AUGUST 21 ON YOUTUBE LIVE

CROSS ROADS #15

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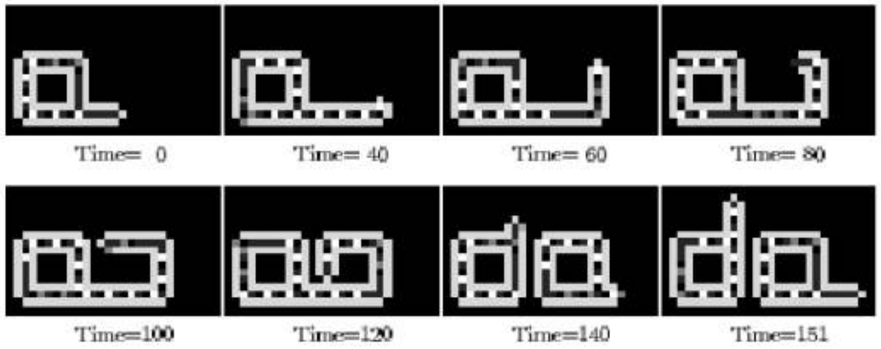
Lenia, Life, and Intelligence

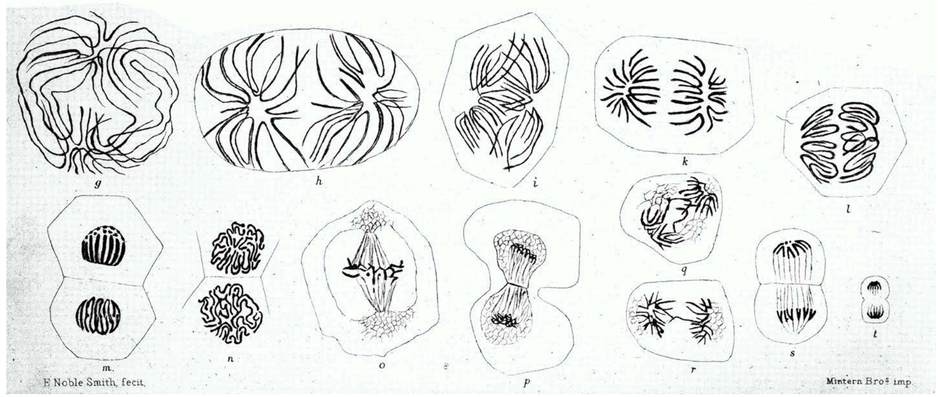
AUGUST 21, 2020, 9:30PM JST

This talk

- Use **Lenia** as example on…
  - How to create **artificial life**
  - Characteristics of **biological life** and **artificial life**
  - Relationships between **artificial life** and **artificial intelligence**



Langton's Ant



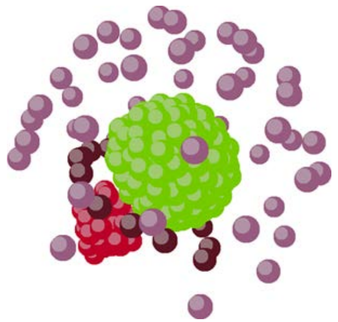
Cell division

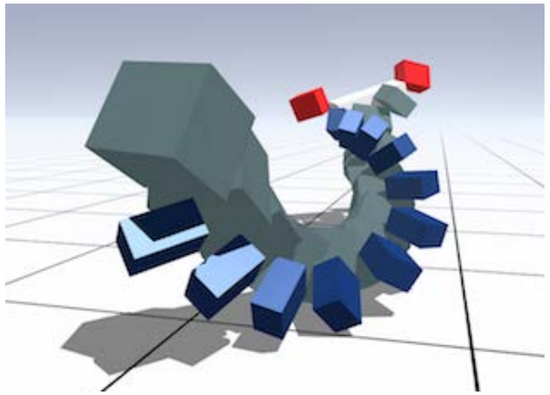
Wellcome Images via Wikipedia

How to create life

Artificial Life (ALife)

- **Simulate** or **create life forms** to answer “What is life?”, “What life can be?”



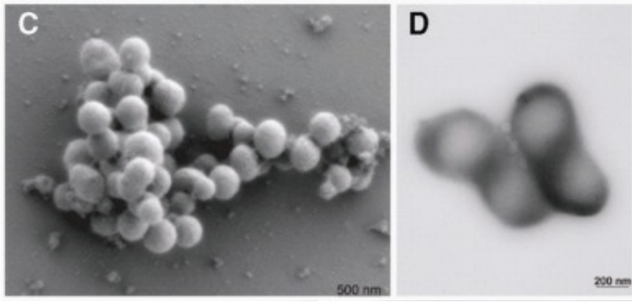


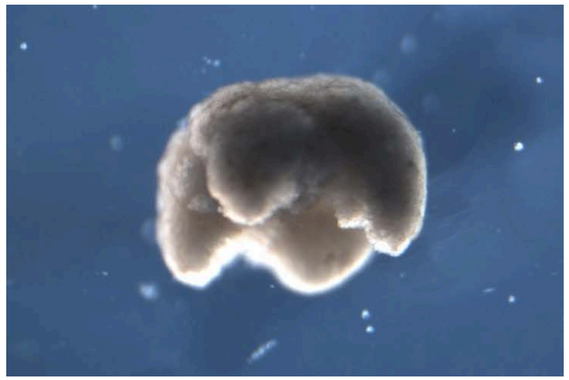
Software ALife
swarm chemistry, virtual creature

bingweb.binghamton.edu/~sayama
Wikipedia

Hardware ALife
Spot & Atlas, Strandbeest

bostondynamics.com
strandbeest.com



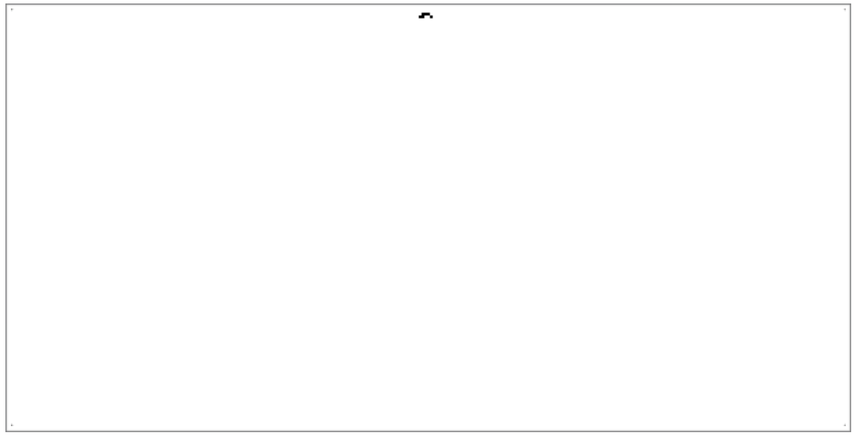


Wetware ALife
Synthia, Xenobot

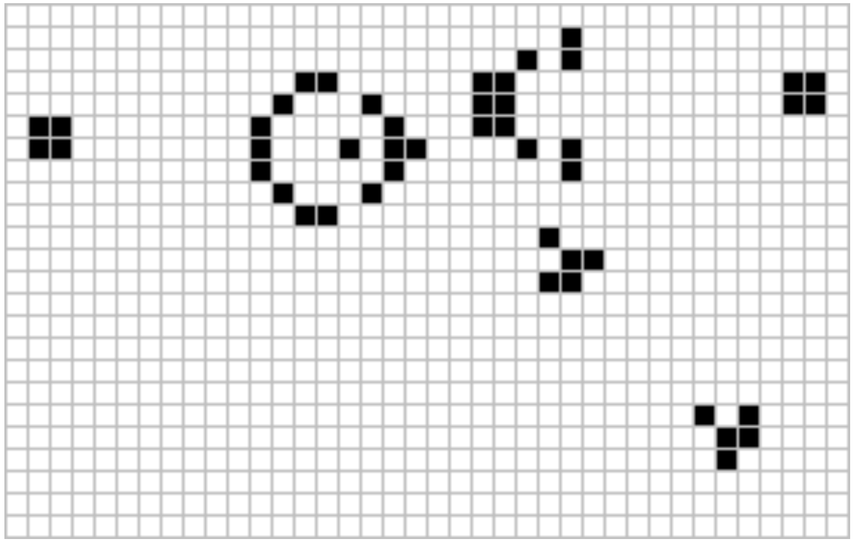
doi:10.1126/science.1190719
cdorgs.github.io

Cellular Automata

- n-Dimensional **grid**
  - Each site has **discrete state**
  - Next state determined by **neighborhood**
  - Whole grid **updated** repeatedly
- Examples: ECA [S Wolfram], GoL [JH Conway]
- Generate interesting **patterns**, even a **computer**
- Used to **model** physical, chemical, social complex systems



elementary cellular automata

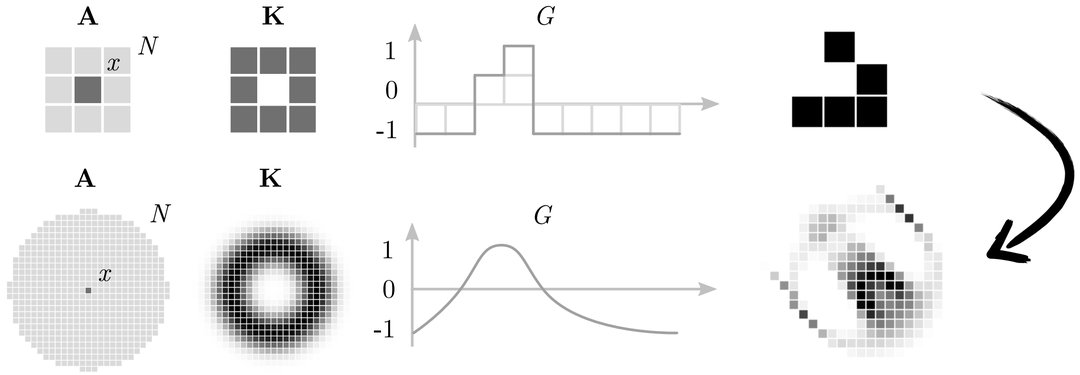


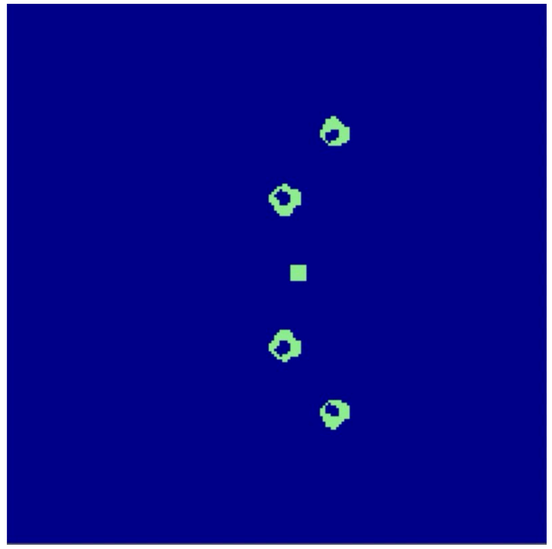
glider gun in Game of Life

flocc.network/model/automata
conwaylife.com/wiki/Gun

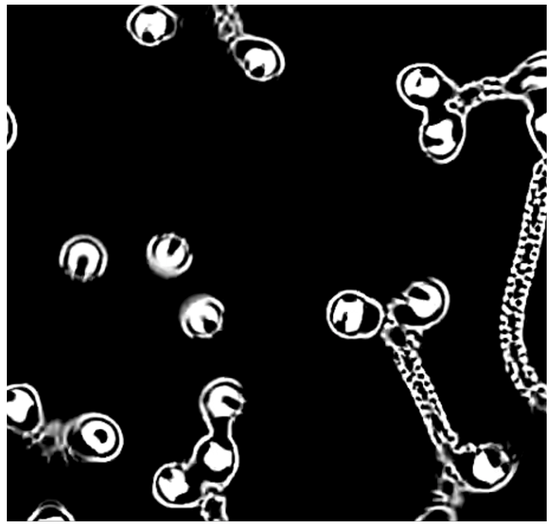
Continuous CA

- From discrete to continuous by:
  - Real values (**continuous states**)
  - Larger neighborhood (**continuous space**)
  - Incremental updates (**continuous time**)
- Examples: LtL [KM Evans], SmoothLife [S Rafler], Lenia
- Generate **geometric lifelike patterns**





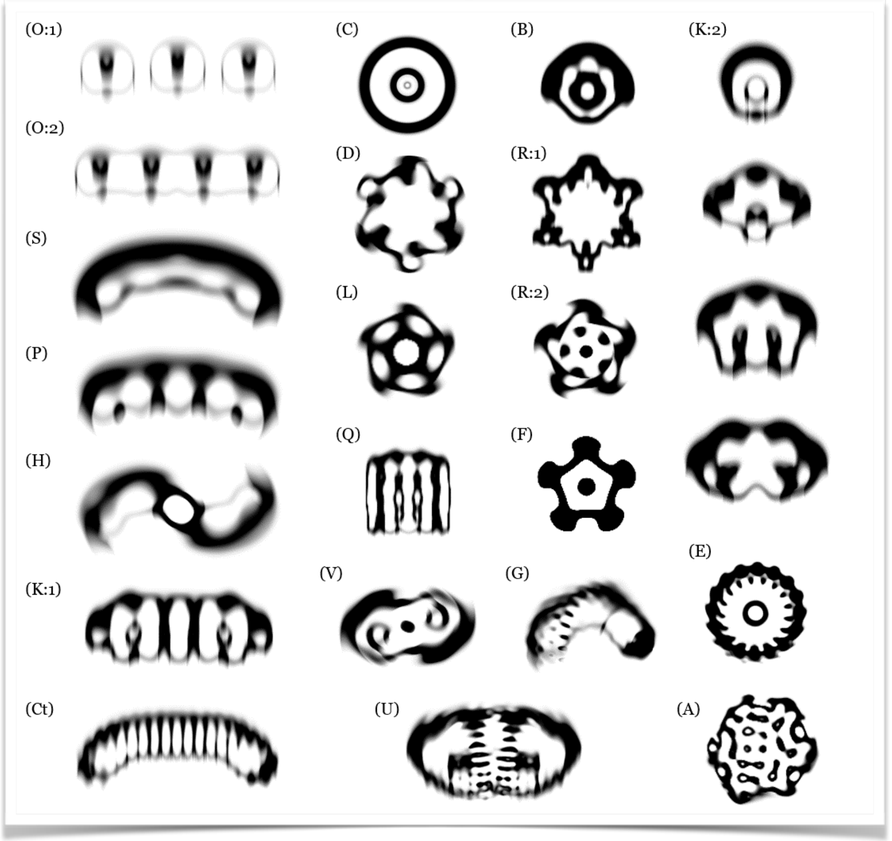
glider gun in Larger-than-Life

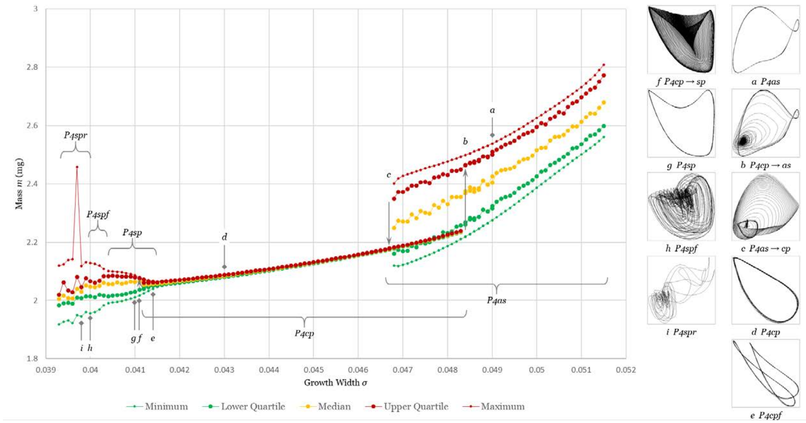


SmoothLife

Lenia (2015)

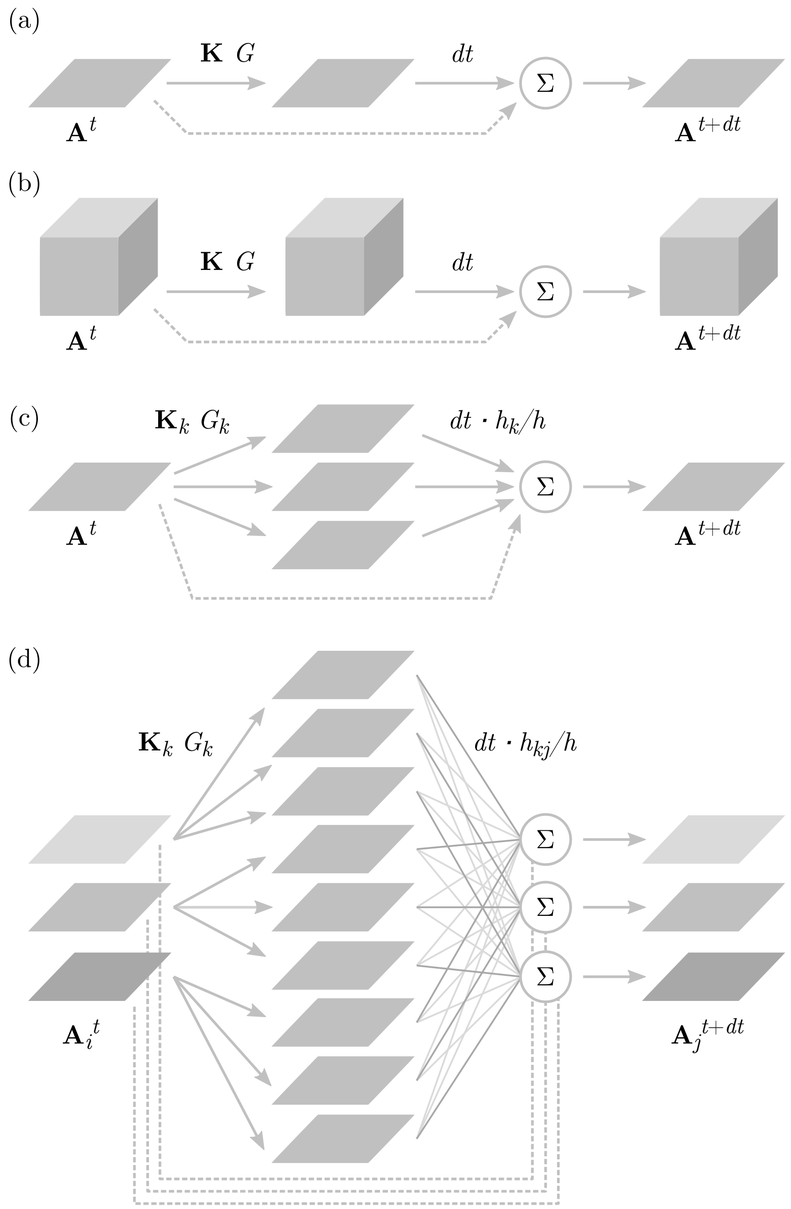
- Futher generalize the rule:
  - Convolution with **kernel**
  - Update using **smooth mapping**
- Highly **diverse** lifeforms (400+ species)
  - **Symmetric** structures & **regular** dynamics
  - Qualitative & quantitative studies
- Video — ALIFE 2018 Tokyo
- Paper — *Complex Systems*





Extended Lenia (2019)

- Further extensions:
  - 2D ➔ 3D or **higher dimensions**
  - Single neighborhood ➔ **multiple kernels**
  - Single grid ➔ **multiple channels**
- Exploding diversity
  - More **irregular** but **robust** lifeforms, more interesting phenomena
- Paper & Video — ALIFE 2020 Montreal



Characteristics of ALife systems

Complex Systems

- = system composed of **many interacting components**
- Characteristics: complexity, nonlinearity, self-organization, emergence, networks, dynamical, adaptation
  - **Complexity** = behaviors not easily inferred from system properties
  - **Nonlinearity** = "*the whole is **more than** the sum of its parts*"
- Examples: snow flakes, cities, ant colonies, many **ALife systems** (e.g. Lenia), **biosphere** (life), **brain** (intelligence)
  - Study one, know others better

Self-Organization

- = **spontaneous global order** arise from local interactions of components
- Characteristics:
  - Spatio-temporal patterns
  - Decentralized, distributed
  - Robust, self-repair from perturbations
- “**Anti-chaos**” = complex interactions → simple patterns
  - vs. chaos = simple interactions → complex patterns

Emergence

- = **irreducible property** arise from local interactions of components
- Characteristics:
  - Impossible to predict
  - "*The whole is ~~more~~ **other than** the sum of its parts*"
- Example: H (explosive gas) + O (burning gas) → H_2O (stable liquid)

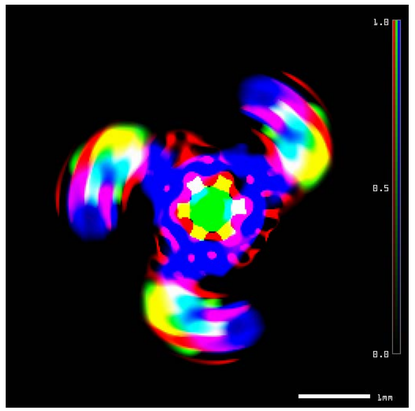
Emergence in Lenia

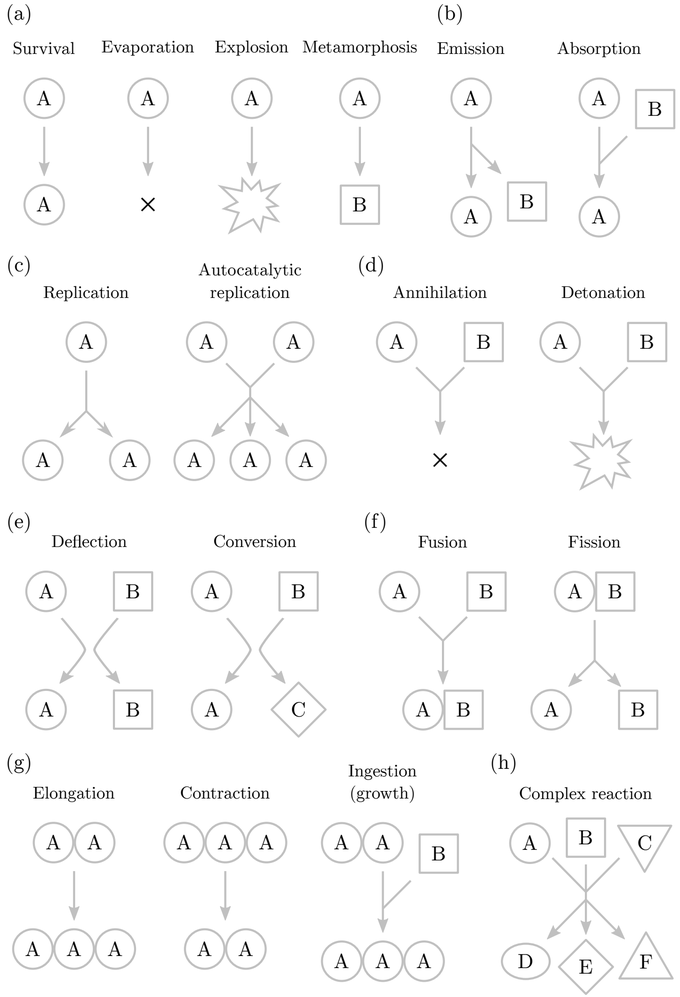
- Original Lenia:
  - **Morphogenesis**
  - **Dynamics**
- Multi-kernel:
  - **Individuality**
  - **Self-replication**
- Multi-channel:
  - **Division of labor**
  - **Polymorphism**
- Multi-dimensional:
  - **Polyhedral symmetry**
  - **3D physiology**

Emergence in Lenia

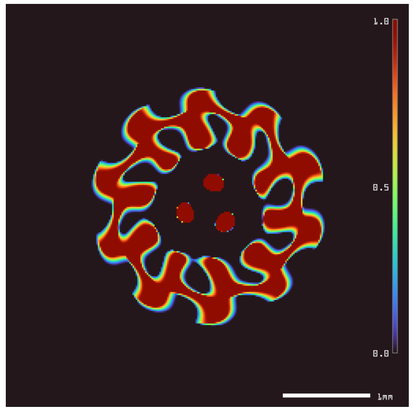
General Features

- Can group into **species** & higher orders by similarity
  - Species occupy an area in parameter space
- “**Analog**” structures (vs. “digitial” GoL patterns)
- **Plasticity** — resist changes & deformations
- Close relation b/t **symmetry & motility**
- Complex **interactions & reactions**

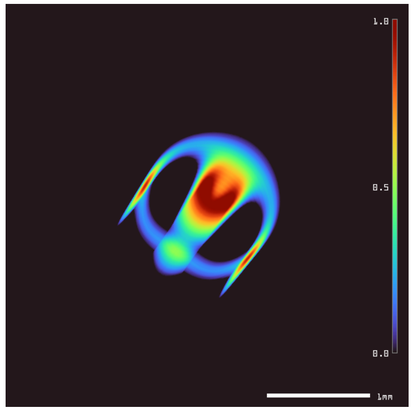




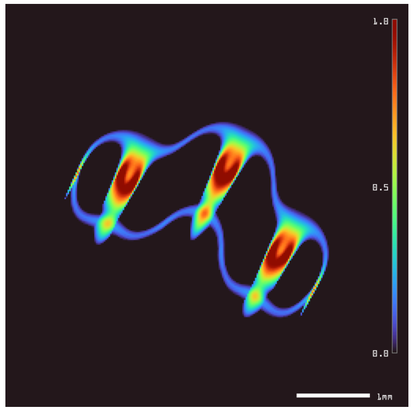
Morphogenesis



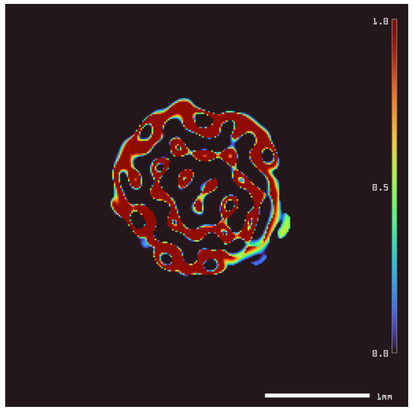
Radial



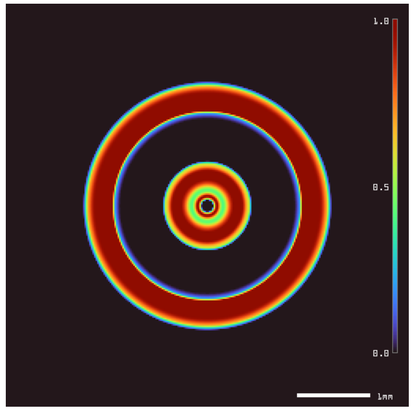
Bilateral



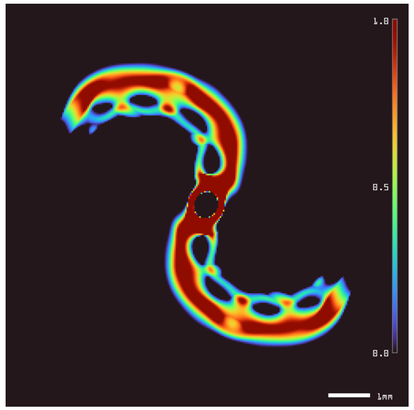
Combinatorial



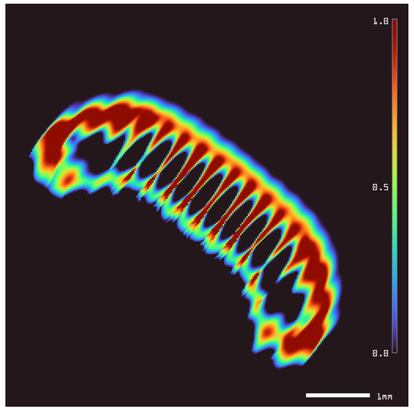
Irregular



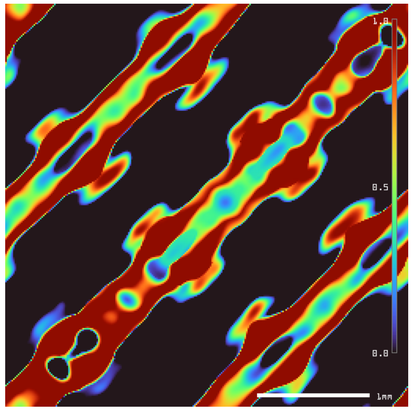
Spherical



Spiral



Linear

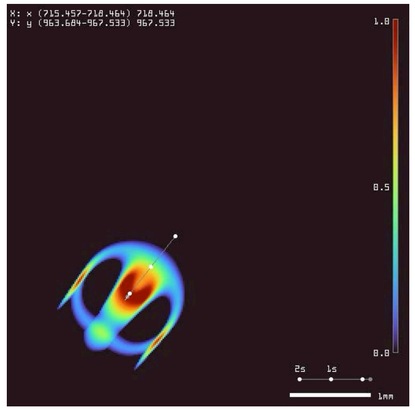


Distributed

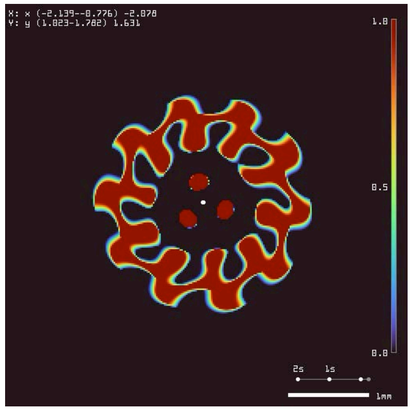
Symmetry

Structure

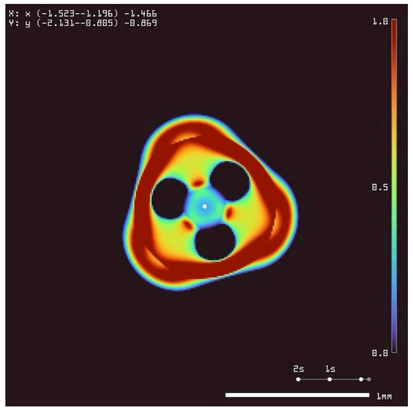
Dynamics



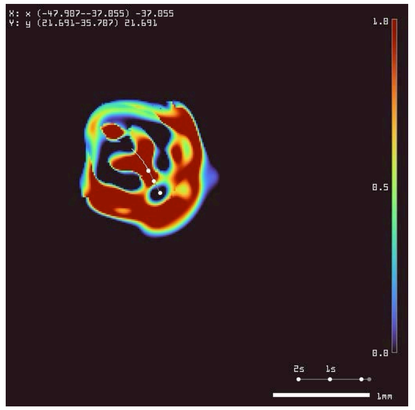
Linear



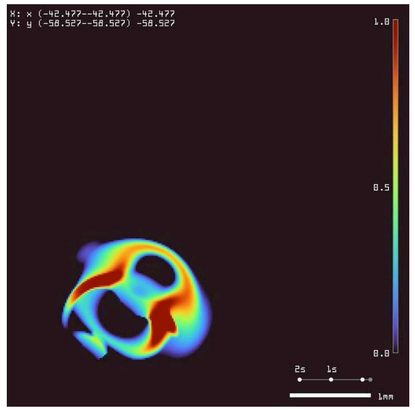
Rotating



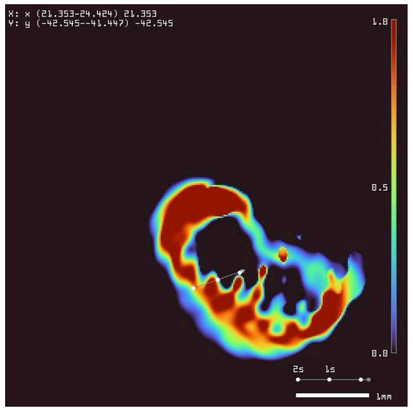
Oscillating



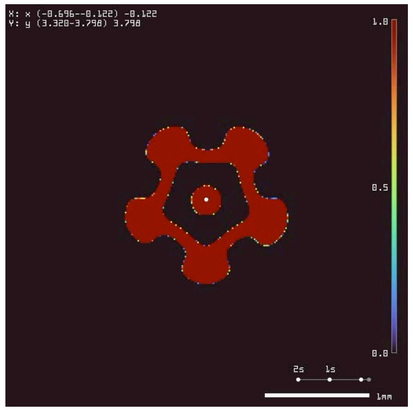
Chaotic



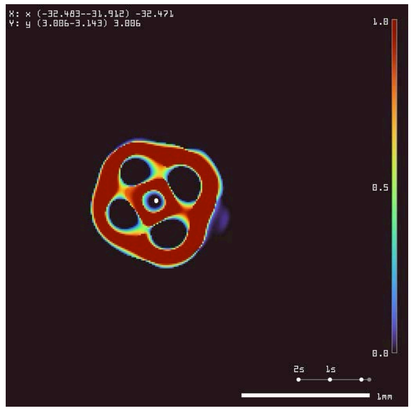
Zig-zag



Gyrating



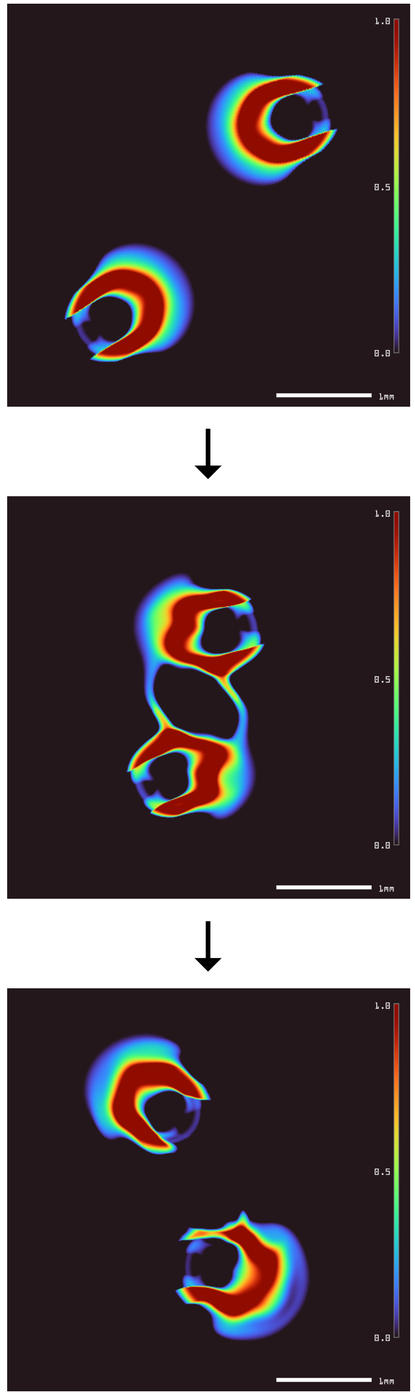
Stationary



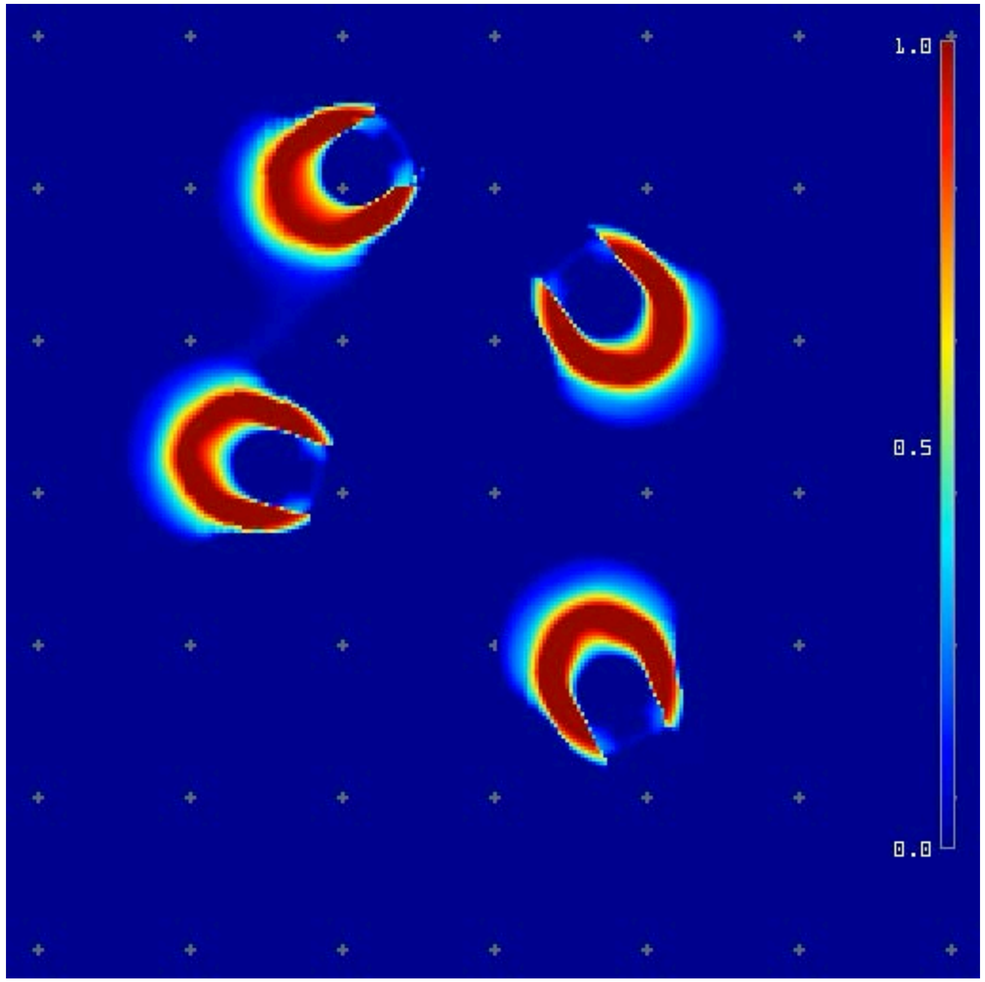
Metamorphosis

Individuality

- In extended Lenia, many lifeforms able to maintain **own boundaries**
  - Self-containment — stablize the lifeform
  - Self-defense — separate from environment or each other
- Become an **individual** or **agent**
  - Interact through attractive & repulsive “forces”
  - Enable **complex interactions**

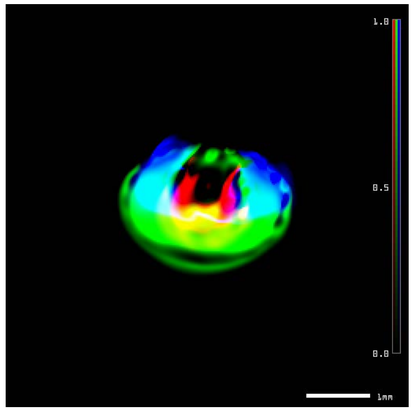


Individuality



Self-Replication

- Some lifeforms able to **reproduce**
  - usually by **binary fission**
  - **autocatalysis** (i.e. more reproductive when crowded)
- Self-replication + occasional death = healthy community



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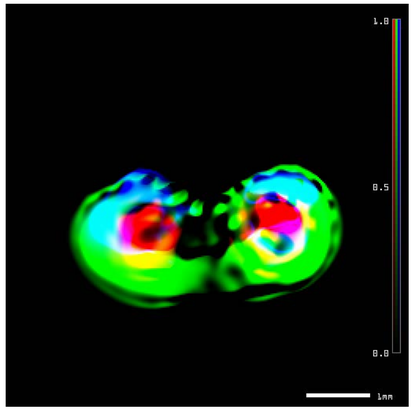
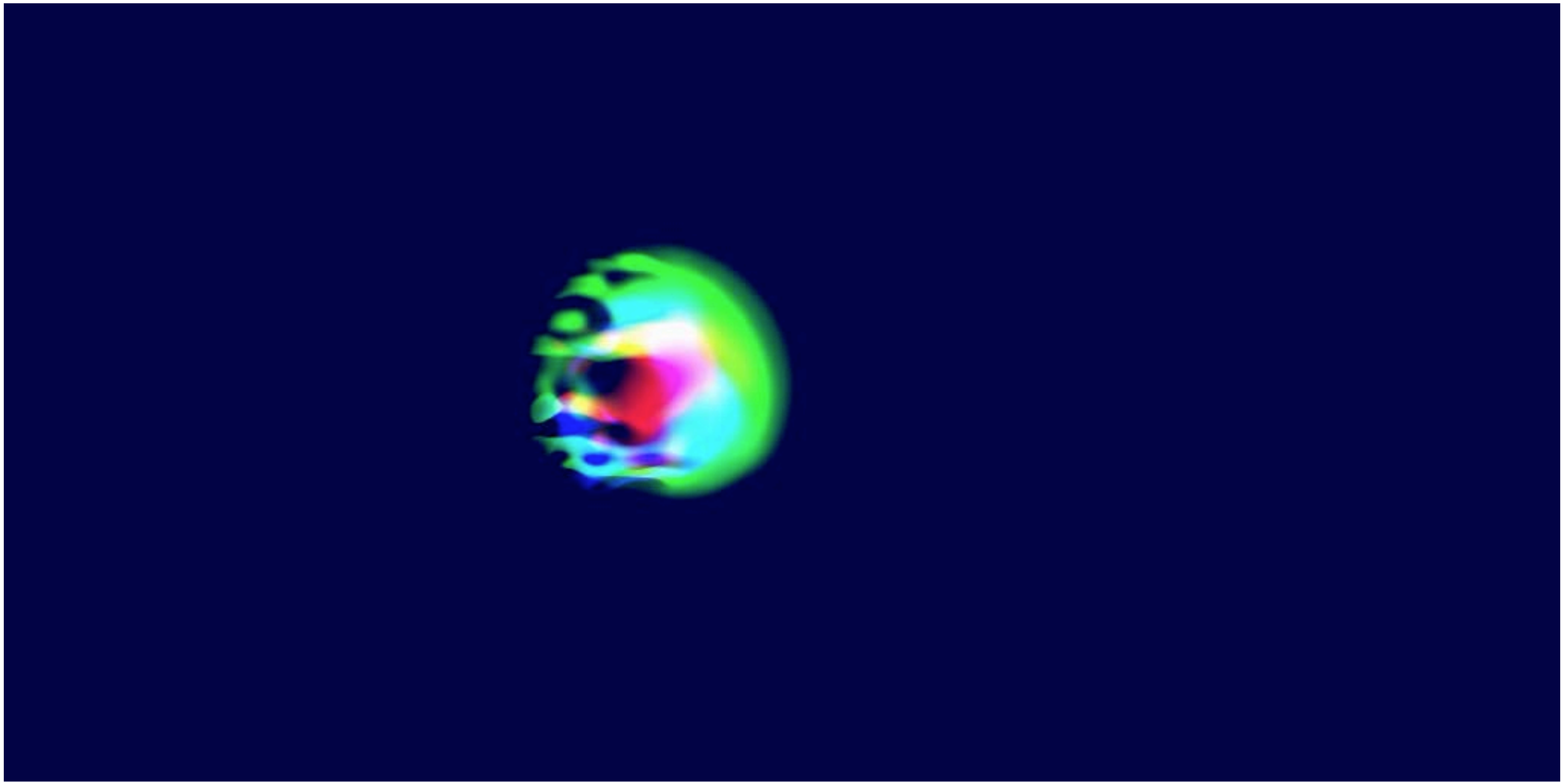
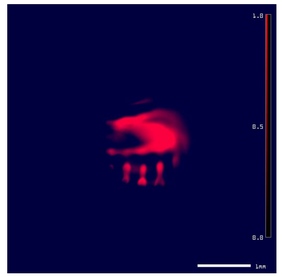


Self-Replication



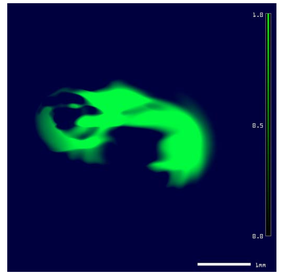
Division of Labor

- Parts coordinate to form an **aggregated, coherent** lifeform
- Parts occupy specific regions, may have **special roles**
  - Core (“nucleus”) — anchor for other parts
  - Body (“cytoplasm”) — extent of the lifeform
  - Director (“pseudopod”) — guide movements
  - Trailing part (“tail”)
  - Particles (“messenger”?)



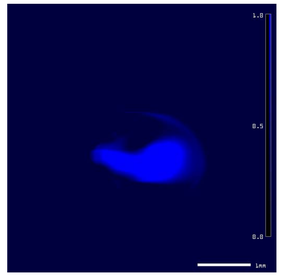
core

+



head+tail

+



body

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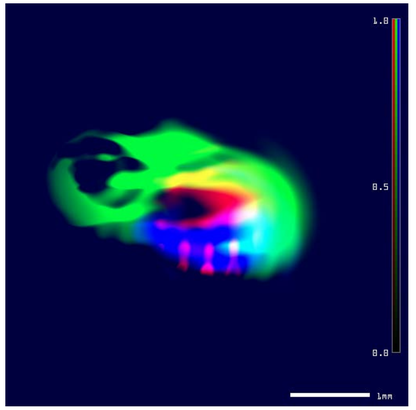
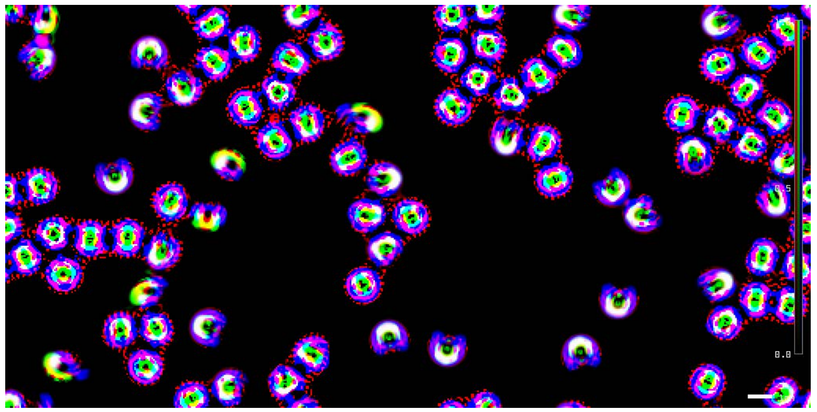
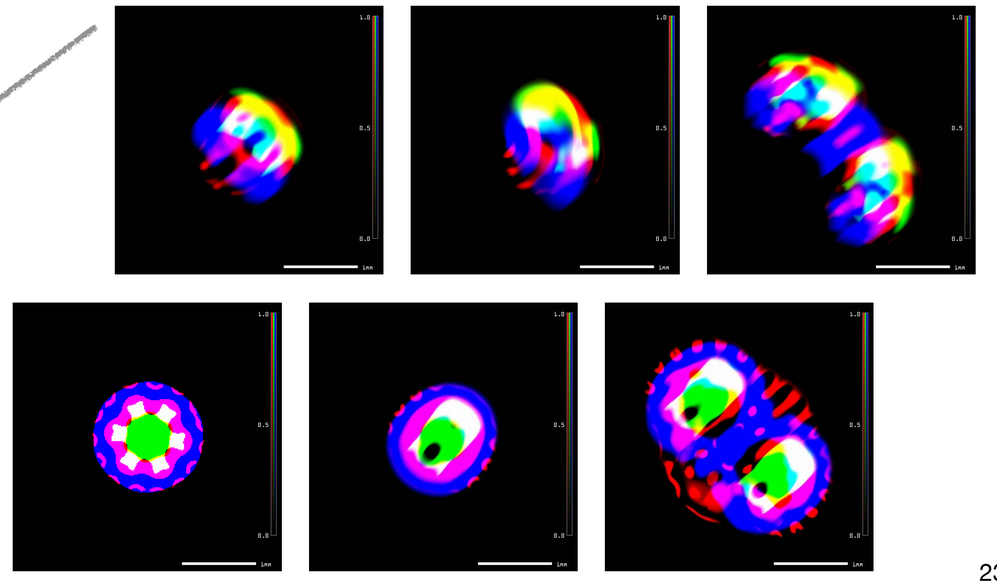


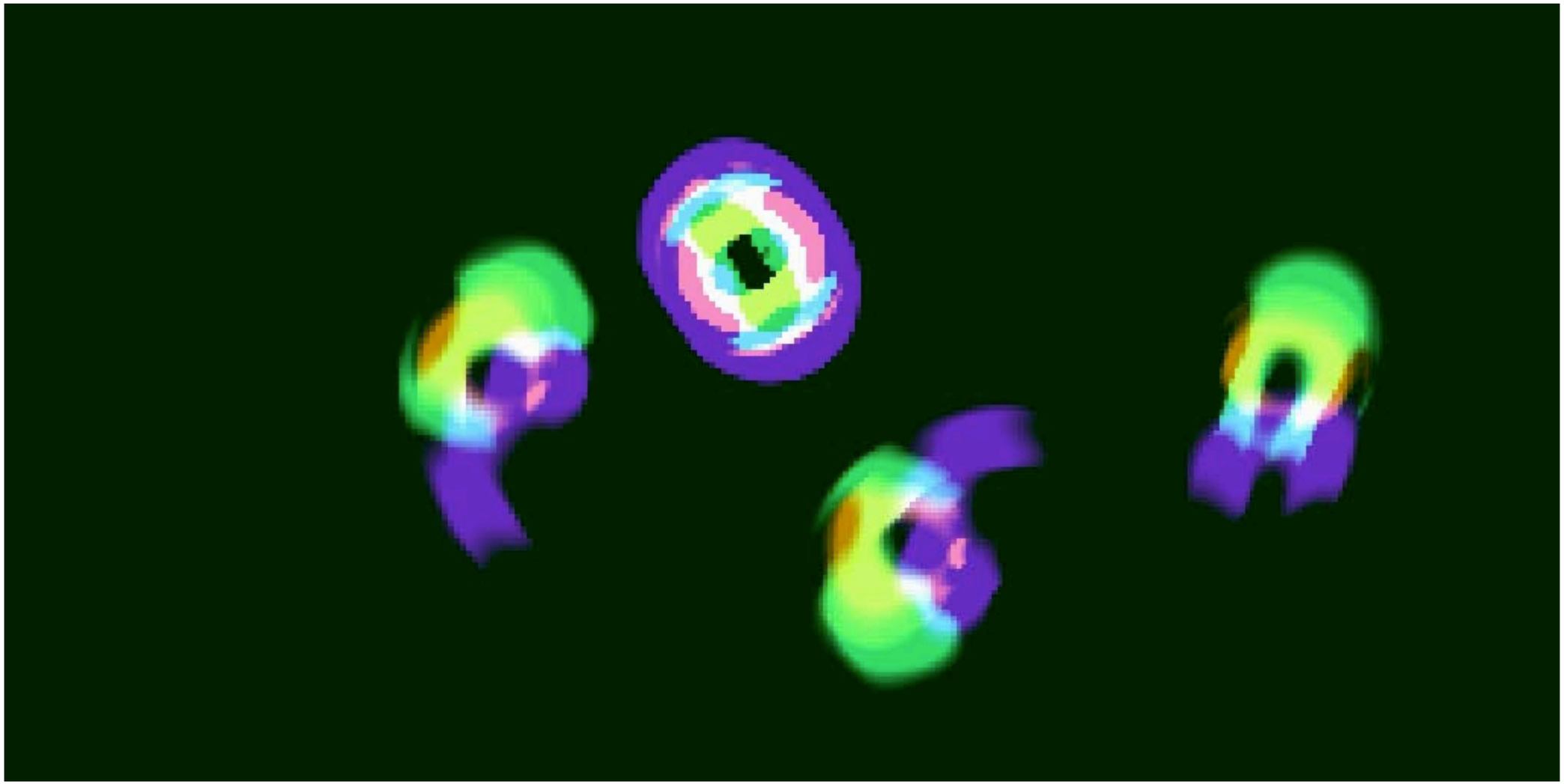
Polymorphism

- **Same genotype** (i.e. rule parameters) may produce **multiple phenotypes**
  - **Switch phenotype** — rearranging parts to reach stable configuration
  - **Group level behaviors**
    - reproducing phenotype = colony of growing population
    - immobile phenotype = tissue-like colony

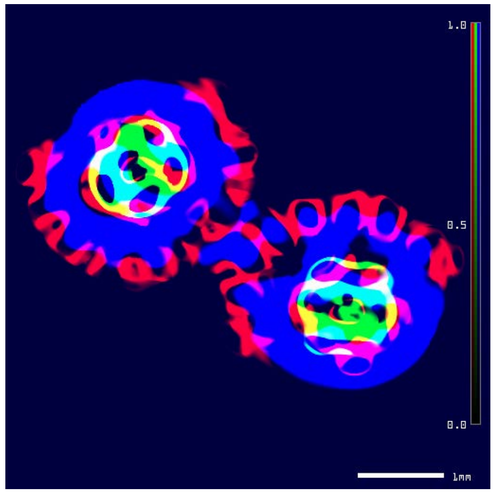




Polymorphism

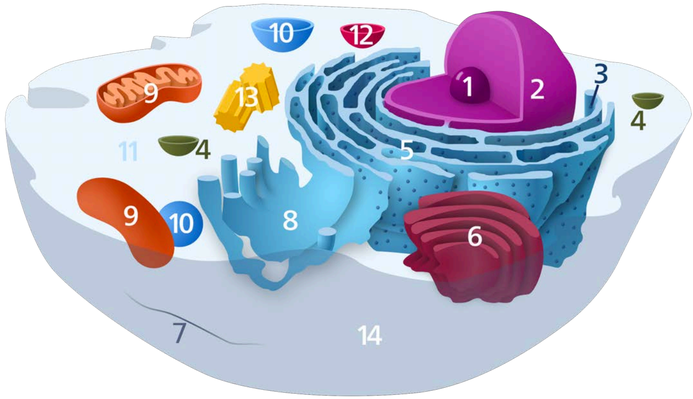


“Virtual Eukaryotic Cells”



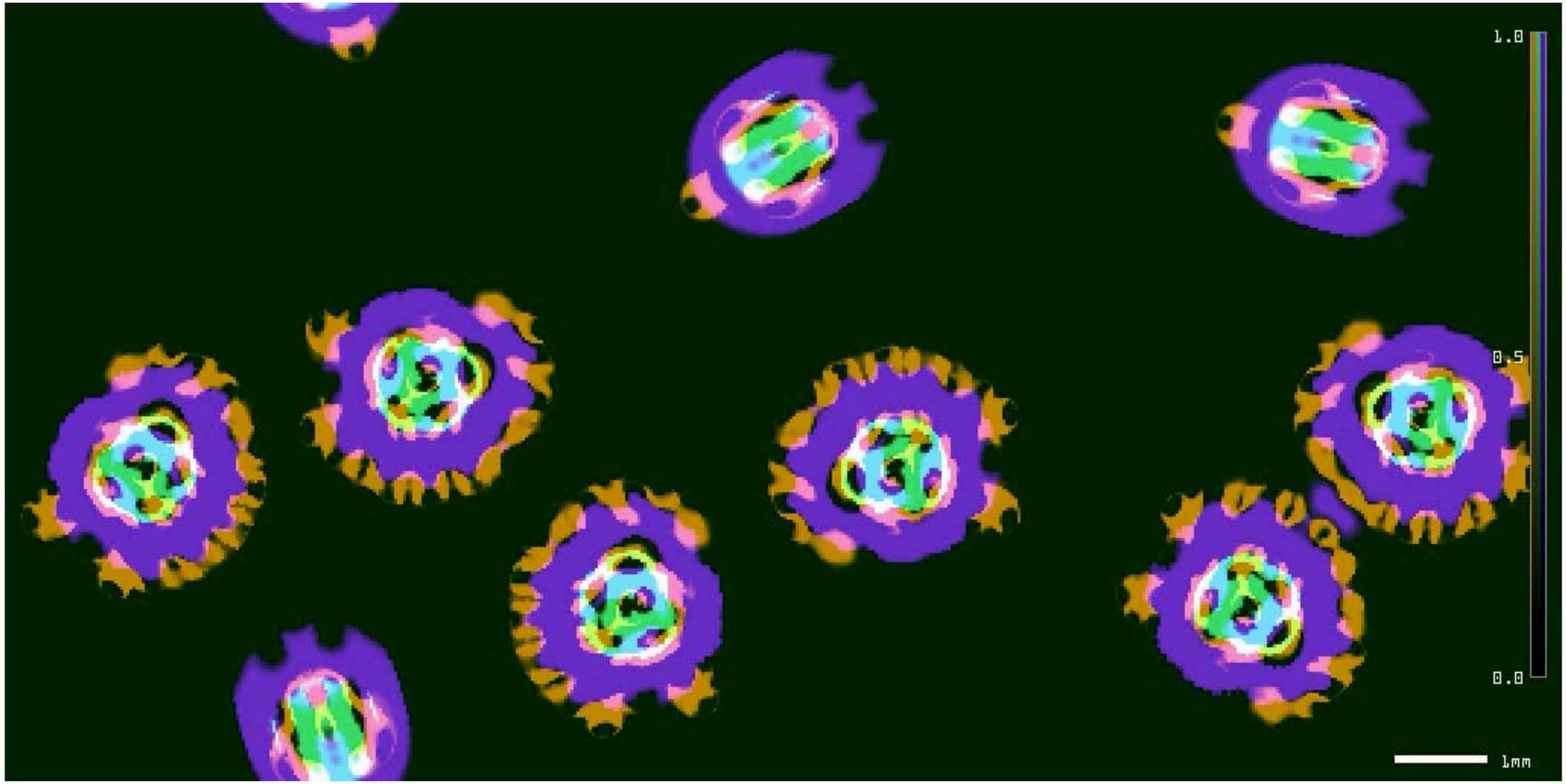
= advanced virtual lifeforms with emergent properties:

1. Individuality with self boundary (“**cell membrane**”)
2. Internal division of labor (“**organelles**”)
3. Phenotypic polymorphism (“**cell differentiation**”)
    - various attributes: moving, stable, reproducing, etc.
4. Megastructure formation (“**multicellularity**”)
5. Cell-cell communication (??)



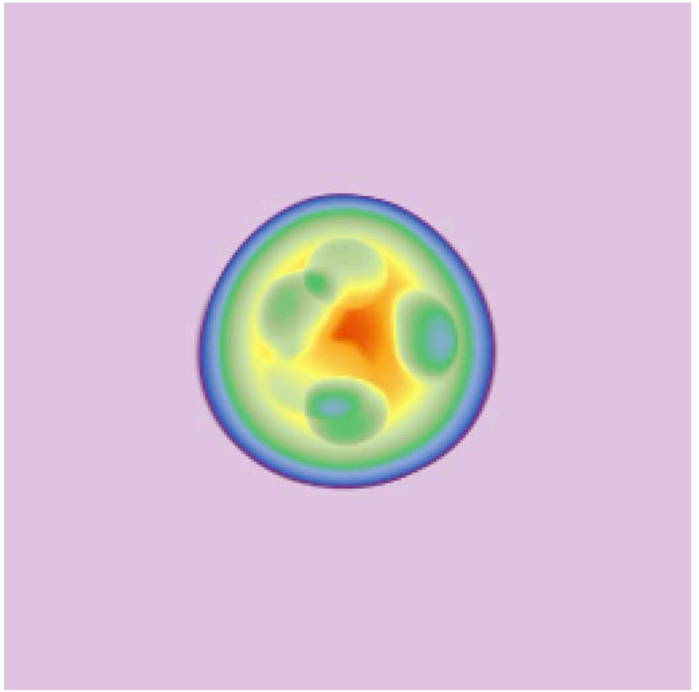
Wikipedia

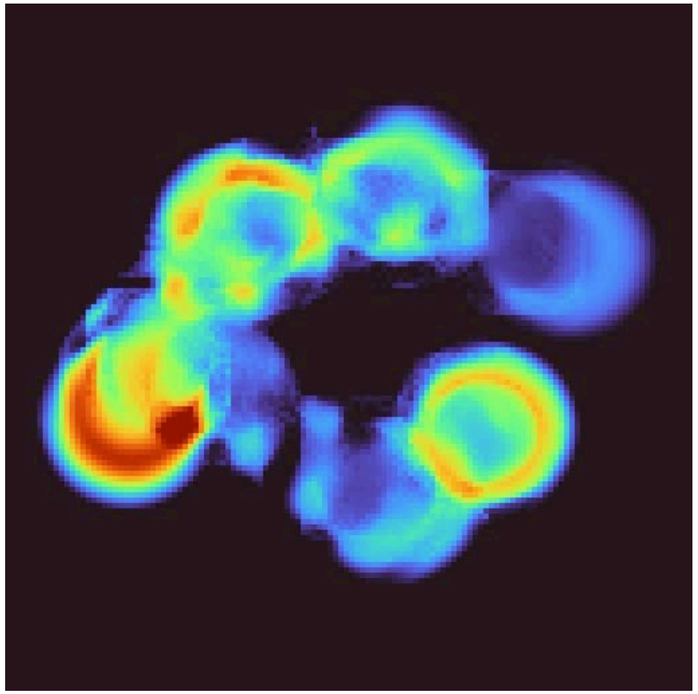
“Virtual Eukaryotic Cells”



3D Structures

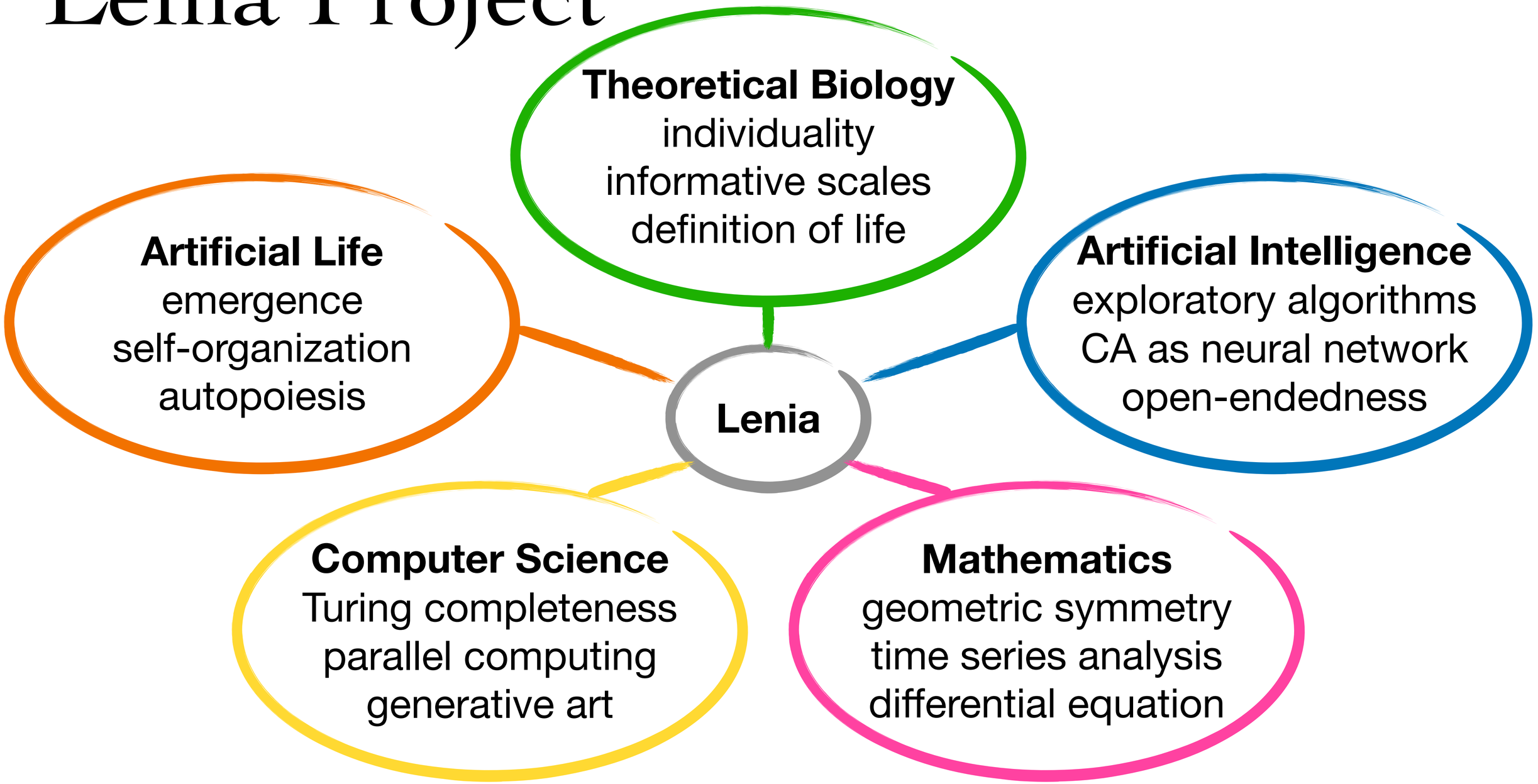
- 3D: Spherical and **polyhedral symmetries**
  - Analogous to radial symmetries in 2D
  - Internal structures arranged in tetrahedron / bipyramid / icosahedron etc.
- 3D creatures with **interesting physiology**
  - e.g. Snake 3D™ grows by ingesting dots
- 4D: simple **hyperspheres** so far



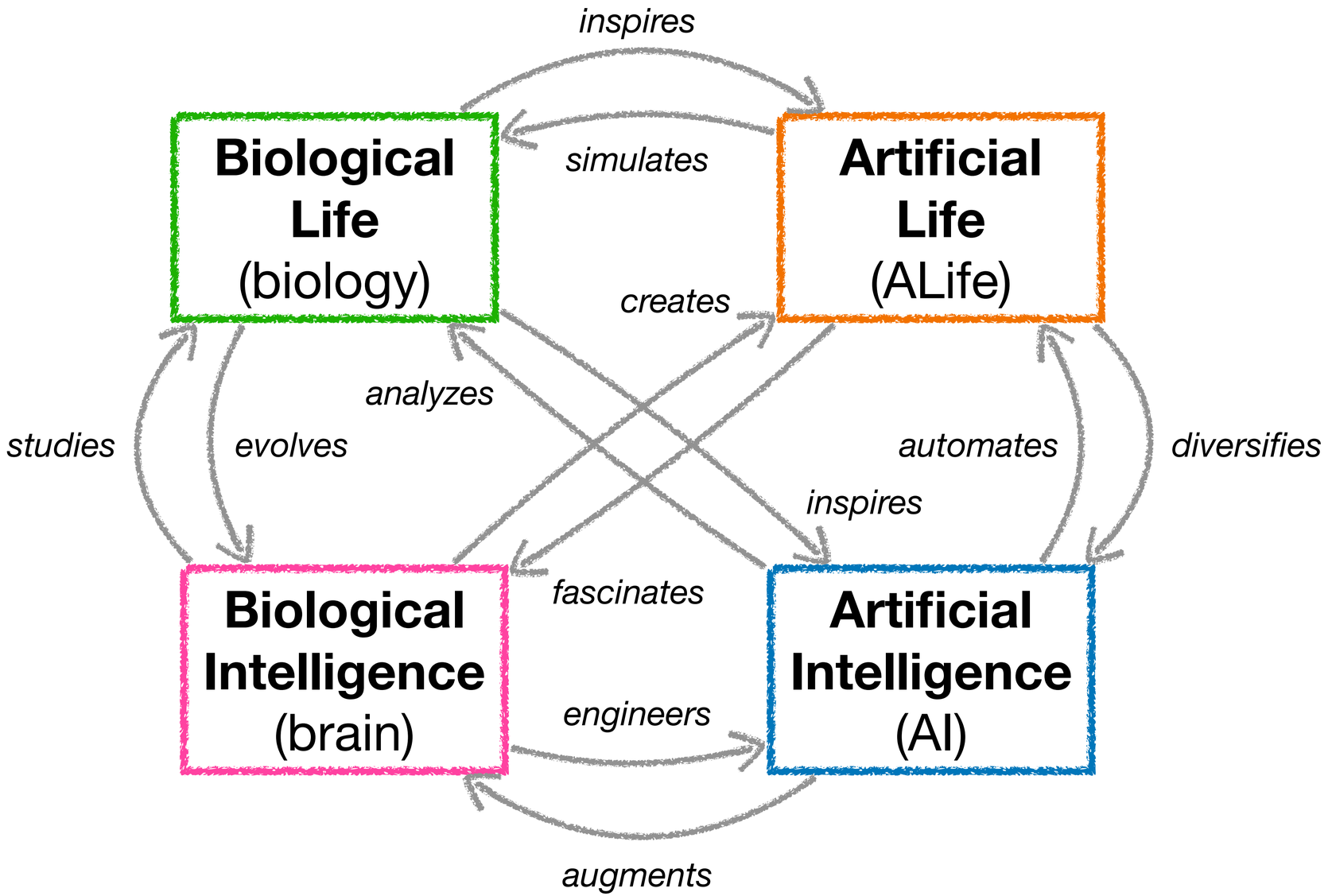


ALife and AI

Lenia Project



Connections of Life & Intelligence

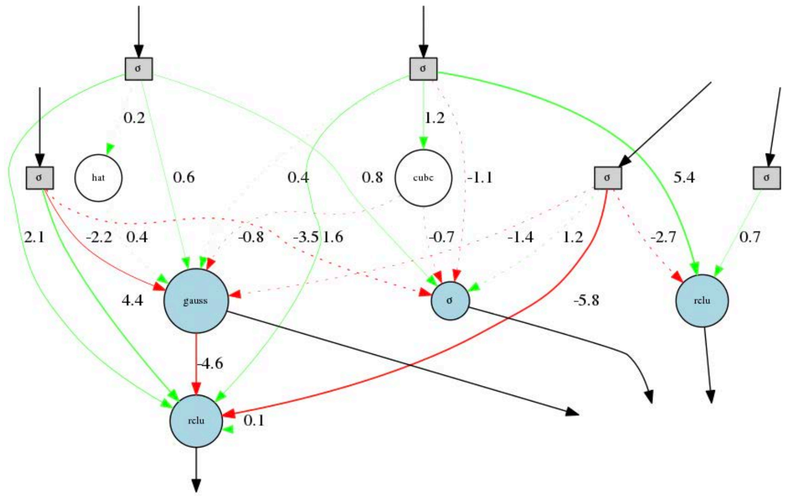


ALife & AI

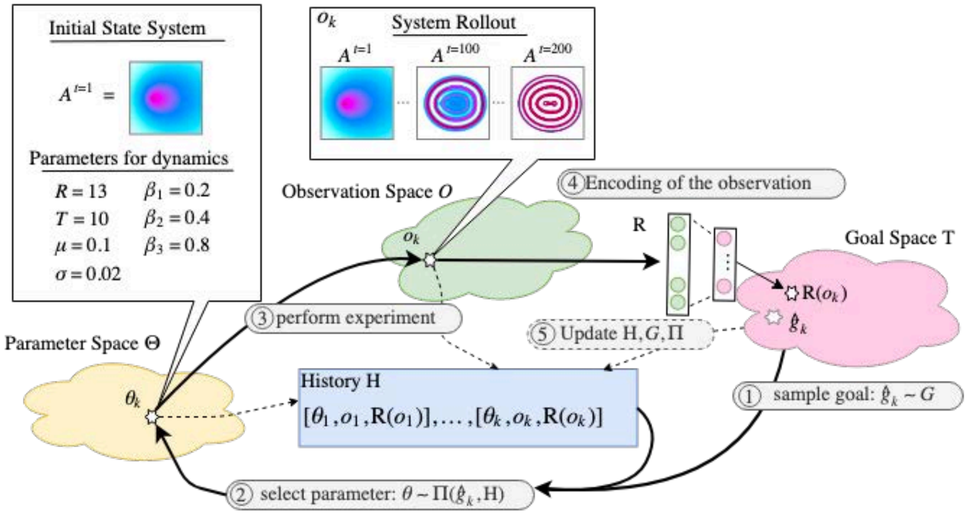
- **Apply AI on ALife**:
  - Lenia as a playground for AI methods
  - Exploratory algorithms & genetic algorithms
  - Pattern recognition, encoding, generation (e.g. VAE, CPPN, GAN, Neural ODE)
- **From ALife to AI**:
  - Lenia’s architecture as a neural network
  - Open-ended evolution

Exploratory Algorithms

- **Genetic algorithm** to discover new lifeforms
  e.g. [T Arita @NagoyaU]
  - minimum criterion: survival
- **Curiosity-driven** algorithms
  e.g. IMGEP [PY Oudeyer @Inria]
- **Novelty search** algorithms
  e.g. quality diversity [KO Stanley @OpenAI]
- **Neuroevolution** to evolve architecture
  e.g. CA-NEAT [S Nichele]



result network in CA-NEAT

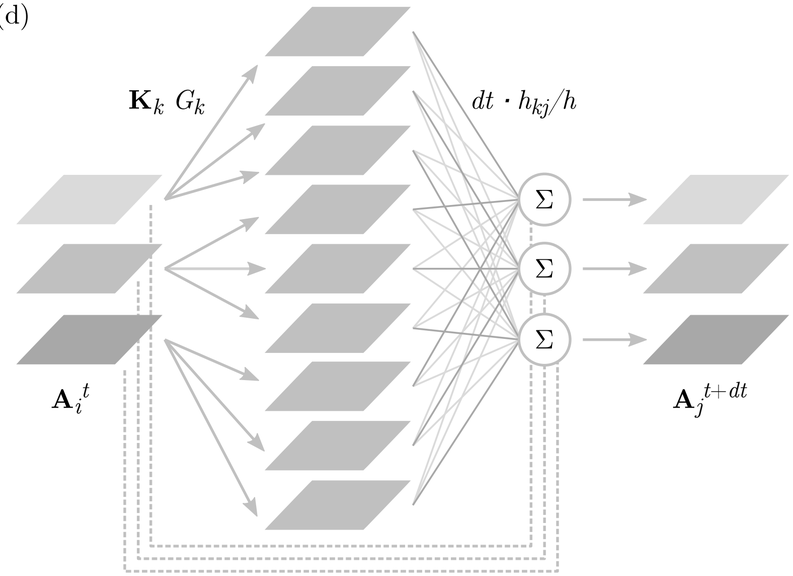


IMGEP algorithm

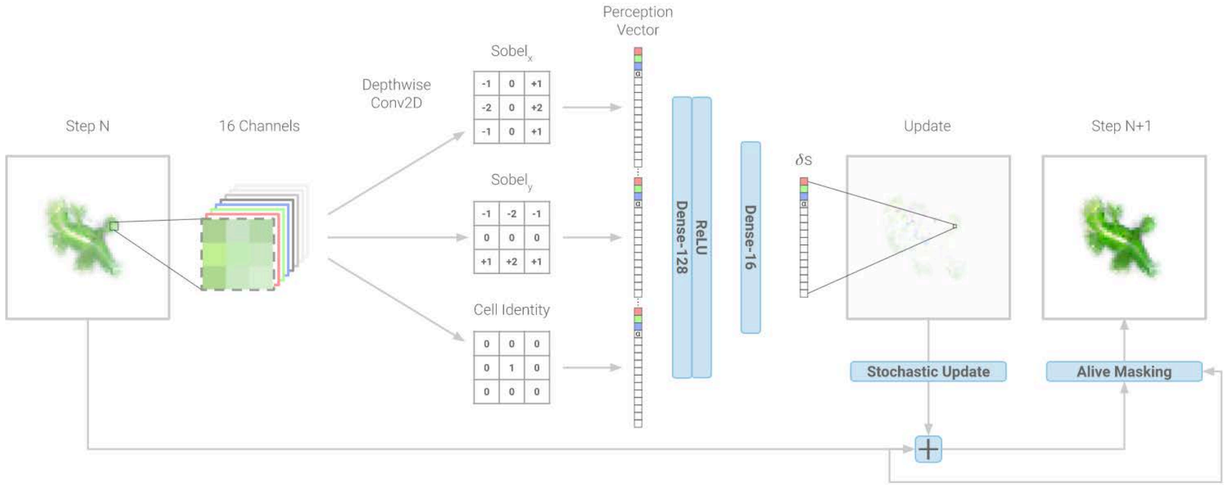
doi:10.1109/TCDS.2017.2737082
developmentalsystems.org

CA as Neural Network (d)

- Latest architecture approaches “Recurrent Residual Convolutional Neural Network” (RRCNN)
  - is **evolvable** (neuroevolution)
  - perhaps **trainable** (back-prop)
  - what would be the loss function?
- cf. **Neural CA**: back-prop through CA [A Mordvintsev @Google]



extended Lenia architecture

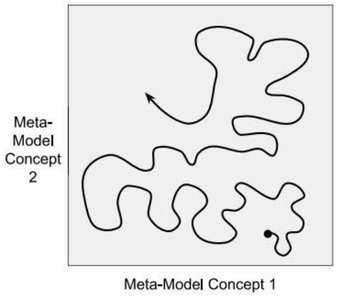


Neural CA architecture

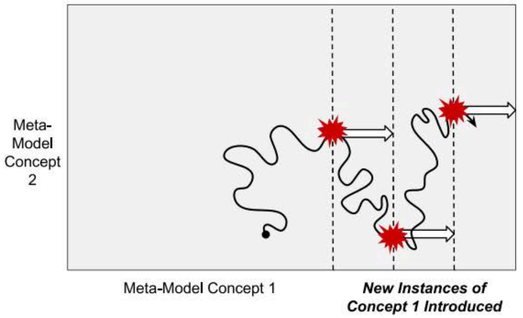
doi:10.23915/distill.00023

Open-Ended Evolution

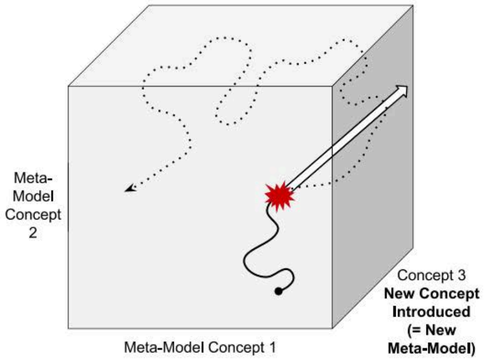
- = single process generates infinite complexity forever
- Routes to OEE [T Taylor] (cf. in Lenia):
  - Exploratory (small mutations), expansive (door-opening species), transformational (extensions)
- Maybe an important component to **AGI**
  [KO Stanley @OpenAI, T Mikolov @CTU]



(a) Exploratory Open-Endedness



(b) Expansive Open-Endedness



(c) Transformational Open-Endedness

doi:10.1162/artl_a_00290
oreilly.com/radar/topics/ai-ml

Life & ALife

- Emergence of **individuals / agents** & **macro-scale** colonies
  - How to quantatively recognize individuals & macro-scales?
  - Use **information theory** [G Tononi, E Hoel, D Krakauer]
- Higher levels of emergence × exploding diversity = open-ended evolution?
- Creating life phenomena **from scratch**
  - Implications to astrobiology & origin of life?

Nautilus/Gracia Lam

Thank you

chakazul.github.io/lenia