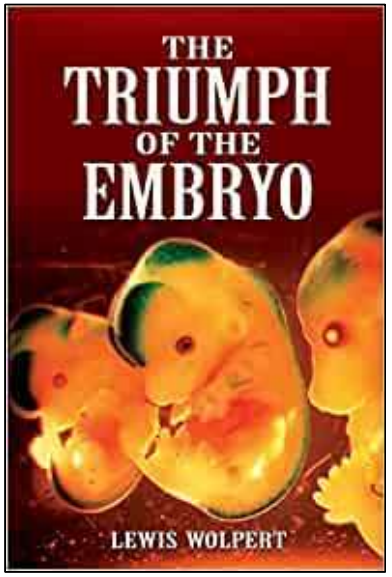
From Evolution to Development…

- Real biological lifeforms *develop* over time: morphogenesis
- Understanding how exactly an egg grows into a person is still one of the most profound scientific challenges
- Since before Turing: *growing* an AI has looked far more feasible than hand-crafting one
  - How can artificial systems grow and develop?
  - How can this development be steered or guided?



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L-Systems

- Lindenmayer Systems, Aristid Lindenmayer (1925-’89)
  - A model of plant development based on grammar rewriting
  - In language: S -> NP+VP; VP -> V+NP; etc., etc.
  - In L-Systems: I -> Y
  - More complex rules:

Przemysław Prusinkiewicz, A. Lindenmayer (1990). *The Algorithmic Beauty of Plants*

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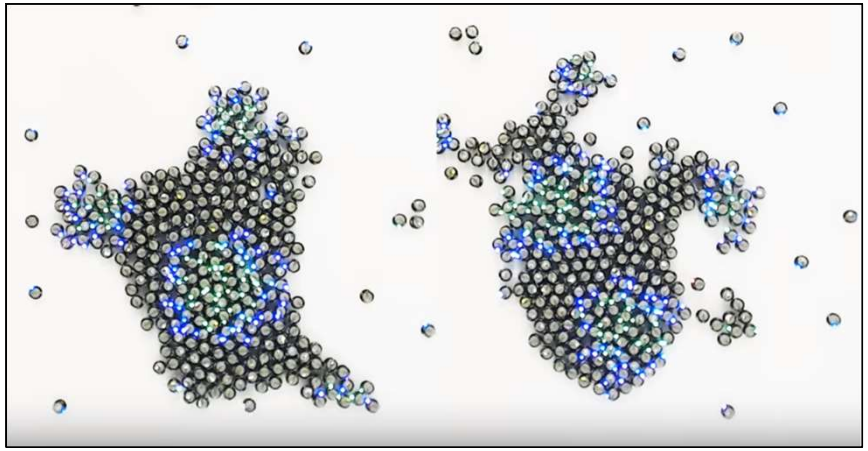
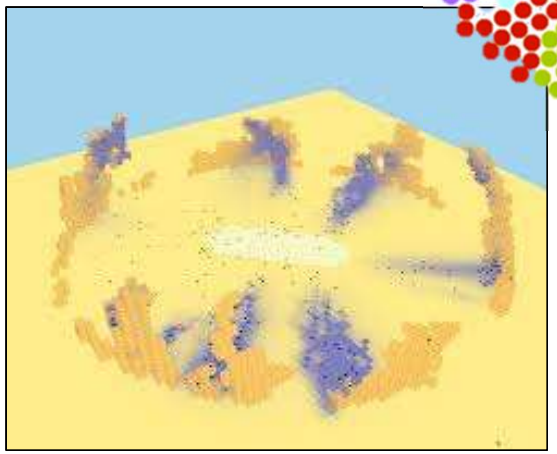
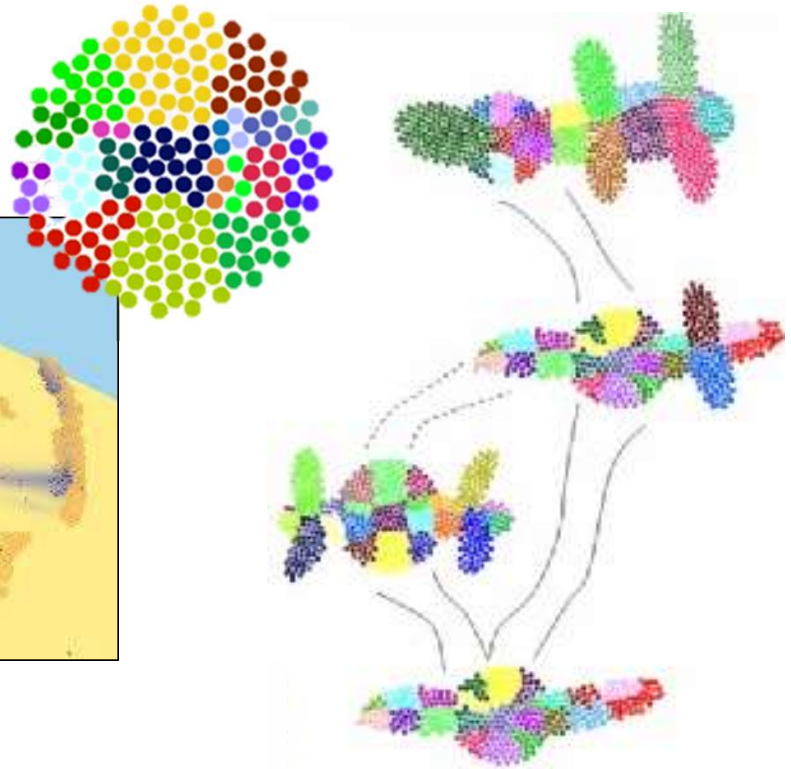
Artificial Morphogenesis

- Morphogenesis is still a growing area of research in Alife: 😂
  - "Morphogenetic Engineering"
  - Swarm Construction







- Evo-Devo Soft Robotics

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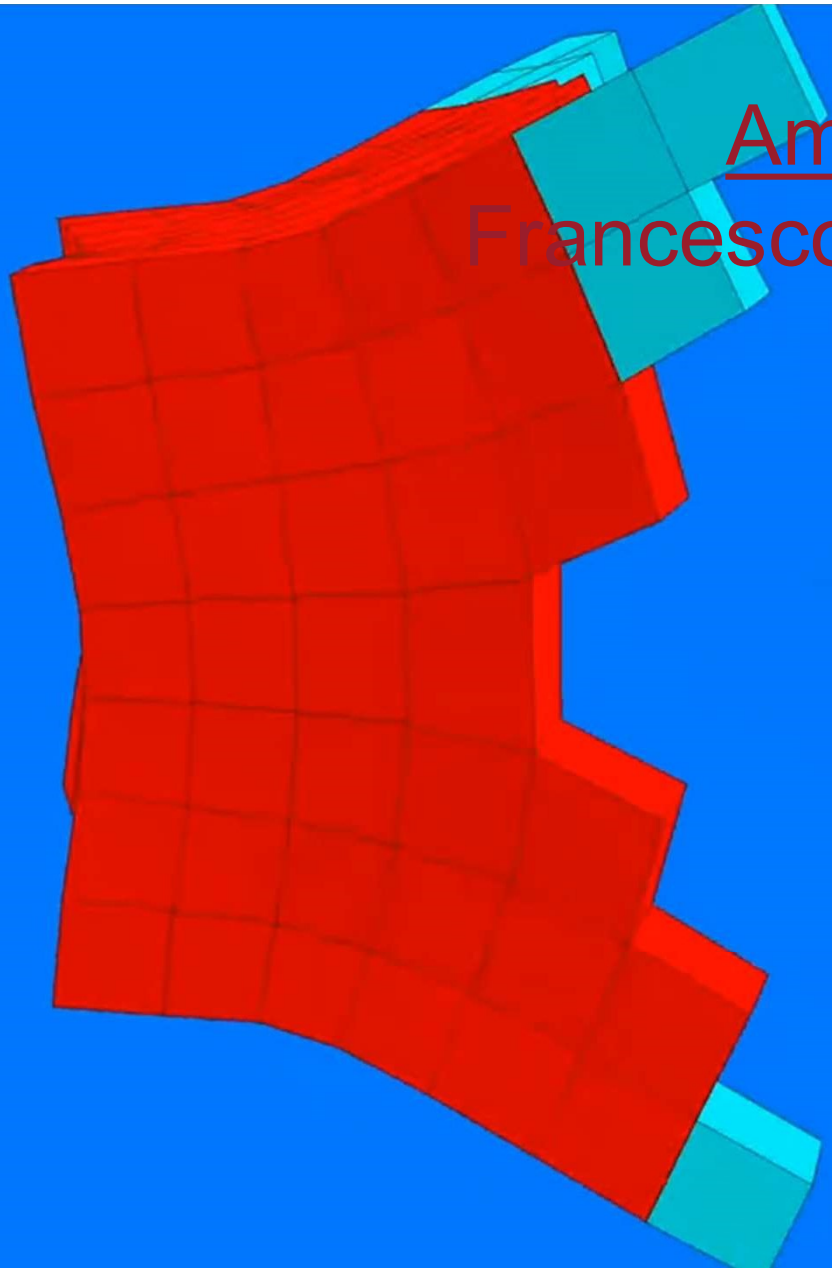

Amphibians

Francesco Corucci

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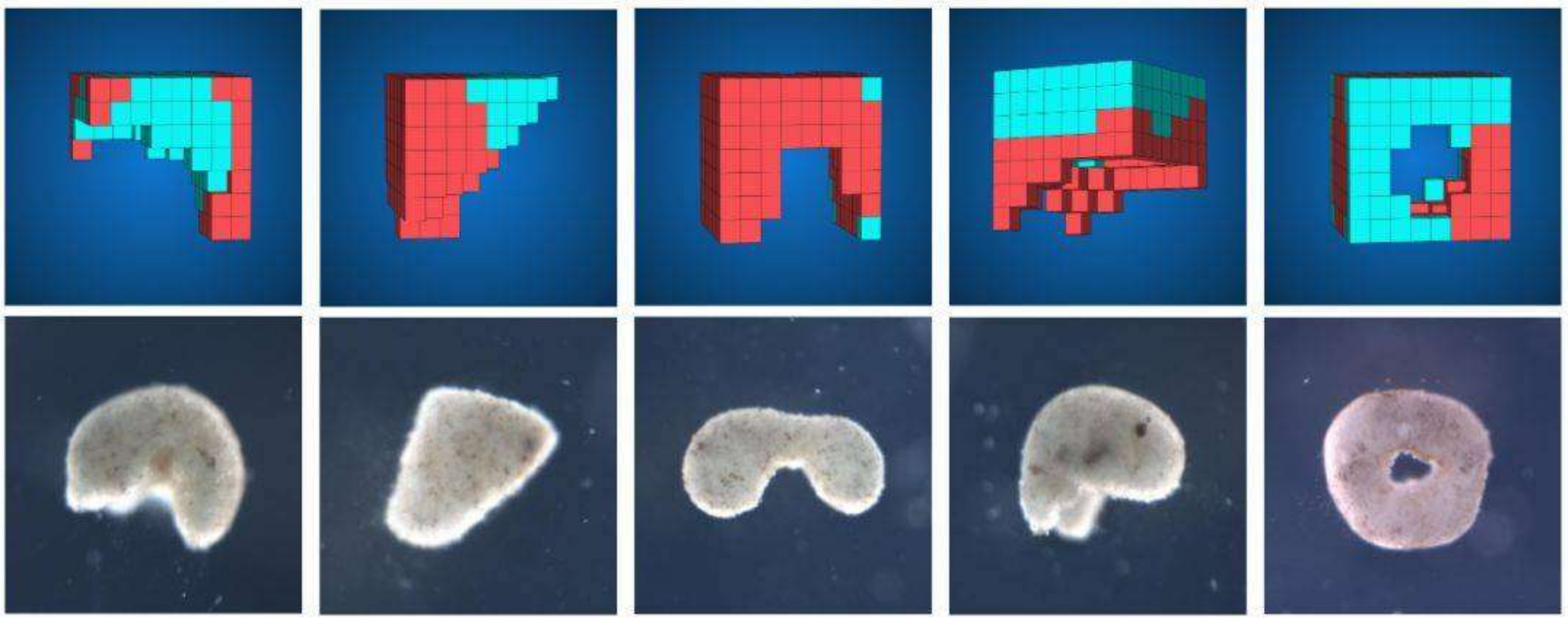
Xenobots

Robotics + soft-body simulation + evo-devo + bio-chemistry…



Josh Bongard (Vermont), Michael Levin (Tufts) and collaborators

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Types of Alife

Alife combines many disciplines

- Computer Science
- Robotics
- Biology
- Physics
- Chemistry
- Philosophy
- Linguistics

+ more

… and considers different life forms:

- Soft Alife: digital life
- Hard Alife: robotic life
- Wet Alife: biochemical life

- Whereas AI has focussed on:
  - Reasoning, Planning, Logic, etc.
- Alife has focussed on:
  - (Co-)Evolution, Development, Learning, Self-Organisation, Emergence, Origins of Life, etc.

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Open Problems

In 2000, a group of nine prominent Alife researchers authored a journal paper: "Open problems in Artificial Life": 14 challenges that are still live + relevant…

- How does life arise from the non-living? (5 problems)
  - Achieve the transition to life in an artificial chemistry.
  - Simulate a unicellular organism over its entire life cycle.
- What are the potentials and limits of living systems? (5 problems)
  - Determine what is inevitable in the open-ended evolution of life.
  - Develop a theory of information processing, flow and generation for evolving systems.
- How is life related to mind, machines, and culture? (4 problems)
  - Demonstrate emergence of intelligence in an artificial living system.
    - Establish ethical principles for artificial life.

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Women in Alife!

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Further Reading

- Langton, C. (1989). Artificial life, in *Artificial Life*, Addison-Wesley.
- Lehman, Clune, Misevic, Adami, et al., [52 authors!] (2020). The surprising creativity of digital evolution: A collection of anecdotes from the evolutionary computation and artificial life research communities. *Artificial Life*, 26:2, 274-306.
- International / European Alife Conference proceedings at alife.org
- The *Artificial Life* journal at MIT Press | Lana Sinapayen's Prezi 🔥
- Hiroki Sayama's PyCX Python package and associated text book
    - NetLogo Life, Alife Virtual Seminars, Alife Papers

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Example Questions

- Which cells in the Game of Life grid shown below will survive to the next time step, and which will not? *[2 marks]*
- How did Von Neumann's insight into self-replicating machines anticipate the DNA molecule? *[4 marks]*
- Why might it be more feasible to grow a general purpose AI rather than code one by hand? *[4 marks]*
- Apply two iterations of the following L-system rules to the starting shape shown below. *[3 marks]*

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Thank you!