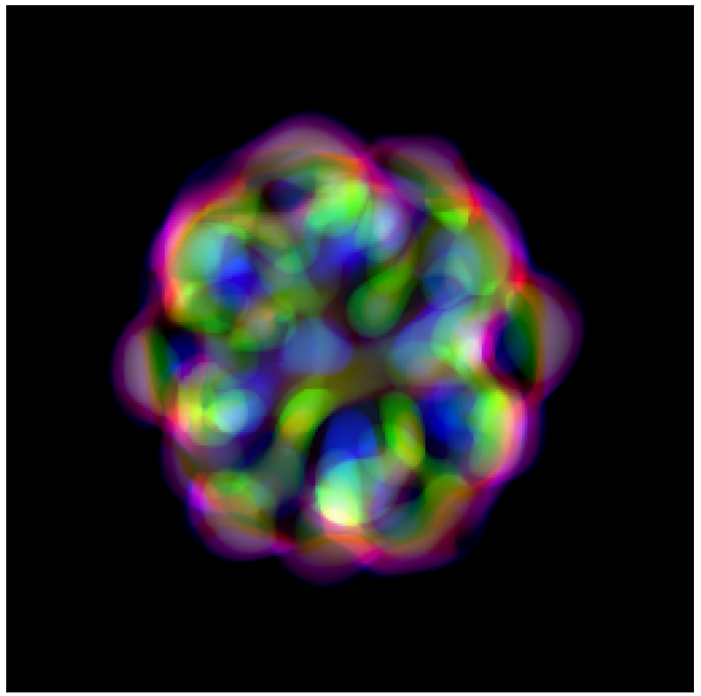
Lenia and Expanded Universe

Model extensions and new findings in continuous cellular automata



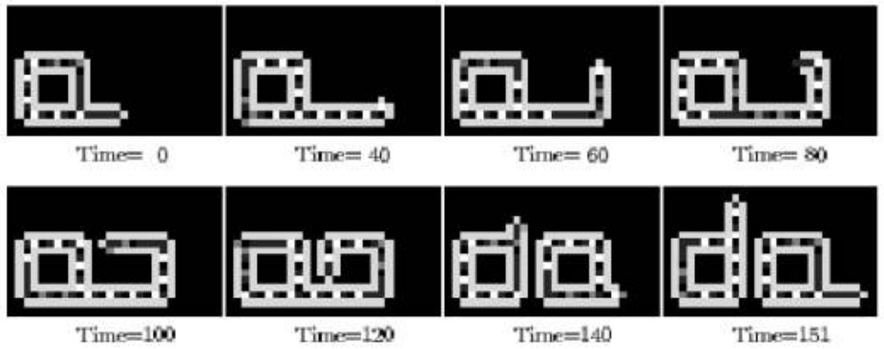
Bert Chan

Independent researcher @ Hong Kong

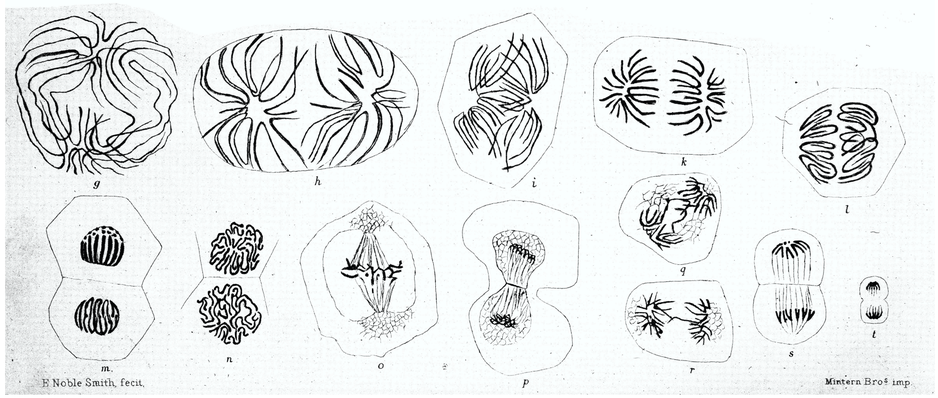
ALIFE 2020, July 16 Thu, 21:00 EDT

How life-like can artificial life be?

Which life phenomena can be observed in ALife?

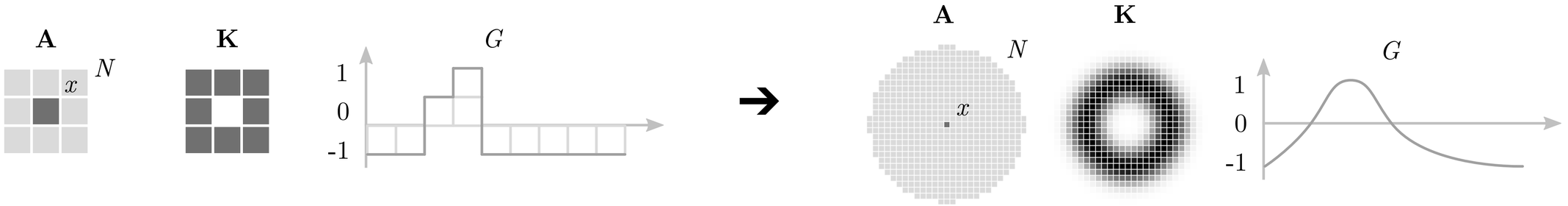


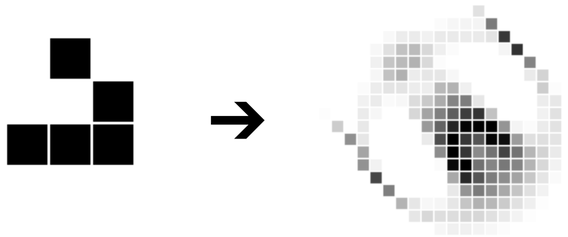
http://sjsu.rudyrucker.com/~shruti.parihar/paper/



Wellcome Images via Wikipedia

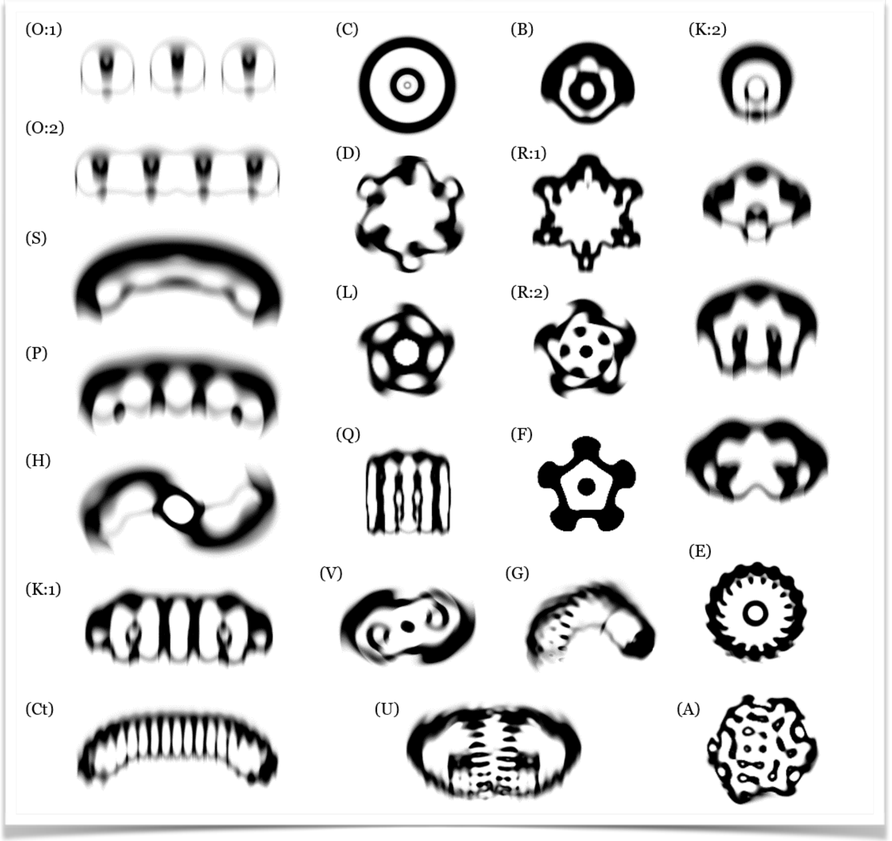
CA: From Discrete to Continuous

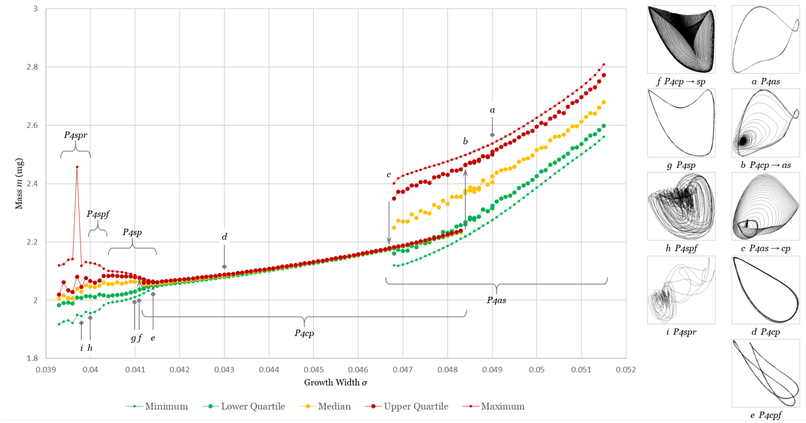


- Start from cellular automata: Conway's Game of Life
  - 0/1 values ➔ Real values (**continuous states**)
  - 8-cell neighborhood ➔ Long-range, circular (**continuous space**)
  - Neighbor count ➔ Weighted sum (i.e. convolution with kernel)
  - Lookup rule, update ➔ Smooth mapping, incremental (**continuous time**)
  - 

Study of Lenia

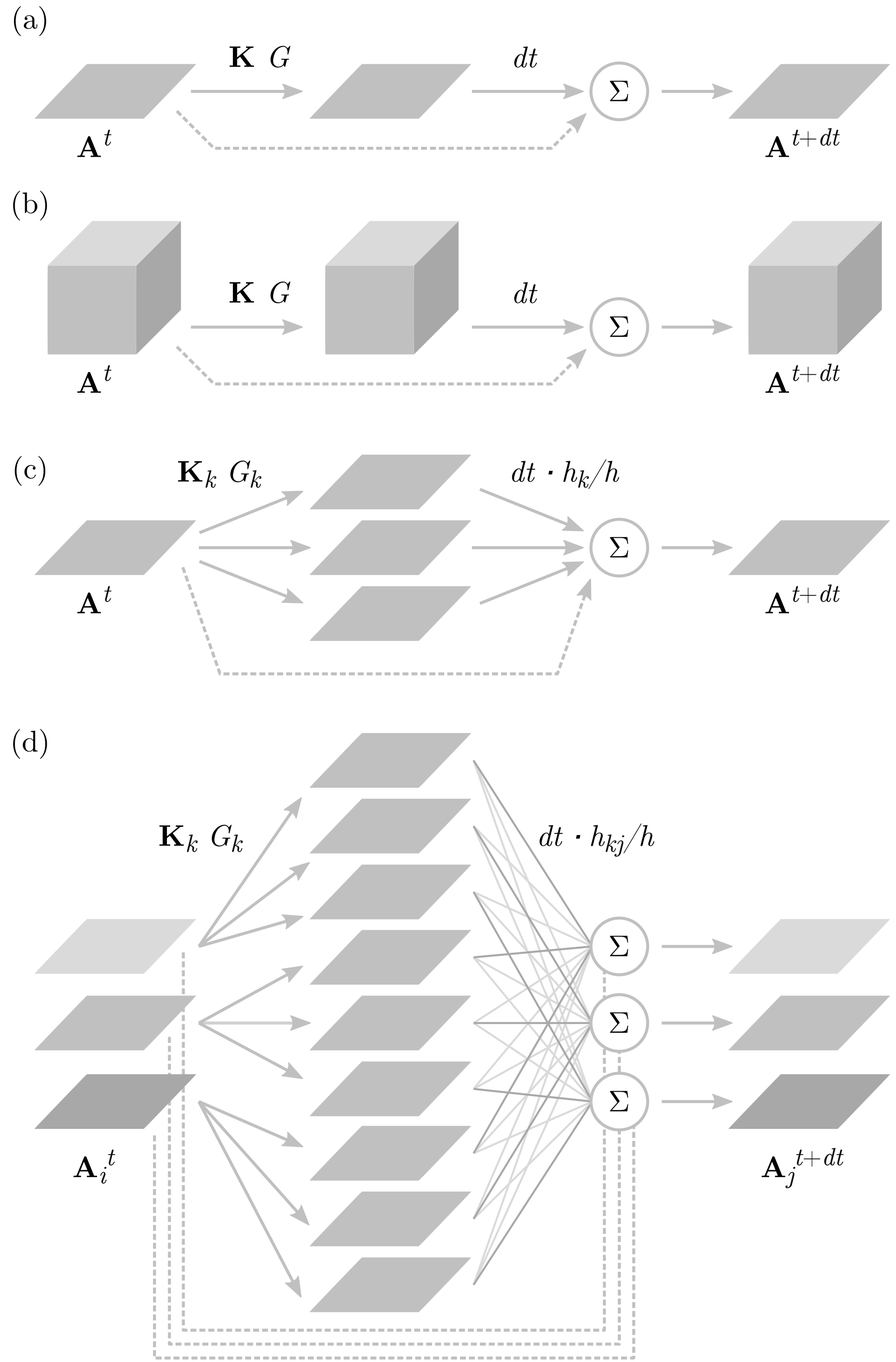
- Continuous CA called “Lenia”
- Self-organizing geometric lifeforms
  - Highly **diverse** (400+ species)
  - **Symmetric** structures (some irregular)
  - **Regular** dynamics (some chaotic)
  - Explore parameter & behavior space
- Video — ALIFE 2018 Tokyo
- Paper — *Complex Systems*





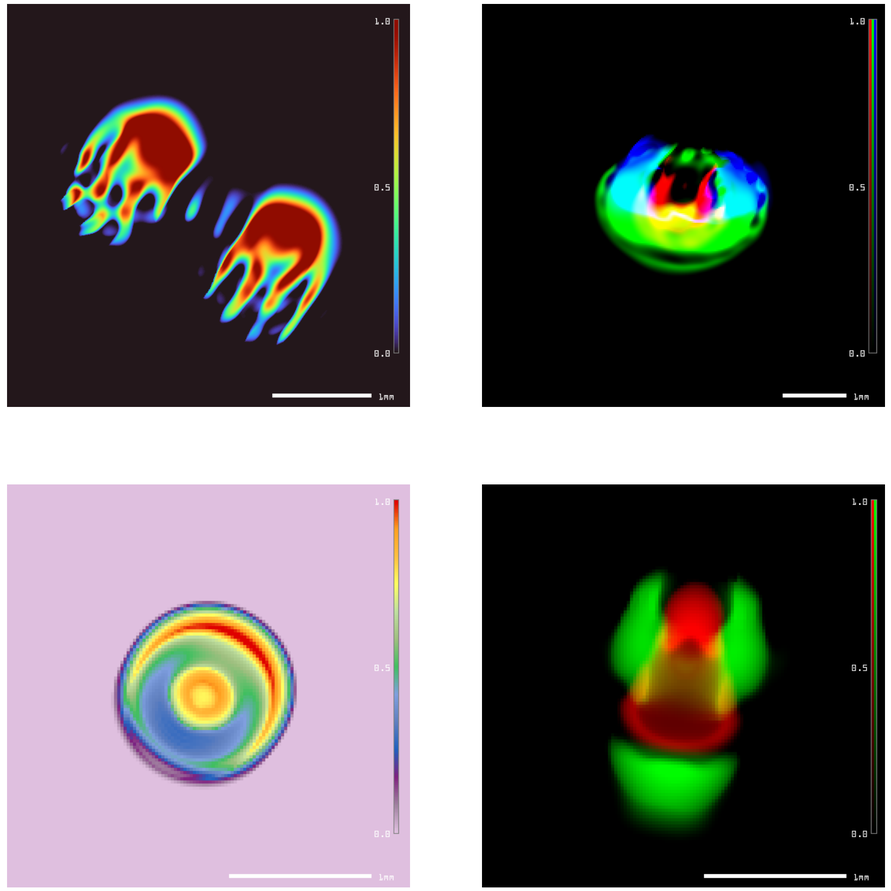
Extend the Rules

- Original rule: World → convolution & mapping → incremental update → next time step
  - 2D world ➔ 3D or **higher dimensions**
  - Single convolution kernel ➔ **multiple kernels**
  - Single world ➔ **multiple channels**
- Architecture approaches a neural network (!)
  - “Recurrent Residual Convolutional Neural Network” (RRCNN)



New Lifeforms

- Exploding diversity
  - Unfathomable parameter & behavior space
  - Use **semi-automatic search** e.g. GA
  - Selection criterion: survival
- More **irregular** structures & **chaotic** dynamics, but…
- More **robust** self-organization! More **complex** morphogenesis!

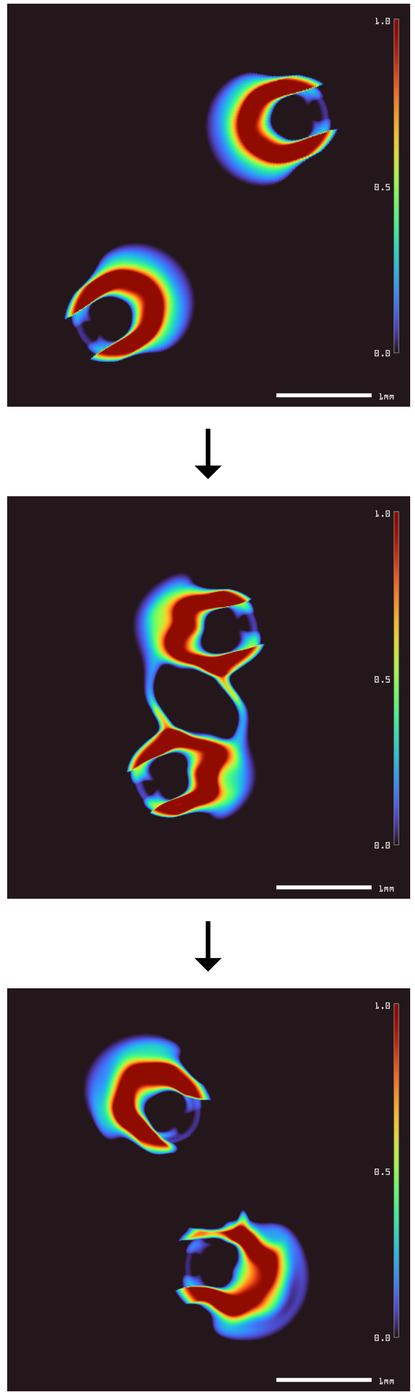


New Emergent Phenomena

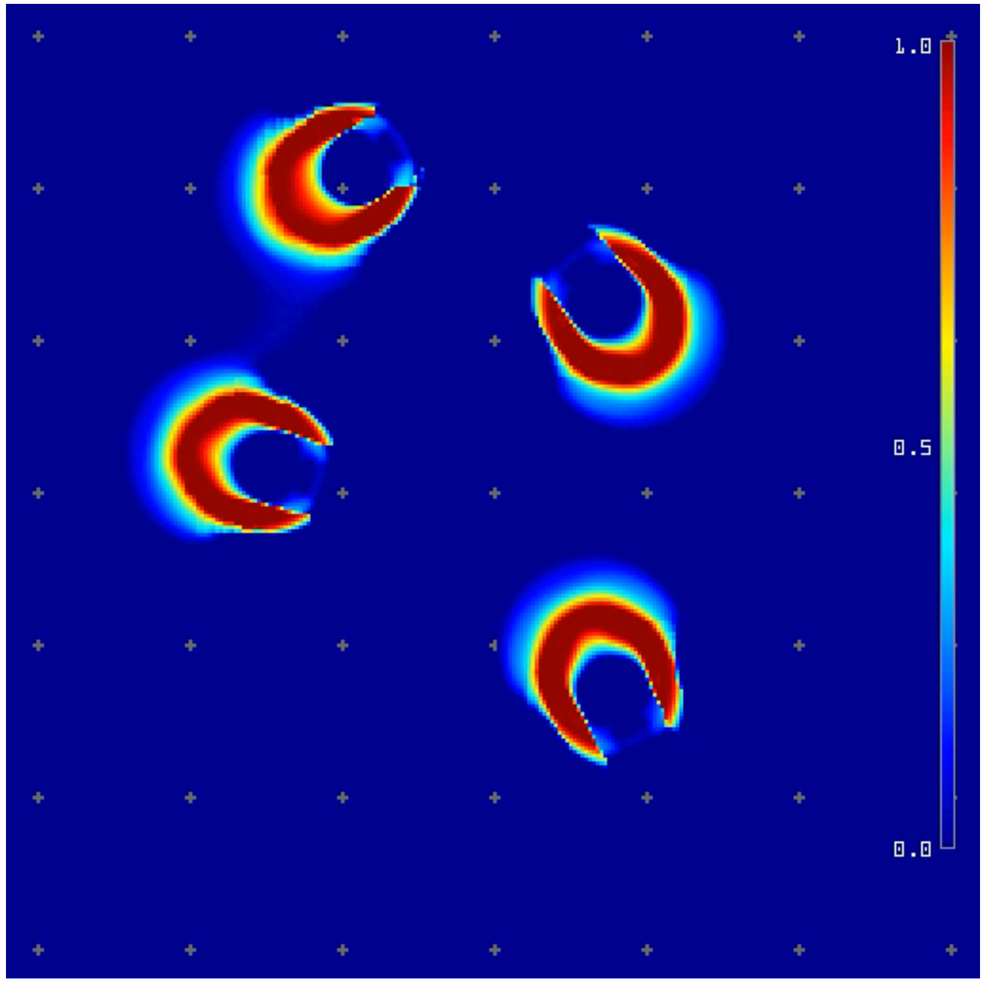
- Multi-kernel leads to
  - **Individuality**
  - **Self-replication**
- Multi-channel leads to
  - **Division of Labor**
  - **Polymorphism**
- Higher dimensions leads to
  - **Polyhedral symmetry**
  - **3D physiology**
- Currently: observations, examples
- Future: systematic experiments, quantitative analysis, theory building

Individuality

- Original Lenia: lifeforms mix up when collide
- Extended: 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”
  - Capable of **complex interactions** & **reactions**

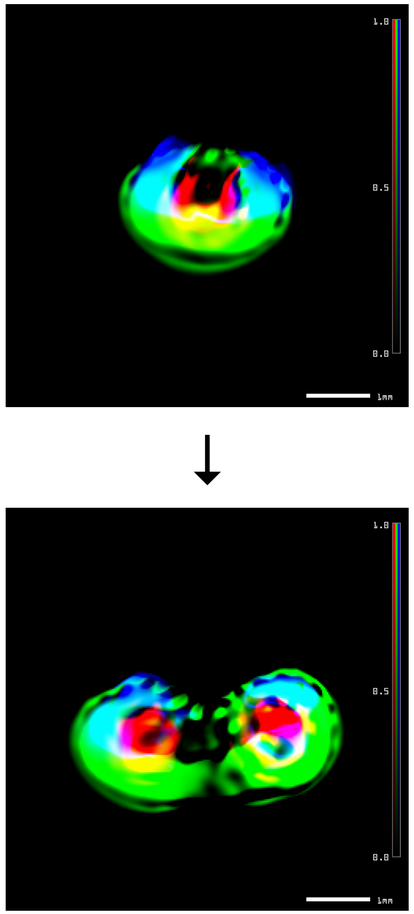


Individuality

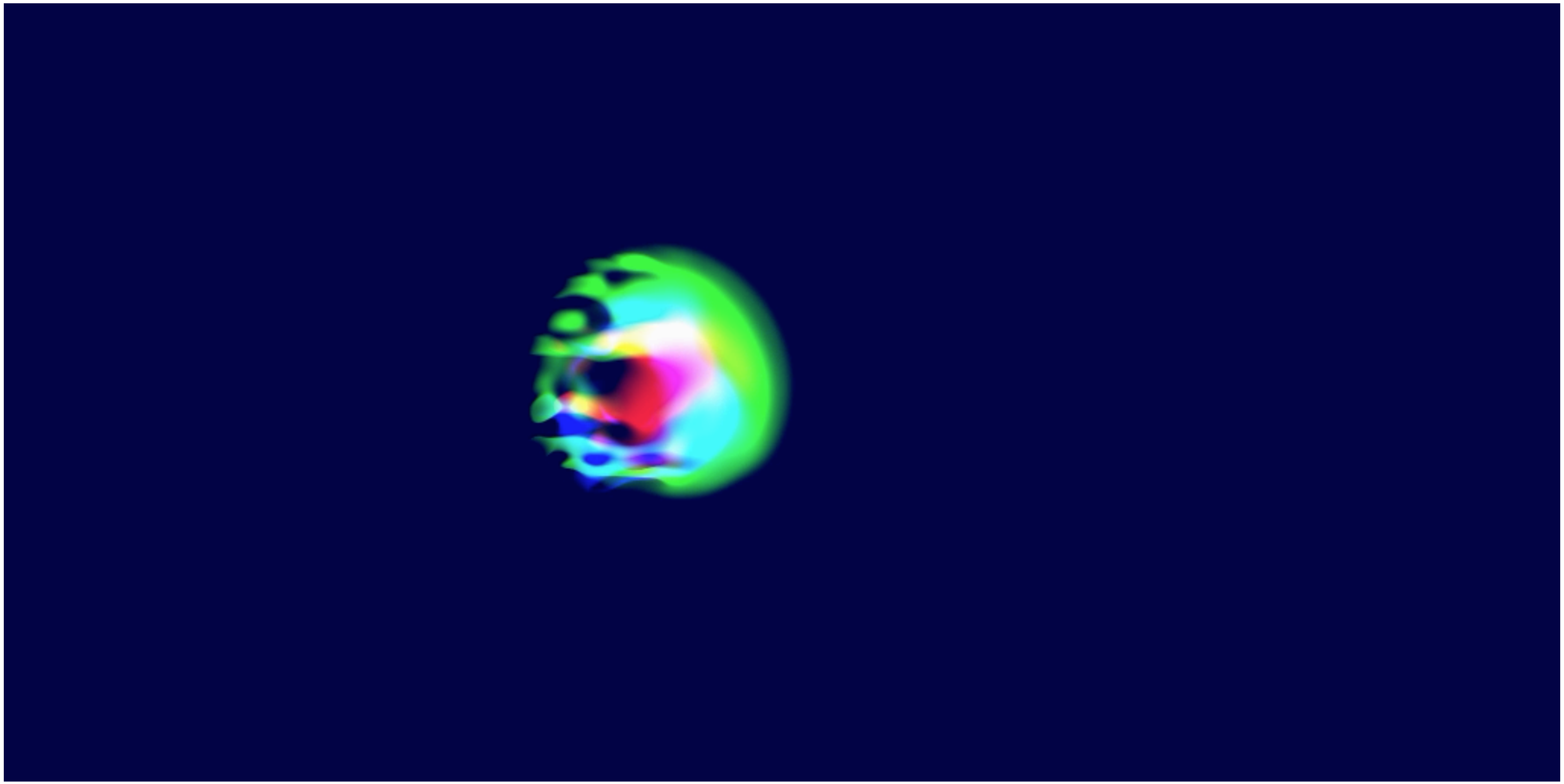


Self-replication

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

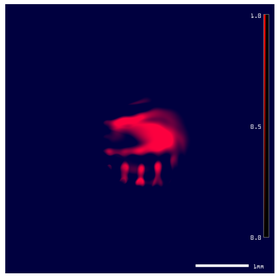


Self-replication



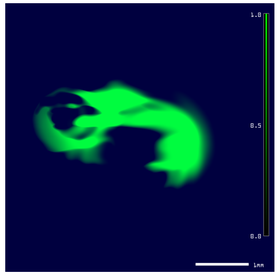
Division of Labor

- Multi-channel 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”?)



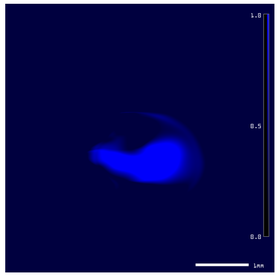
core

+



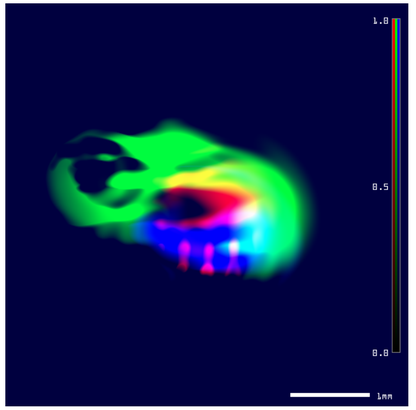
head+tail

+



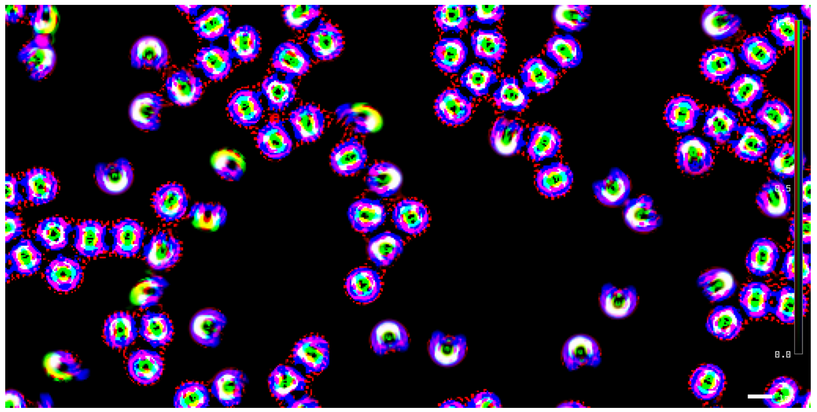
body

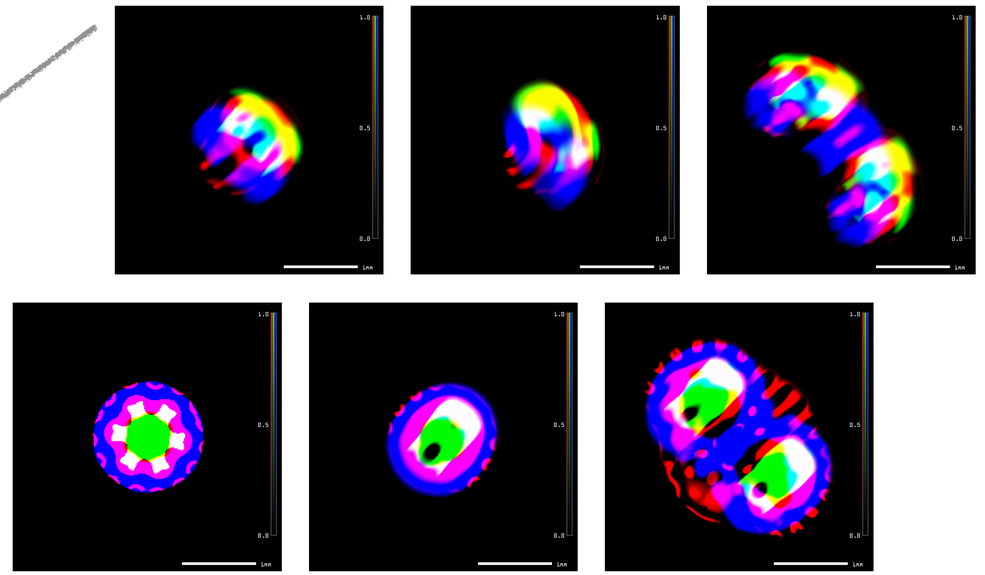
=



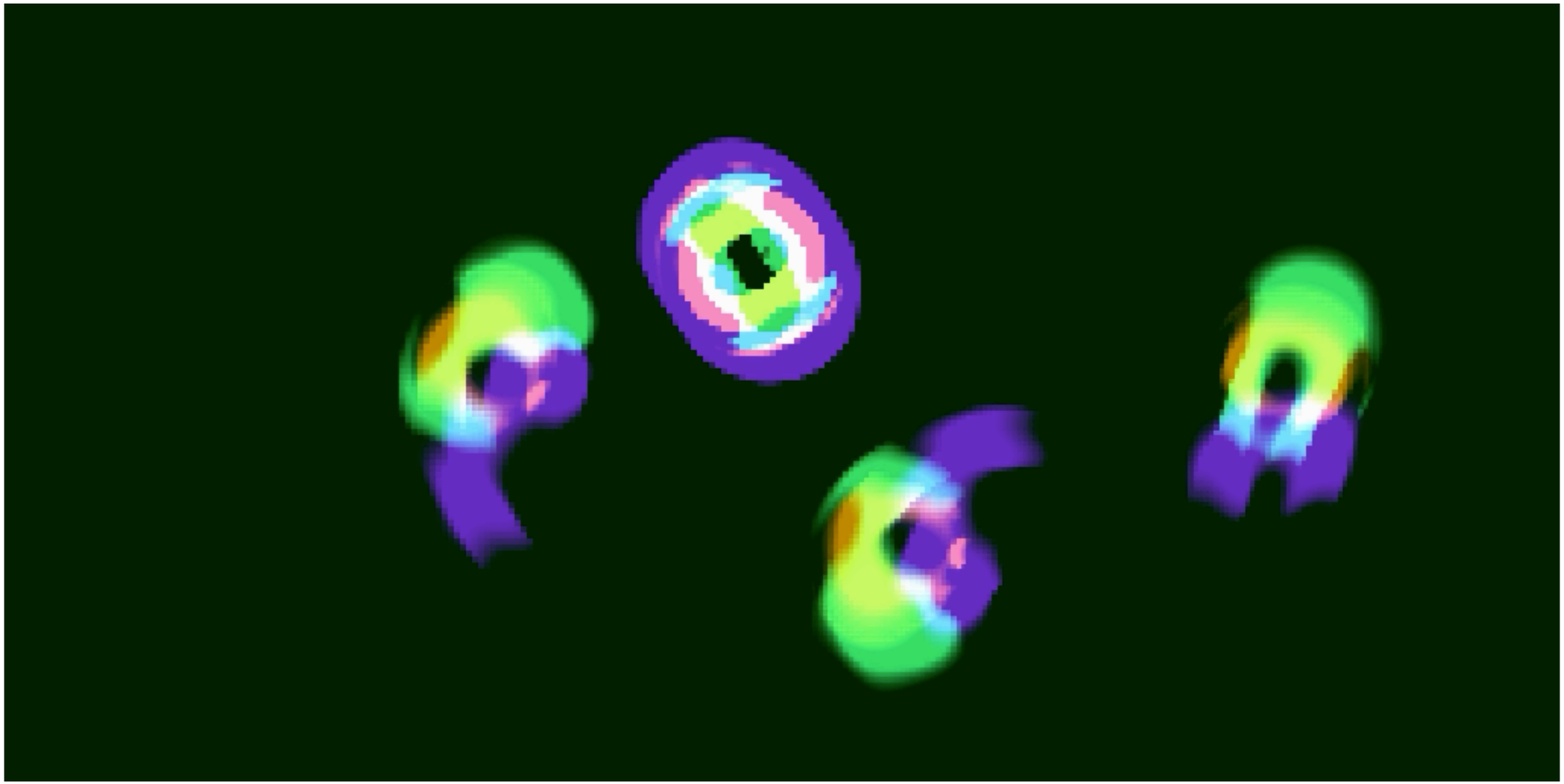
Phenotypic Polymorphism

- **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

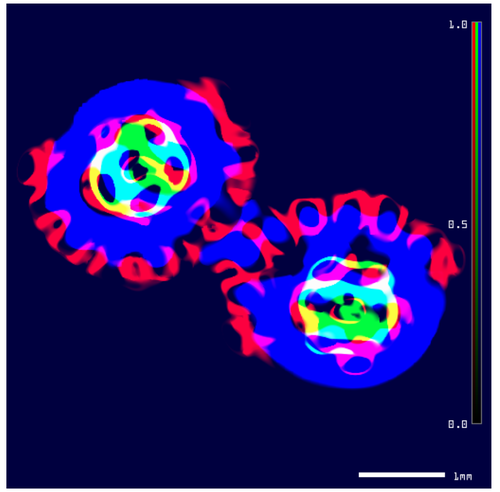




Phenotypic Polymorphism

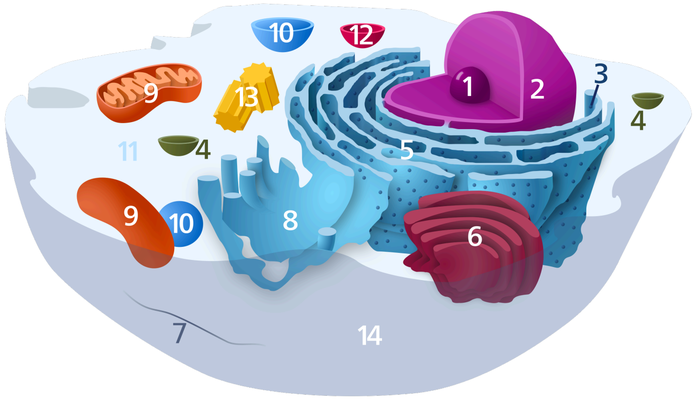


“Virtual Eukaryotic Cells”



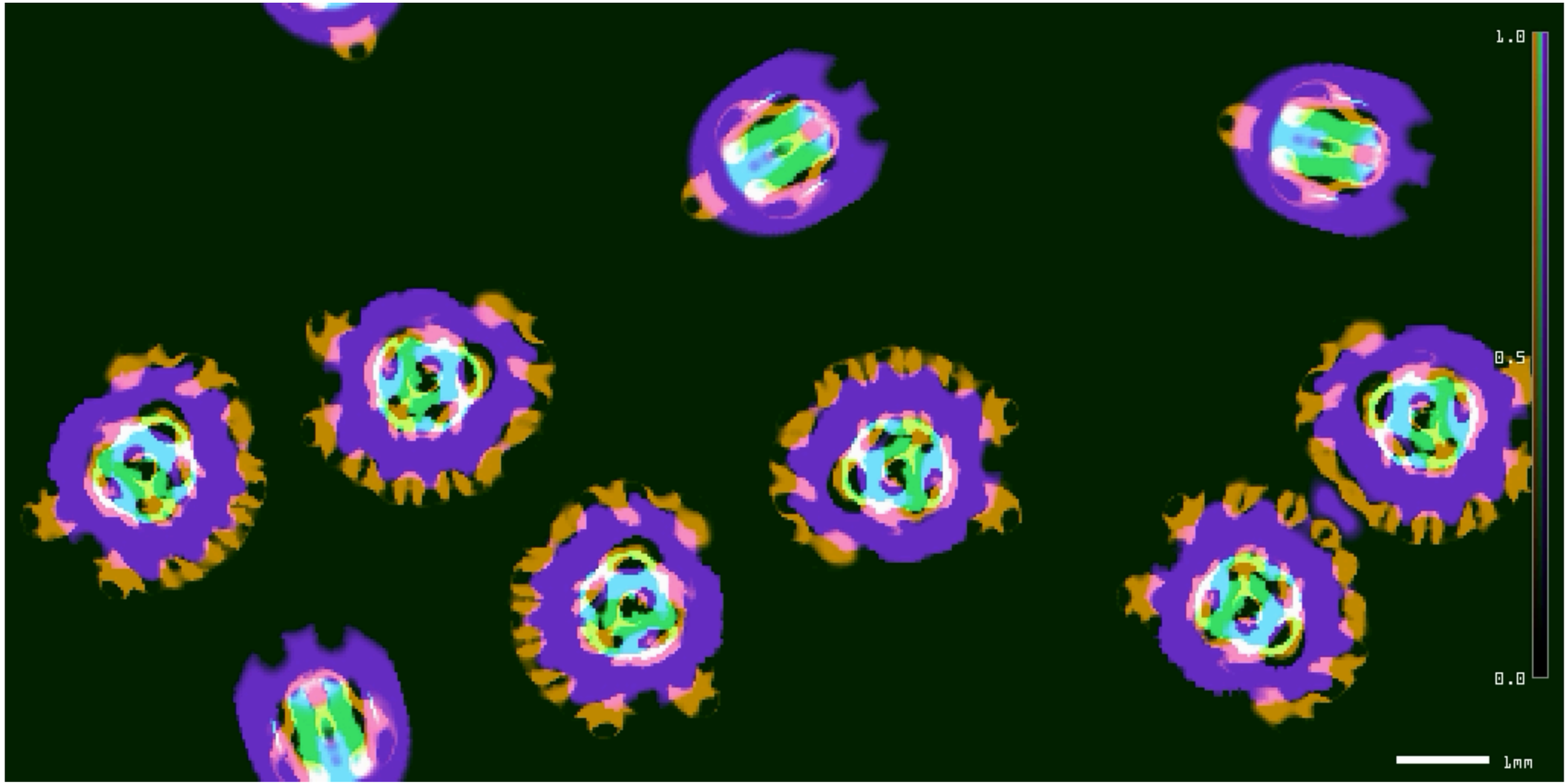
= advanced virtual lifeforms with emergent properties:

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 (??)



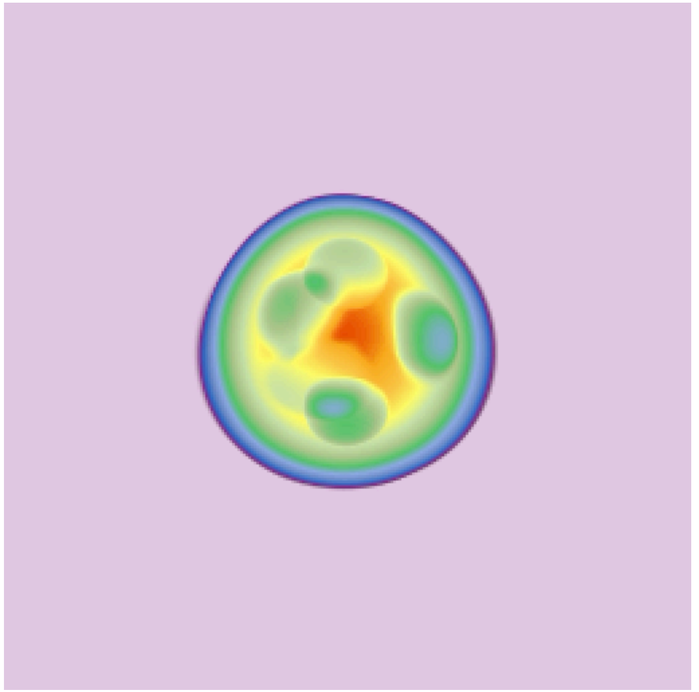
Wikipedia

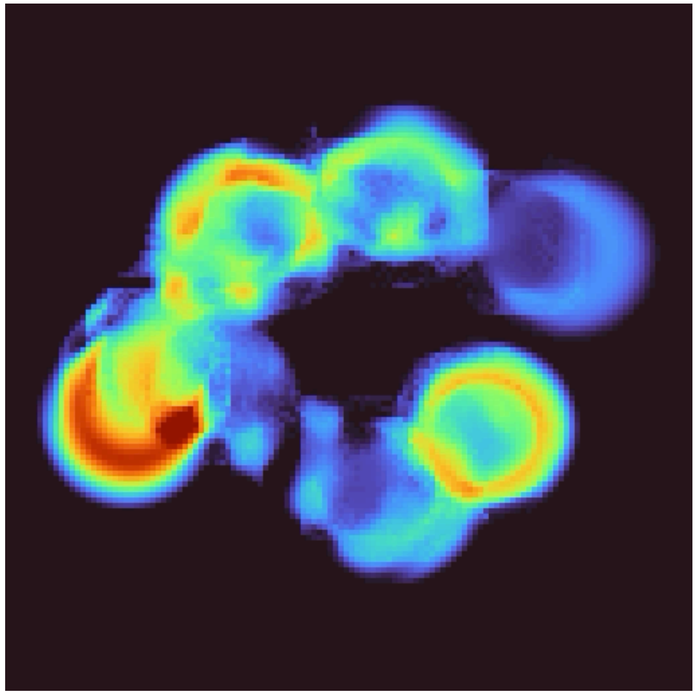
“Virtual Eukaryotic Cells”



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





More thoughts

ALife & AI

- **From AI to ALife**: Lenia as a playground for AI methodologies
  - Goal exploration, CPPN, VAE (PY Oudeyer team @ Inria)
  - Genetic algorithm (my study; T Arita team @ NagoyaU)
  - Quality diversity, GAN, etc.
- **From ALife to AI**: Lenia's extended architecture
  - approaches "Recurrent Residual Convolutional Neural Network"
  - is evolvable (neuroevolution), perhaps trainable (back-prop)
  - cf. CA-NN hybrid (e.g. A Mordvintsev et al. @ Google)

ALife & Life

- **Emergence of agents / individuals** within a grid-based system
  - may apply agent-based methods, reinforcement learning
- How to **recognize individuals**? Need e.g.
  - integrated information theory (IIT), information theory of individuality (ITI)
- Now 3 levels of emergence: (1) geometric patterns, (2) virtual cells, (3) multicellular megastructure. **More emergent properties? Higher levels?**
  - More levels x exploding diversity = open-endedness?
- **Recreating life phenomena**, implications to astrobiology, origins of life / lyfe

Thank you

Full video in Gallery

chakazul.github.io