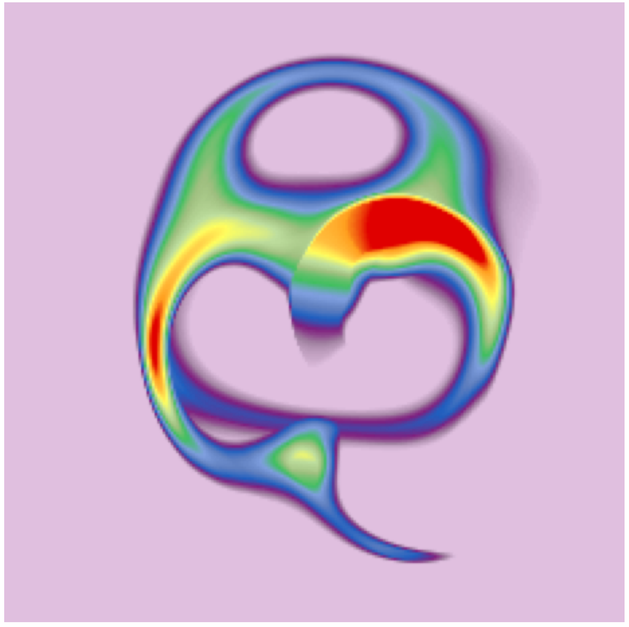


Stanford University
EE380 Computer Systems Colloquium

Lenia: Biology of Artificial Life

Bert CHAN Wang-Chak
Independent Researcher, Hong Kong

4:30pm, 15 Jan 2020
Shriram Center Room 104

About Me

- **Bert Chan** from Hong Kong
  - BSc Comp Sci (CUHK), MA Cog Sci (LundU)
  - Software & data engineer
  - Independent researcher - artificial life, human evolution
  - Designer - infographics, typeface

@ Ven, Sweden

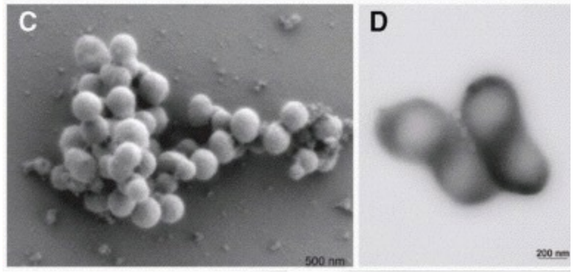
Agenda

Introduction
Biology of Lenia
Discussion
Q&A

Introduction

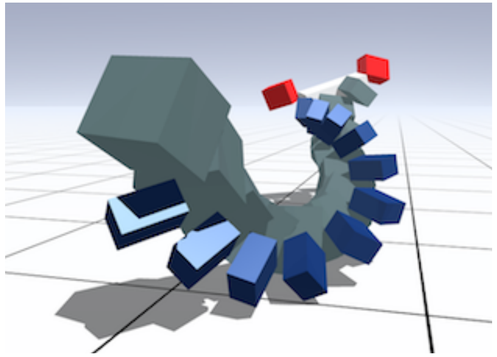
Artificial Life

- **Create** life to answer “what is life”, “what life can be”
  - **Wet**ware ALife - Synthetic biology, Biochemistry
  - **Hard**ware ALife - Robotics, Engineering
  - **Soft**ware ALife - Computer simulation
  - **Art** - graphics, objects
  - **A.I.** - Artificial neural networks, Genetic algorithms



Synthia


Atlas


virtual creature


Strandbeest

Synthia: Gibson et al. 2010 Science. Atlas: Boston Dynamics @ YoutTube

Virtual creature: Wikipedia. Strandbeest: strandbeest.com

Computer Simulations

- Complex life-like patterns / behaviors **emerge** from simple rules

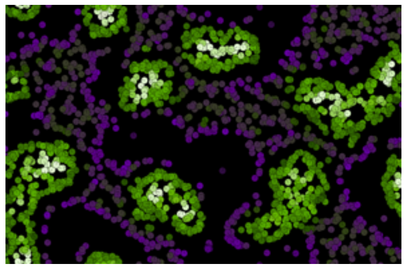
  Avida, Boids

  Evolved virtual creatures, Soft robots

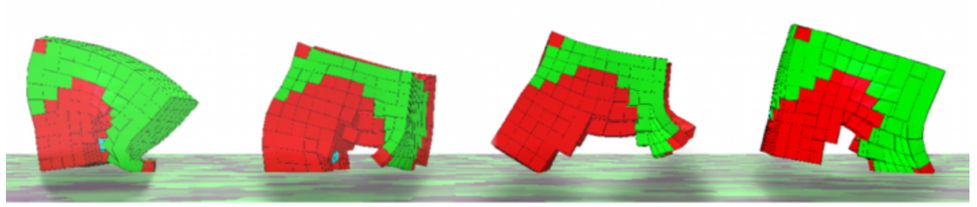
  Cellular automata, Reaction-diffusion

  Swarm chemistry, Primordial particle systems (PPS)

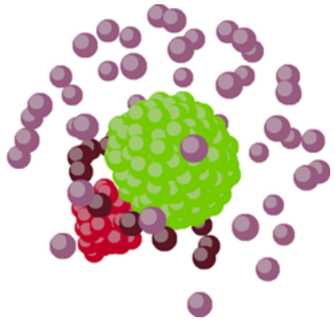
Boids



PPS



Evolved soft robot



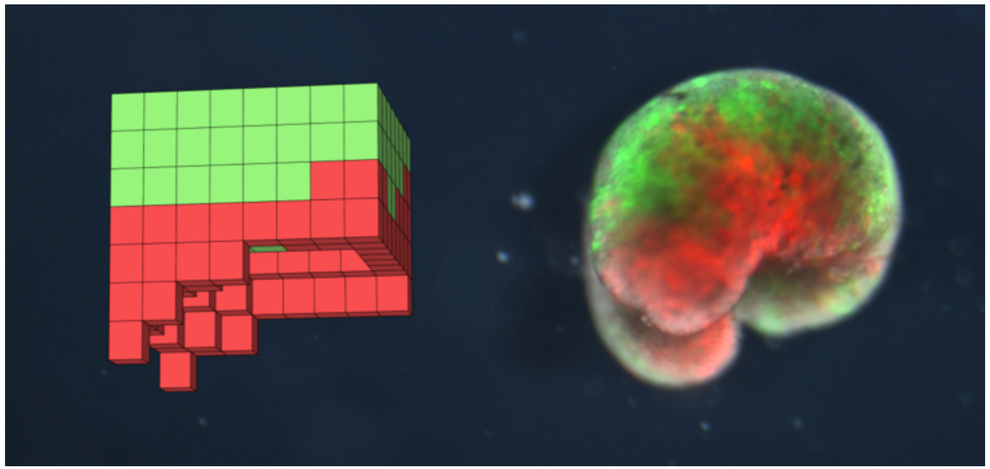
Swarm chemistry

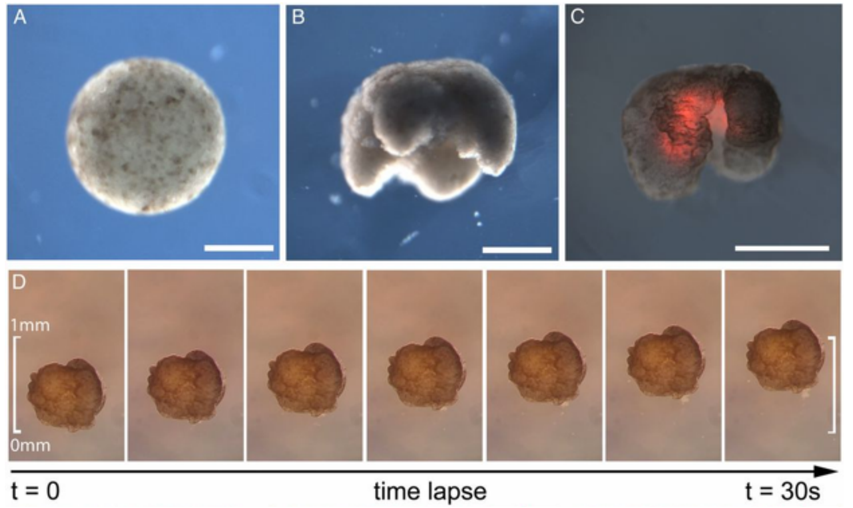
Boids: Reynolds 1987 SIGGRAPH. PPS: softologyblog.wordpress.com

Soft robot: evolvingai.org. Swarm chemistry: bingweb.binghamton.edu/~sayama

Soft → Wet

- Soft robots evolved virtually (e.g. to walk)
- Final design transferred to frog cells = **computer-designed organism**





CDO: Kriegman et al. 2020 PNAS, cdorgs.github.io

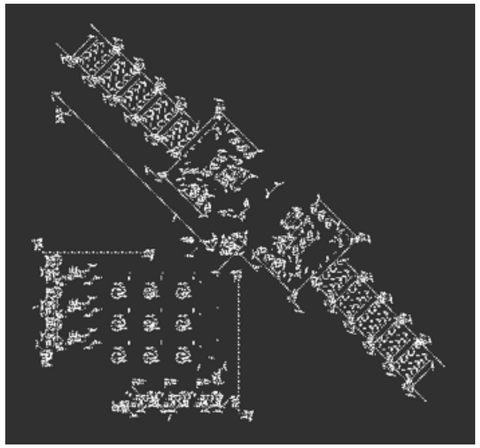
The Beginnings

- My first PC in 1990
  - **80286** CPU
    8 MHz (with Turbo button to 16 MHz!)
    MS-DOS
- Pascal, BASIC, Assembly
- Wrote **simulations** of gravity, Lorentz attractor, Mandelbrot set, Game of Life

not mine

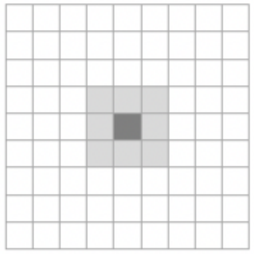
Wikipedia

Game of Life

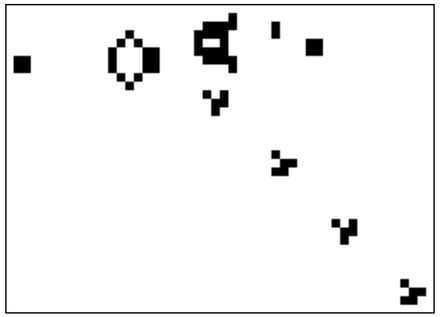


Turing machine

- **Cellular automaton** (CA), by John H. Conway 1970
  - 2D rectangular **grid** of cells
  - Binary **states** (0/1=dead or alive), local **neighborhood** (8 neighbors)
  - Totalistic sum N, **update** rule (N=2-3⇒survival, N=3⇒birth, else⇒death)
- Glider → Glider gun → Logic gates
  → Computer = Turing complete



neighborhood

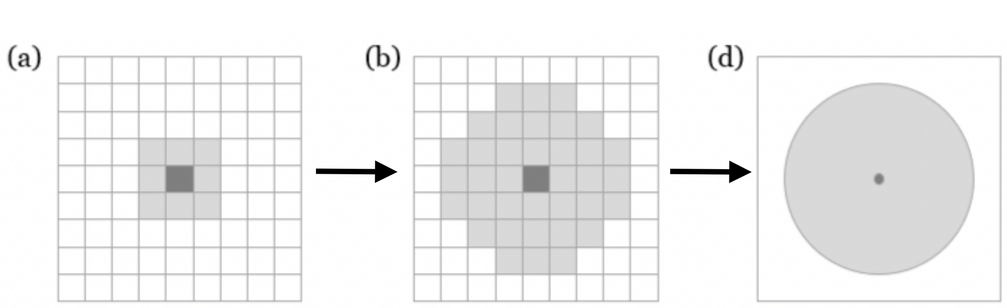


glider gun

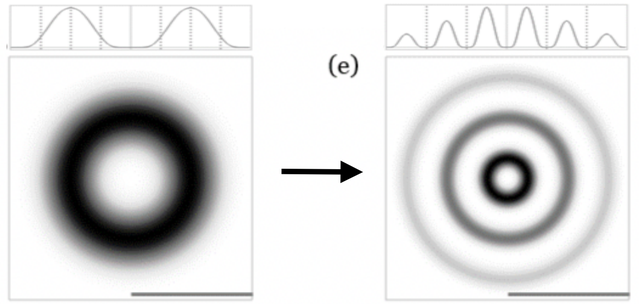
Wikipedia

Generalizing GoL

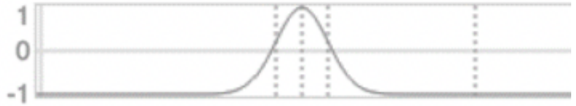
- Binary states → Multi-value → Flaoting point = **continuous states**
- 8 neighbors → Long range, circular = **continuous space**
- Totalistic sum → Weighted sum → Concentric rings = **convolution**
- If-then-else update → Mapping, incremental = **continuous time**



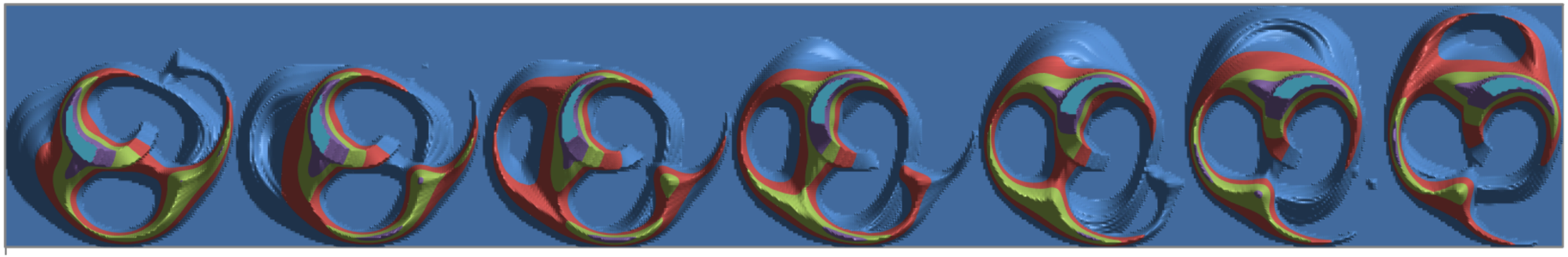
neighborhood

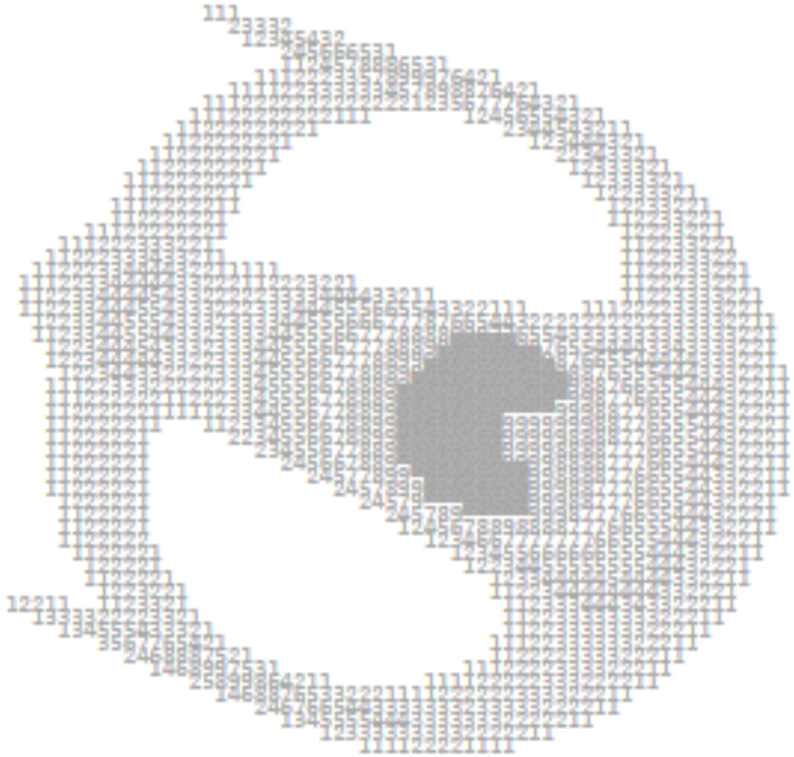


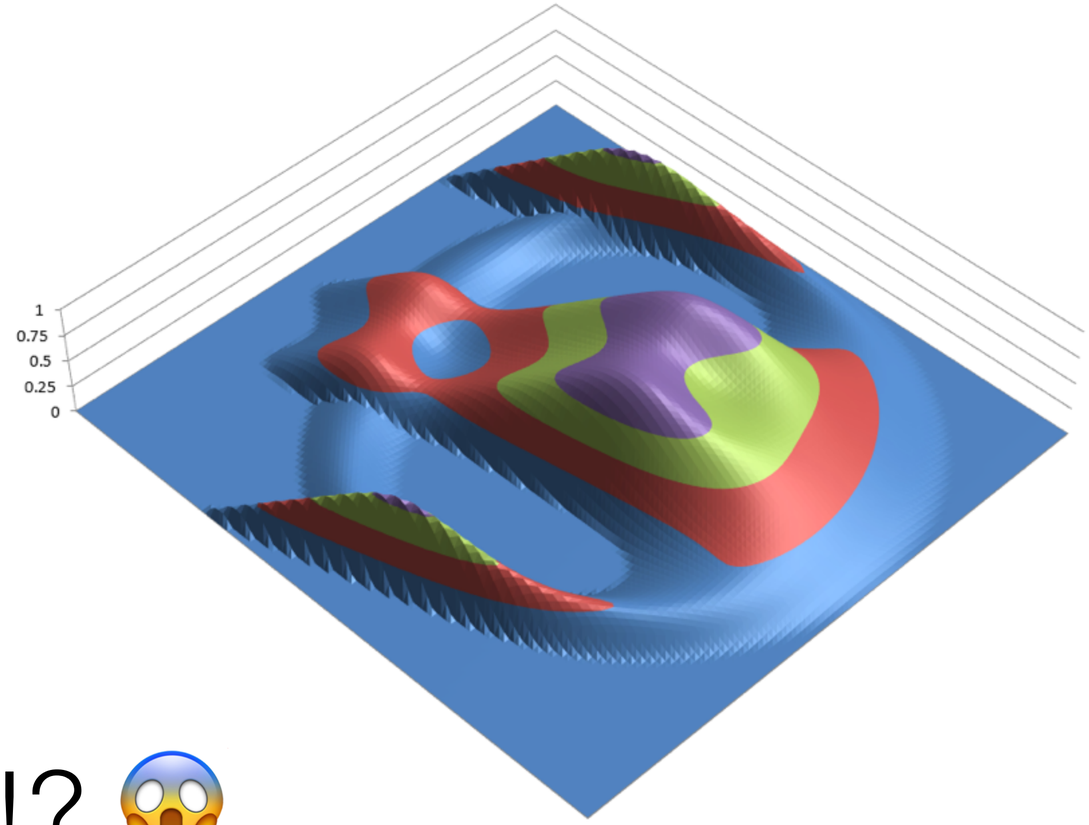
kernel



mapping





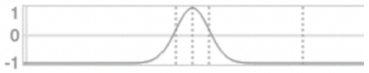


Nani !? 😱

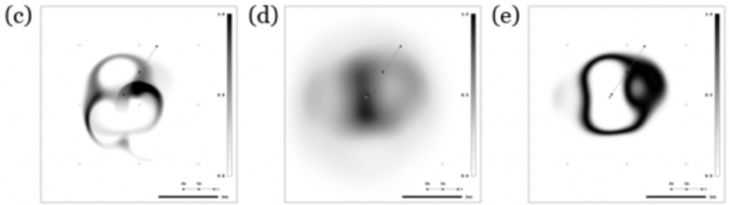
Lenia *(Latin: "those smooth")*

- Mathematically, *n*-Dimensional **continuous CA**
  - Update rule: $\mathbf{A} \rightarrow clip[\ \mathbf{A} + \Delta t\ g(\mathbf{K} * \mathbf{A})\ ]$
  - Parameters to tune: g (μ, σ), $\mathbf{K}$ (β)
  - PDE-like: $\partial \mathbf{A}/\partial t \approx g(\mathbf{K} * \mathbf{A})$
- **Biological-like** patterns, 500+ species
  - Study their structures, dynamics, symmetries, statistics, etc.

kernel $\mathbf{K}$



mapping g

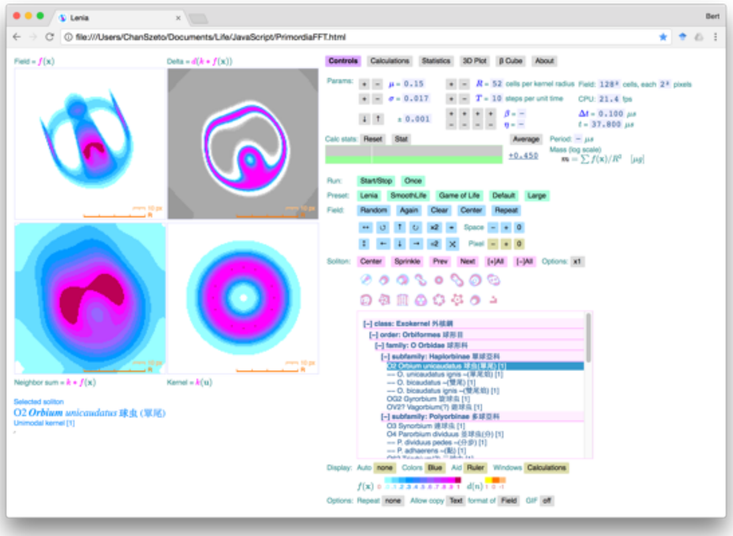


cells $\mathbf{A}$ → $\mathbf{K}*\mathbf{A}$ → $g(\mathbf{K}*\mathbf{A})$

+

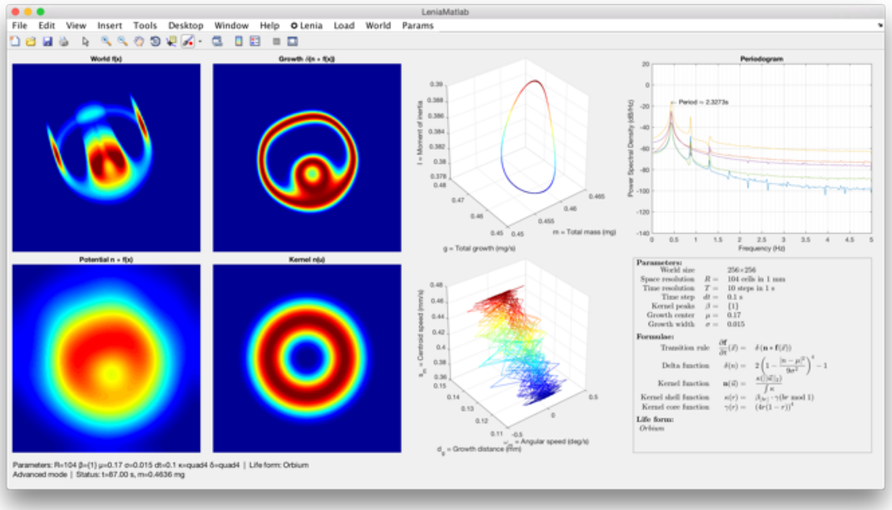
Software

- Developed in JavaScript, C#, MATLAB, Python



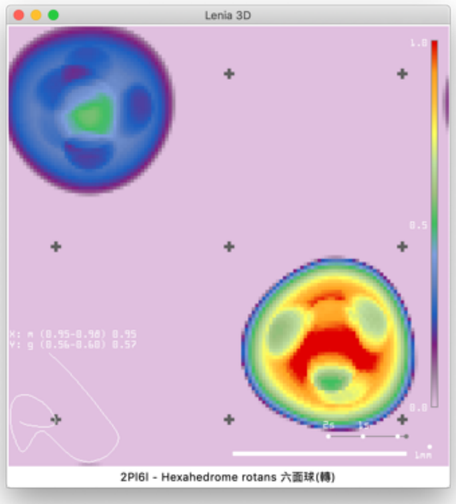
web version

- easily accessible



MATLAB version

- lots of proprietary tools

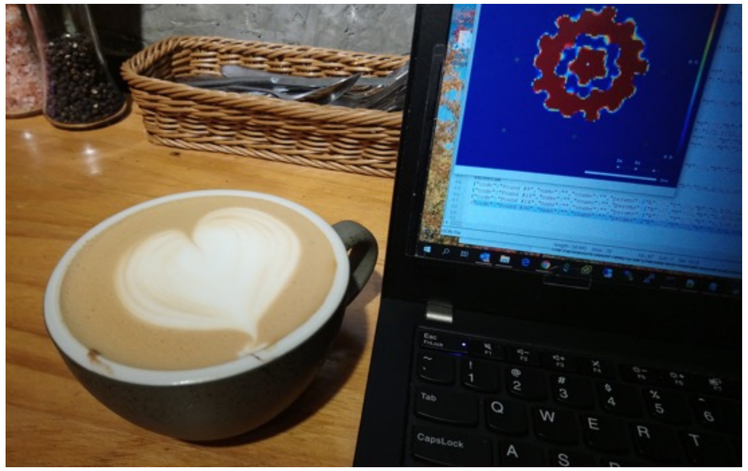


Python version

- zillions of libraries

Software Engineering

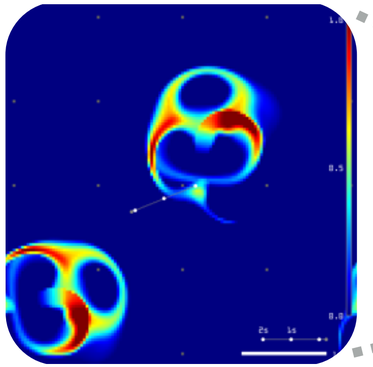
- **Laboratory** for simulation, observation, experimentation
- **Faster** - Convolution theorem → use Fourier transform (FFT); parallel computing (GPGPU, maybe FPGA)
- **Interactive** UI - manipulate, evolve, auto search, record patterns
- **Analysis** - statistics, detect symmetry, periodicity, chaoticity



Data Flow

500+ speciments

lifeforms.json



observe, experiments

Lenia UI

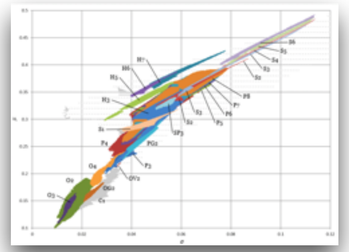
Python

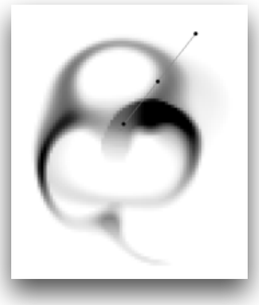
Lenia Auto

C#

Excel, MATLAB

clean, explore, visualize





.png .gif .mov .json .rle .csv

statistics.csv

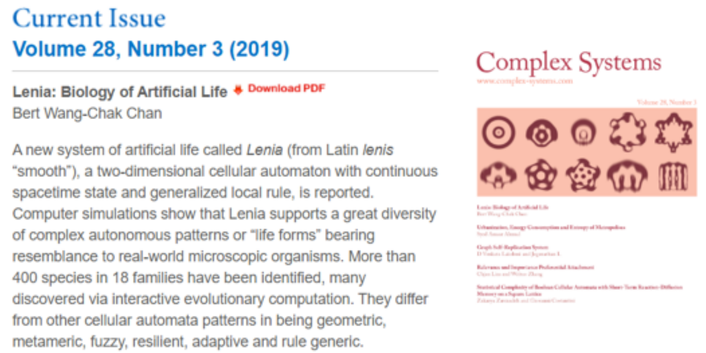
1.2 billion data points

Lenia API

on cloud on TPU TBA

Lenia Project

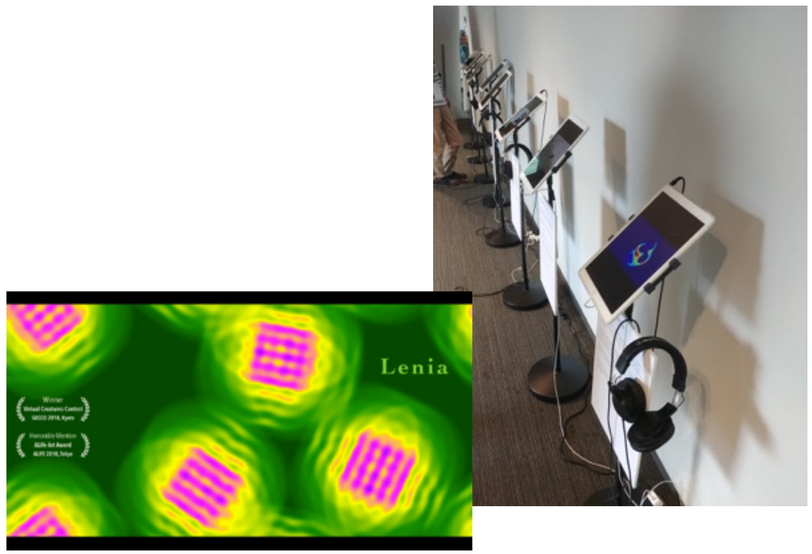
- **Software** - open-source in GitHub (1K+ stars)
- **Art** - video *“Lenia – Mathematical Life Forms”* awarded in 2018 GECCO Kyoto, ALIFE Tokyo
- **Research** - *“Lenia: Biology of Artificial Life”* published in arXiv, *Complex Systems*
- **Talks** - in code conferences, universities
- **Future** - ALife x AI


Current Issue
Volume 28, Number 3 (2019)

Lenia: Biology of Artificial Life Download PDF
Bert Wang-Chak Chan

A new system of artificial life called *Lenia* (from Latin *lenis* “smooth”), a two-dimensional cellular automaton with continuous spacetime state and generalized local rule, is reported. Computer simulations show that Lenia supports a great diversity of complex autonomous patterns or “life forms” bearing resemblance to real-world microscopic organisms. More than 400 species in 18 families have been identified, many discovered via interactive evolutionary computation. They differ from other cellular automata patterns in being geometric, metameric, fuzzy, resilient, adaptive and rule generic.

Complex Systems



Biology of Lenia

Studying Alien Life

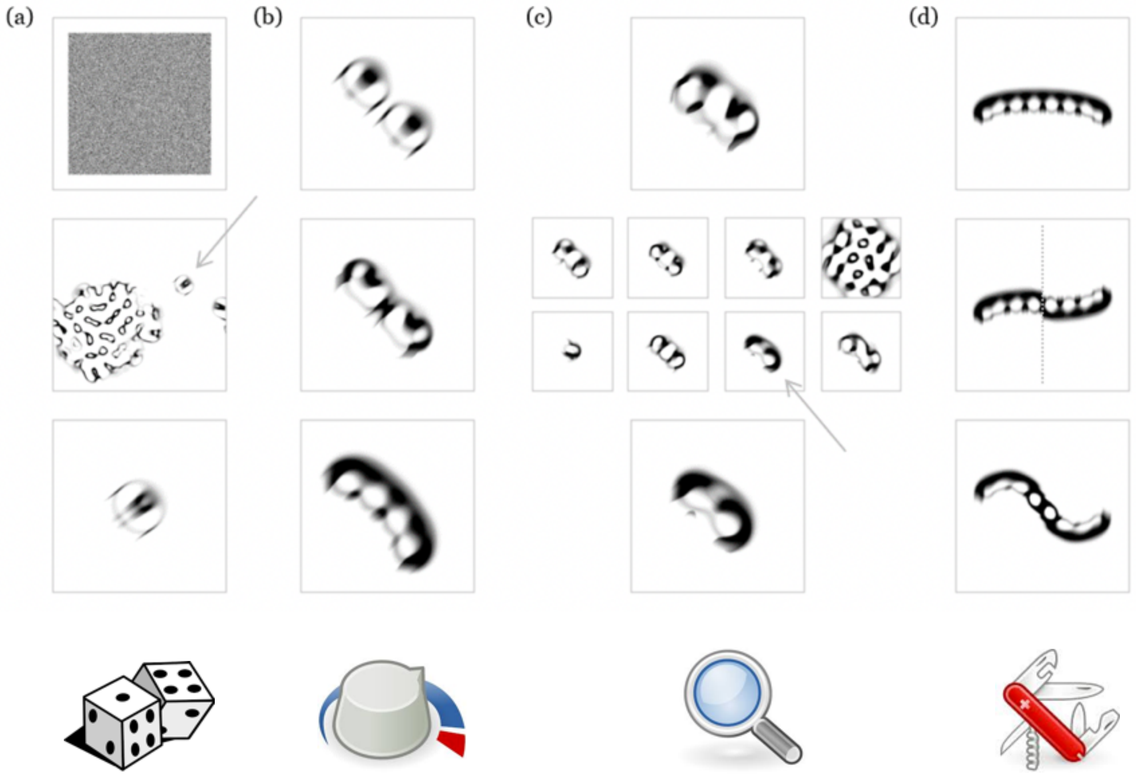
- Imagine we discovered life on **exoplanet**…
  - Communicate + study
  - Different, but may have things in common
- Concepts & terminology **borrowed from biology**
  - Classification & distribution - “Taxonomy”, “Ecology”, “Evolution”
  - Structures & dynamics - “Morphology”, “Behavior”, “Physiology”, “Morphometrics”

symmetriad in Solaris

Wikipedia

Evolution (Create patterns)

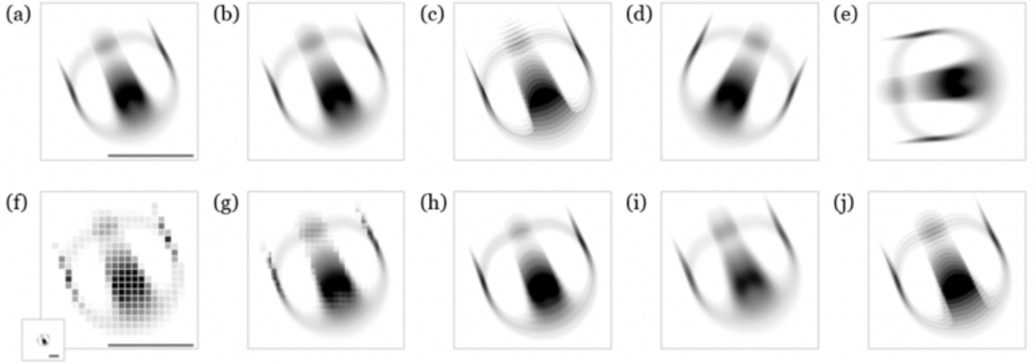
- *Interactive* Evolutionary Computation (IEC)
- **Evolve** new species by:
  - Random generation
  - Tweak parameters (μ, σ, β)
  - Automatic grid search
  - Manual mutate & stabilize



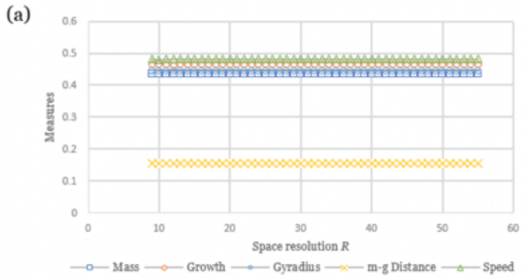
Wikipedia

Physics (Space-time properties)

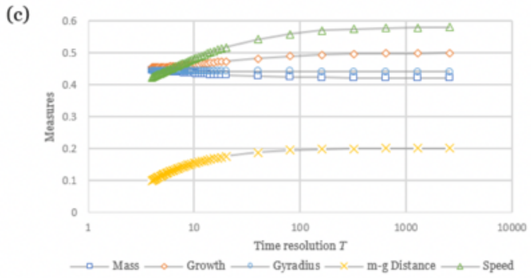
- Patterns **invariant** / **persist** under:
  - Scaling of space-time
  - Functions in $\mathbf{K}$, g (e.g. step)
  - Transformations (flip / rotate)
  - Deformations, perturbations



effects of changes

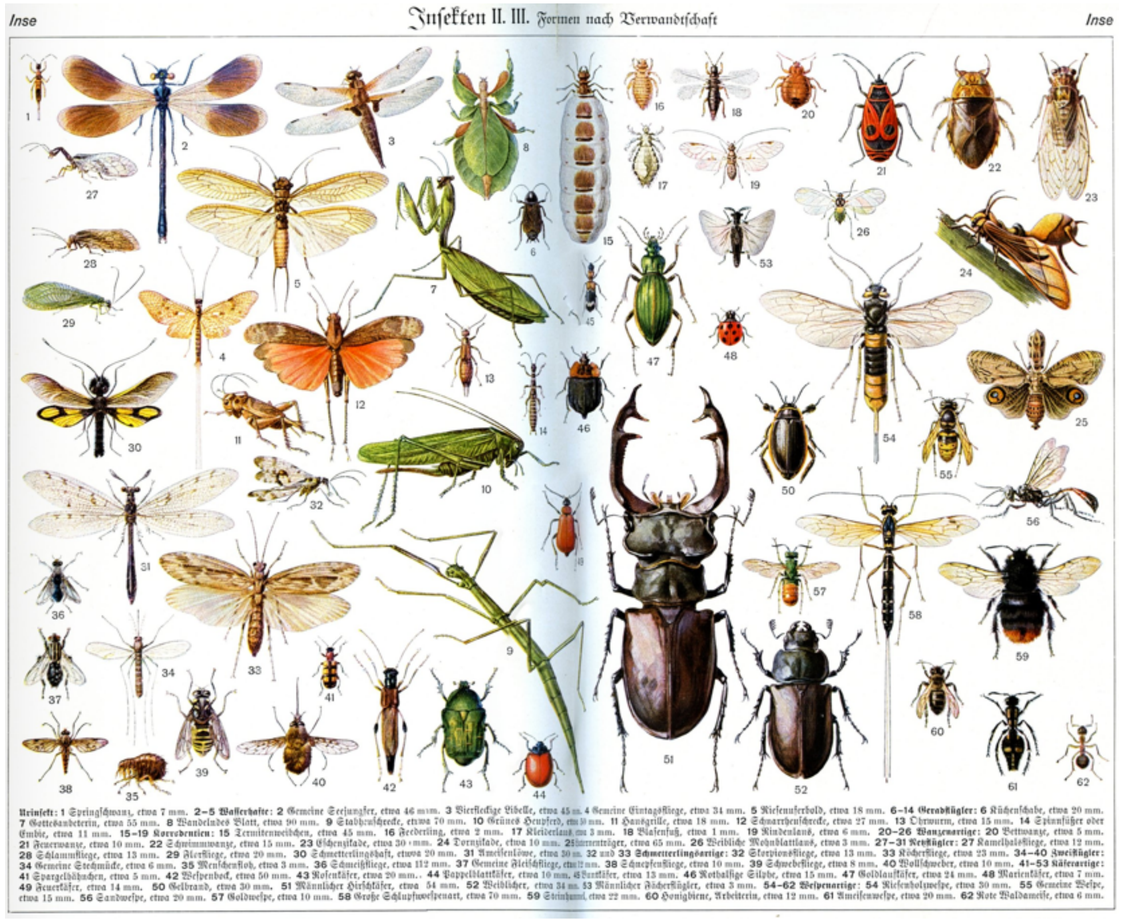


effects of space



effects of time

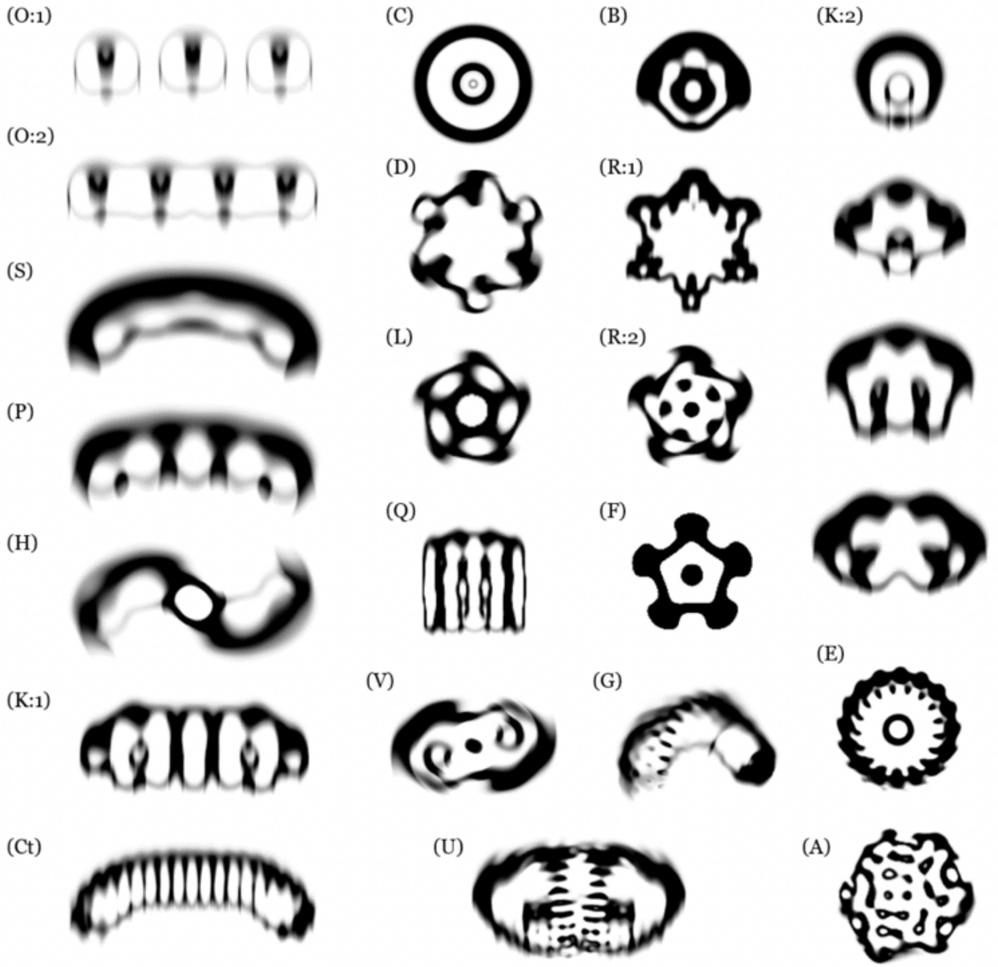
Taxonomy (Classification)



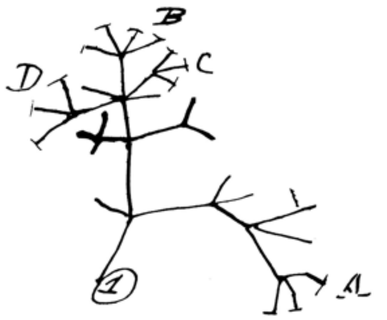
Wikipedia

Taxonomy (Classification)

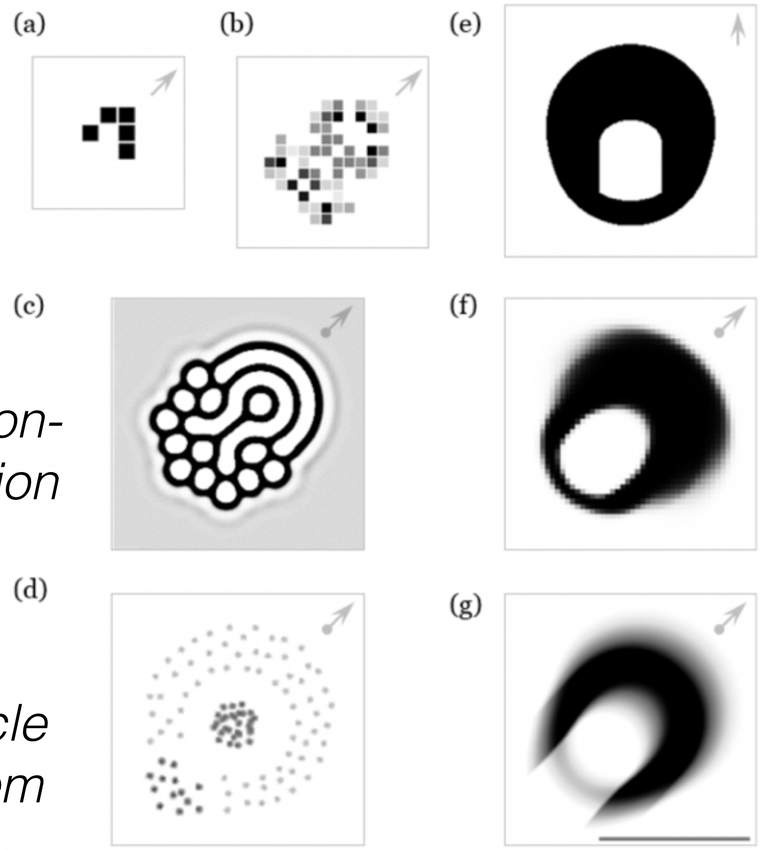
- Classify patterns into taxa:
  - **Species** - continuous variation, smooth morphing possible
  - **Genus** - local deviation in structure / behavior
  - **Family** - similar building blocks
- Binomial names, e.g.
  Asterium rotans, family Radiidae



Tree of Artificial Life



Discrete CAs *Continuous CAs*



reaction-diffusion

particle system

Artificialia

Domain Synthetica	"Wet" biochemical synthetic life
Domain Mechanica	"Hard" mechanical or robotic life, e.g. [39]
Domain Simulata	"Soft" computer simulated life
Kingdom Sims	Evolved virtual creatures, e.g. [7, 8, 9]
Kingdom Greges	Particle swarm solitons, e.g. [3, 29, 40, 41]
Kingdom Turing	Reaction-diffusion solitons, e.g. [4, 28, 42]
Kingdom Automata	Cellular automata solitons
Phylum Discreta	Non-scalable, e.g. [20, 21, 43]
Phylum Lenia	Scalable, e.g. [25, 27]

The current taxonomy of Lenia (Figure 8):

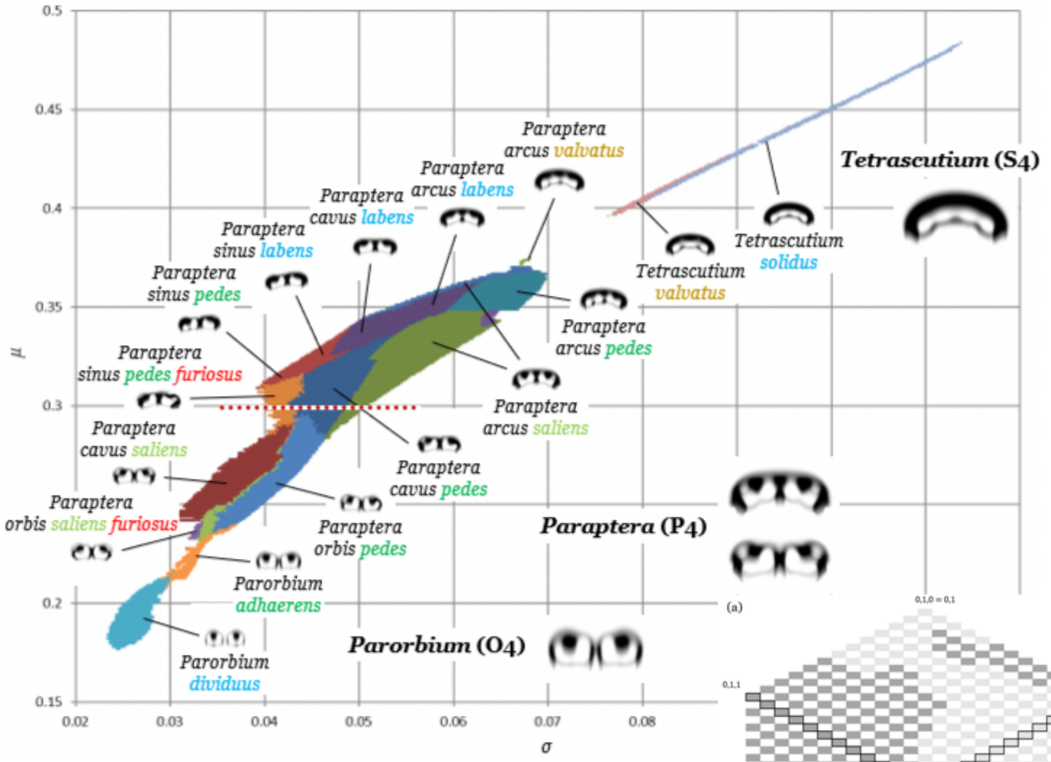
Phylum Lenia

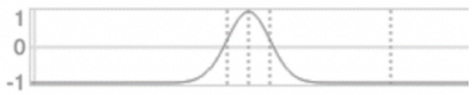
Class Exokernel	having strong outer kernel rings
Order Orbiformes	
Family Orbidae (O)	"disk bugs", disks with central stalk
Order Scutiformes	
Family Scutidae (S)	"shield bugs", disks with thick front
Family Pterifera (P)	"winged bugs", one/two wings with sacs

Wikipedia

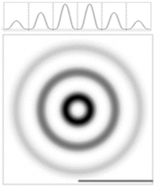
Ecology (Distribution)

- Plot **parameter space**:
  - Mapping g - μ-σ map
  - Kernel $\mathbf{K}$ - β cube
- Species occupy continuous areas (habitats / **niches**)
- Most in central diagonal
  = the **edge of chaos**
  = Wolfram's class 4 CA

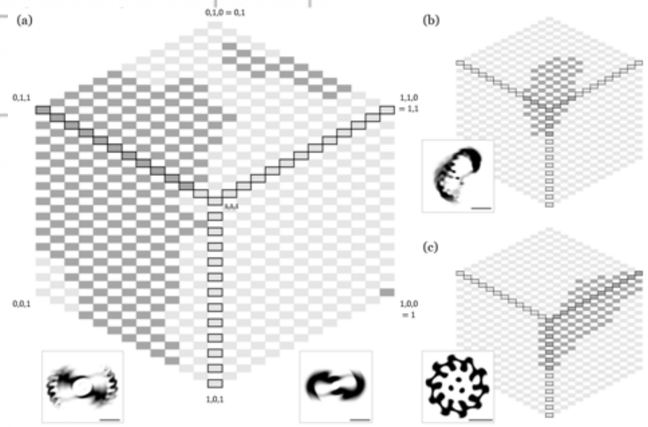




mapping g

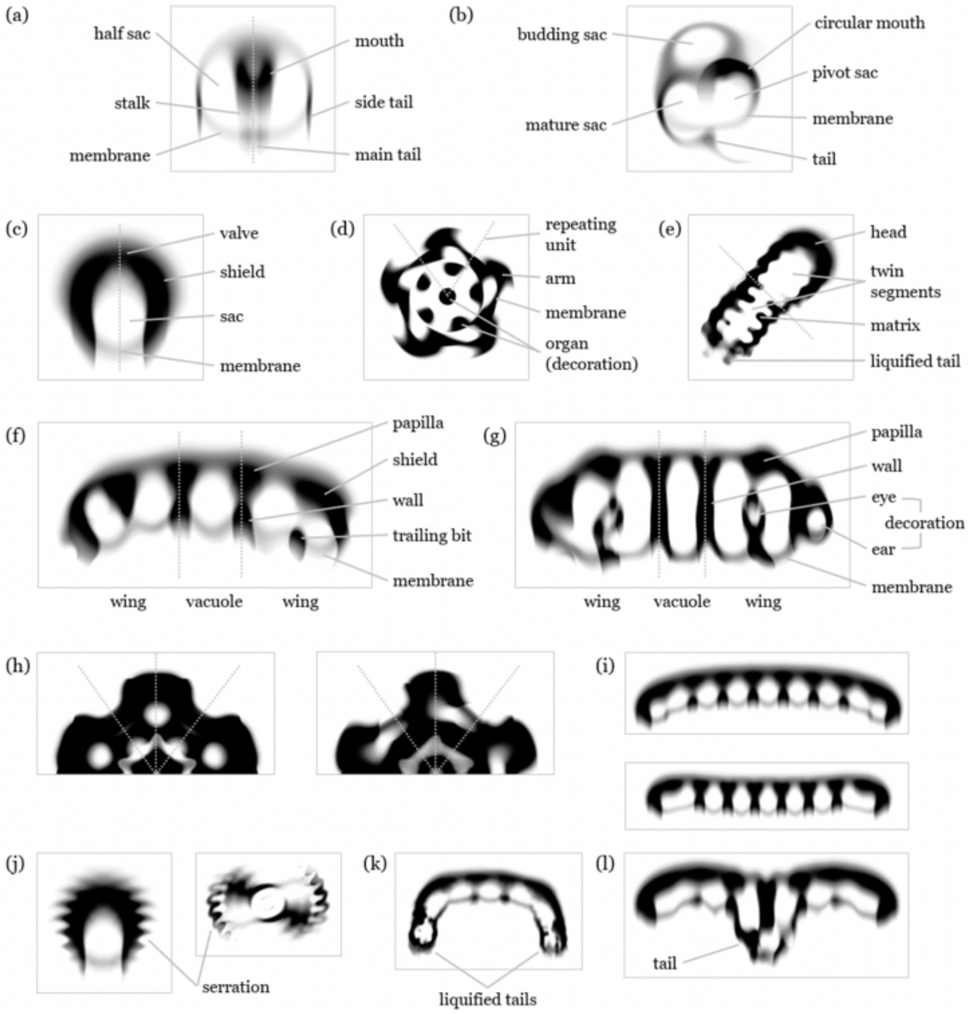


kernel $\mathbf{K}$



Morphology (Structures)

- **Symmetry**
  - Bilateral → fast moving
  - Radial → slow moving / stationary / rotating
- **Segmented** (metamerism)
  = repeating components
- **Swarm** of granular masses



Morphology (Structures)

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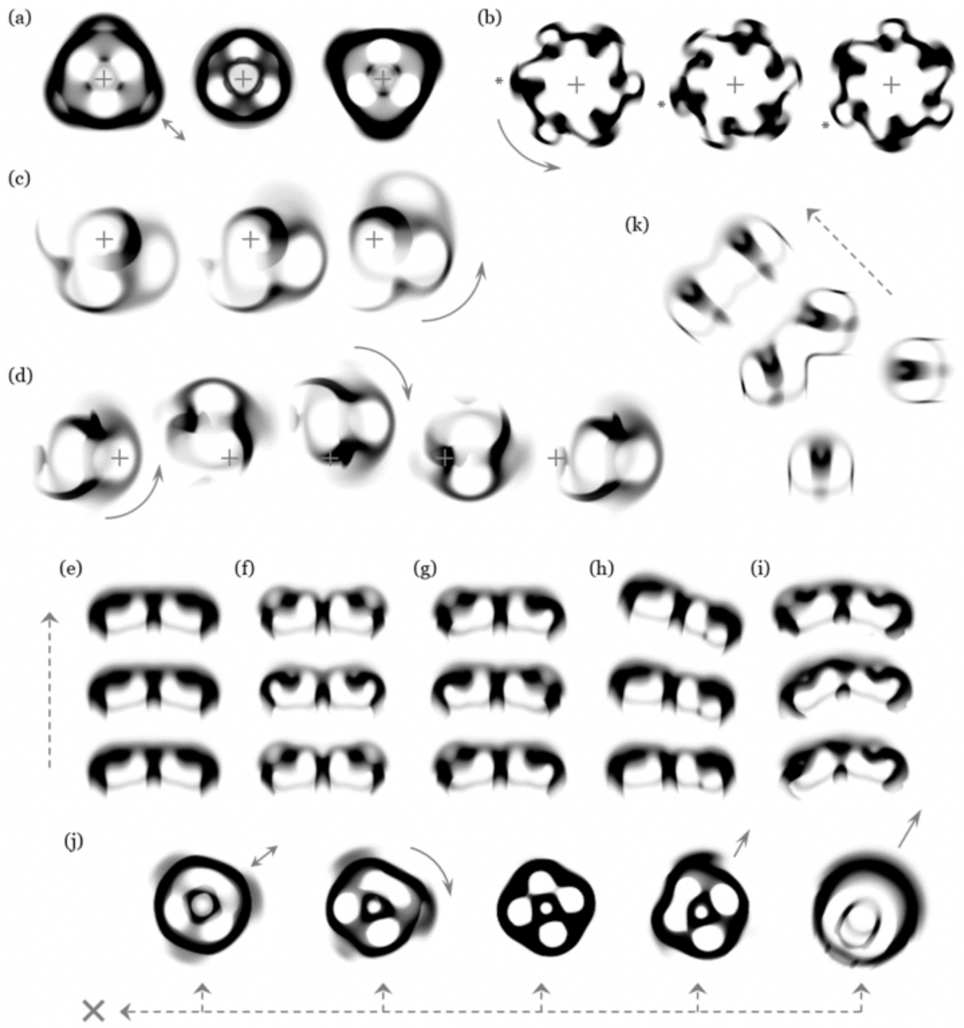
Wikipedia

Behavior (Dynamics)

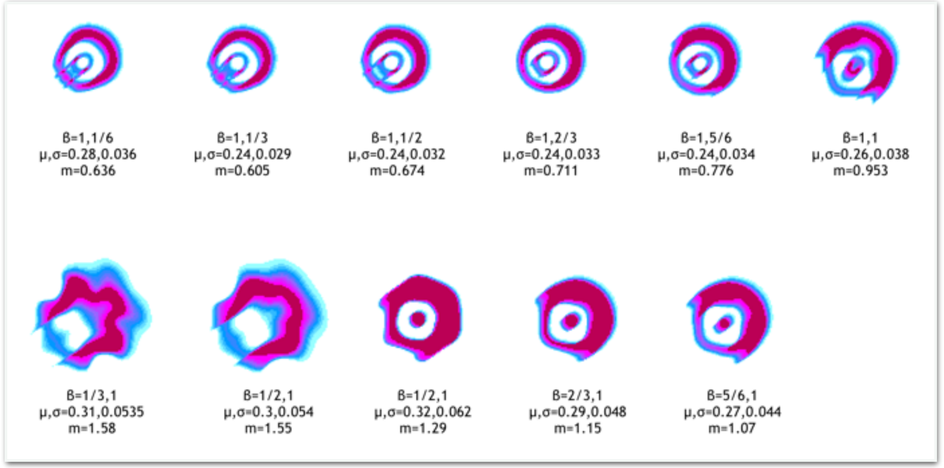
- Overall movement (**locomotion**)
  - stationary / rotational / directional / gyrating
- Local movement (**gait**)
  - solid / oscillating / alternating / deviated
- Chaotic, e.g. **metamorphosis**
  = switch among modes
- Particle **reactions** e.g. fusion, fission



Morphometrics (Statistics)

- **Variations** within a species or between different species
- **Quantitative** analysis of form & function

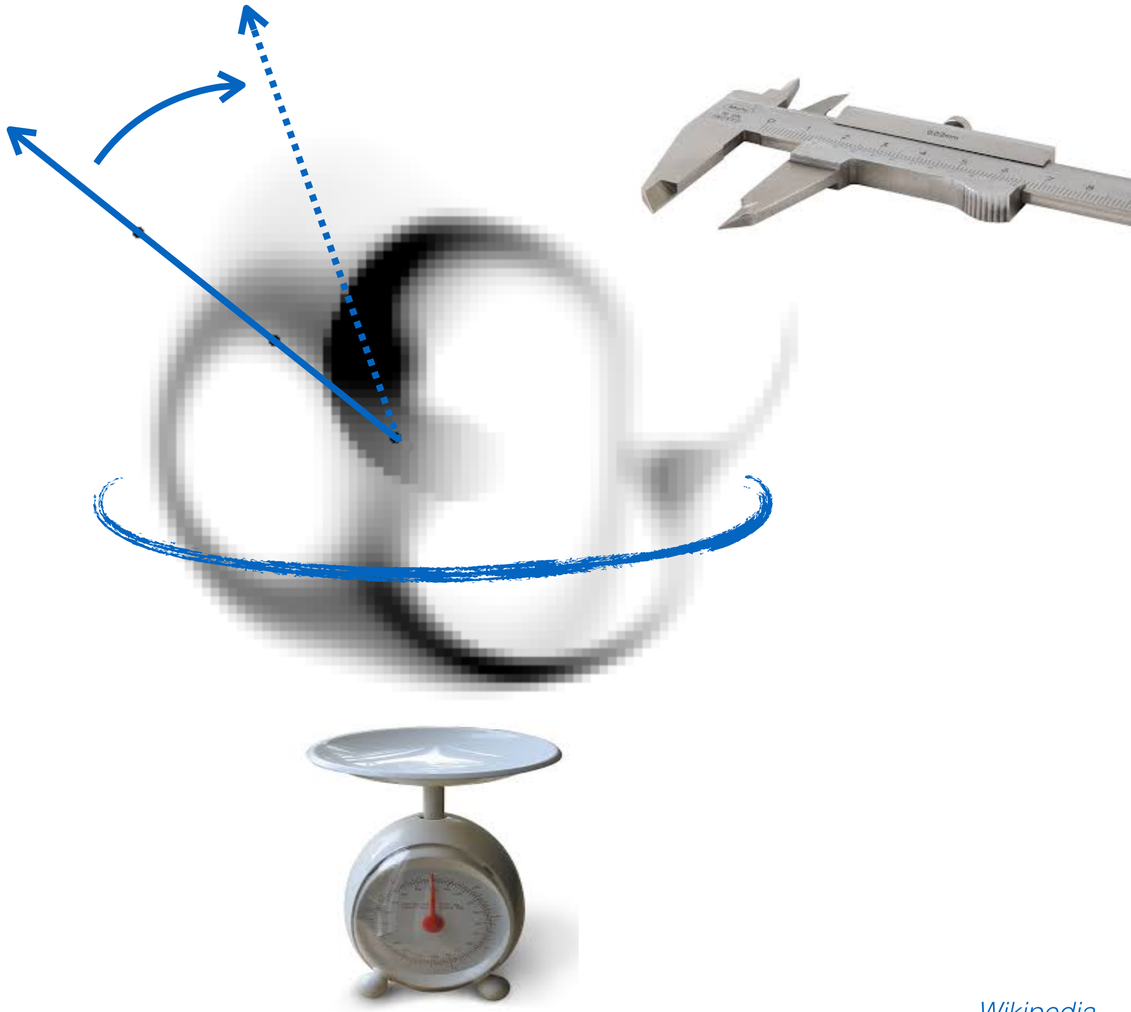
@ Seoul Grand Park



early studies

Morphometrics (Statistics)

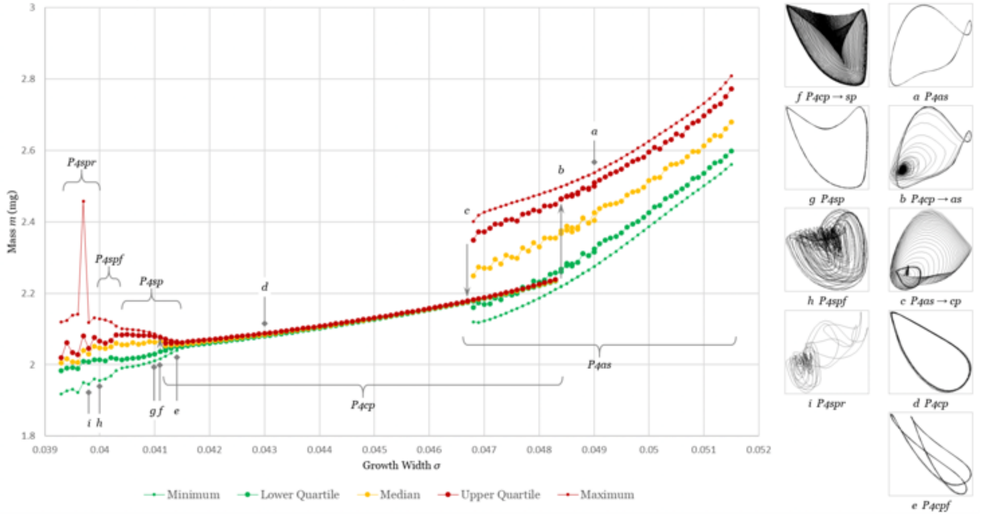
- Calc & collect **measurements** - mass, size, shape, linear speed, angular speed, etc.
- Plot **graphs** to uncover subtle trends, variations, correlations
- Advanced: symmetry, periodicity, chaoticity, etc



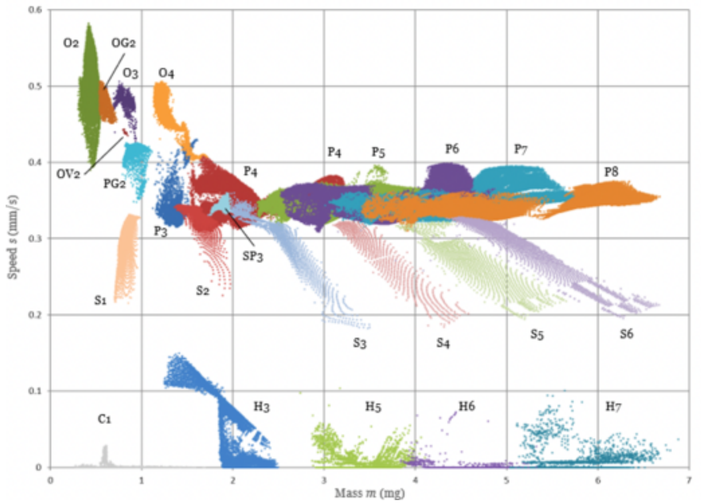
Wikipedia

Morphometrics (Statistics)

- Calc & collect **measurements** - mass, size, shape, linear speed, angular speed, etc.
- Plot **graphs** to uncover subtle trends, variations, correlations
- Advanced statistics: symmetry, periodicity, chaoticity, etc



mass vs σ



speed vs mass

Discussion

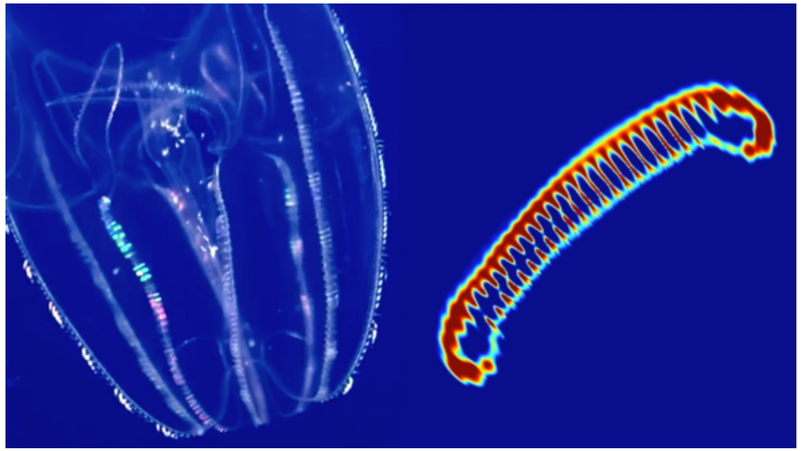
Discrete vs Continuous

- **Discrete** CAs (GoL)
  - Patterns are precise, fragile, "digital", can calculate
- **Geometric** CAs (Lenia)
  - Patterns are fuzzy, resilient, "analog", life-like
- **Continuous** CAs (RealLife)
  - Continuum limit of geometric CA scaling up

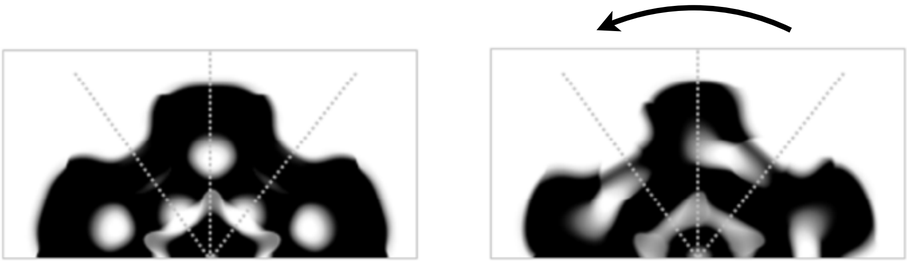
Standard CA patterns (e.g. GoL, ECA)		Geometric CA patterns (e.g. SmoothLife, Lenia)
	Structure	
"Digital"		"Analog"
Non-scalable		Scalable
Quantized		Smooth
Localized motifs		Geometric manifolds
Complex circuitry		Complex combinatorics
	Dynamics	
Deterministic		Unpredictable
Precise		Fuzzy
Strictly periodic		Quasi-periodic
Machine-like		Life-like
	Sensitivity	
Fragile		Resilient
Mutation sensitive		Mutation tolerant
Rule-specific		Rule-generic
Rule change sensitive		Rule change adaptive

Lenia & Earth Life

- **Similarities** between Lenia & Earth life:
  - Inherently vivid & appealing
  - (Bio)**diversity**
  - **Plasticity**: adaptable, evolvable
  - Symmetry = **stability**,
    asymmetry = **motility** *(my hypothesis)*



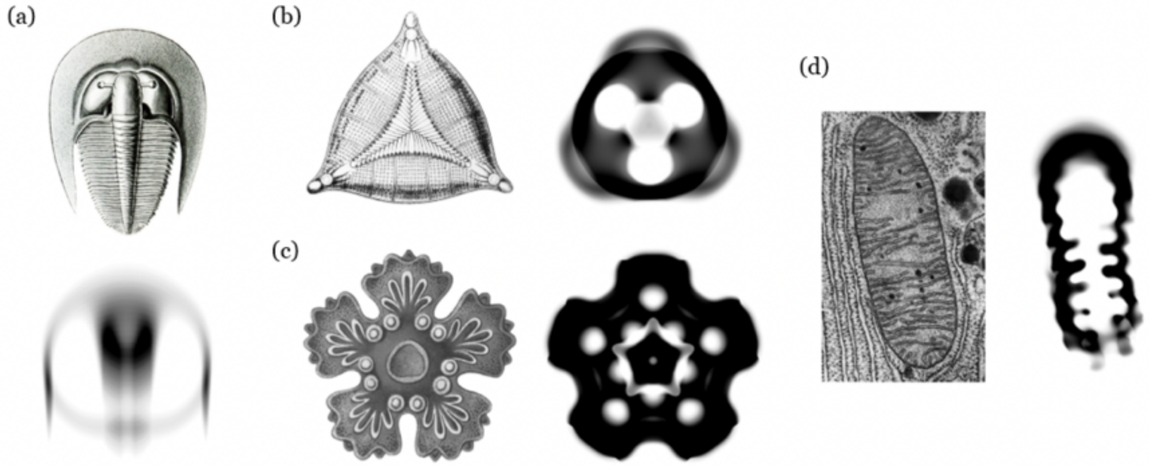
Ctenophore & "Ctenium"
video: bit.ly/LeniaCtenium

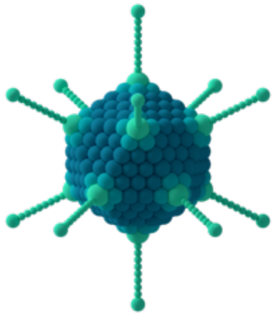


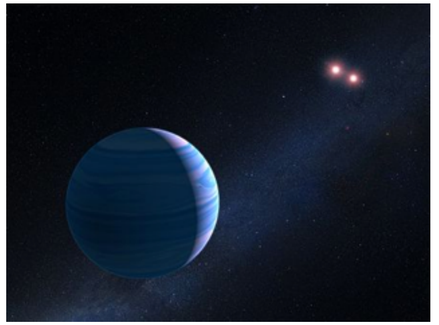
Ctenophore: Monterey Bay Aquarium @ YouTube

What is Life?

- **Definition(s)** of Life
  - “I know it when I see it”
  - Self-organization, self-regulation, self-propulsion, self-replication, metabolism, growth, response to stimuli, adaptability, evolvability
- Lenia exhibits some = **partially** alive? (cf. astrobiology, virology)







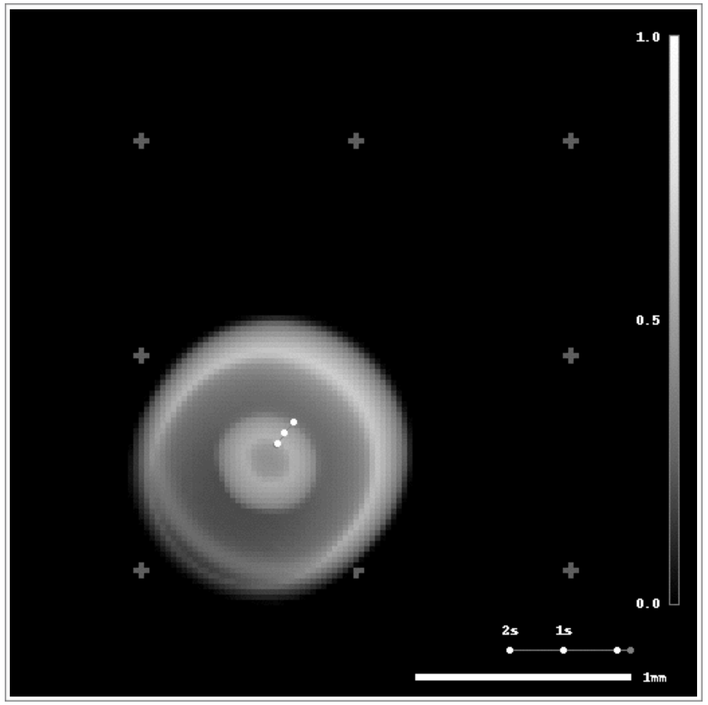
Wikipedia

Future Directions

- **Questions** - self-replicator? emitter? Turing complete?
- **Variations** - higher dimensions, parallel universes, etc.
- **API** & **dataset** - for data science & machine learning
- **ALife** x **AI** - e.g. apply AI to do automated search in ALife

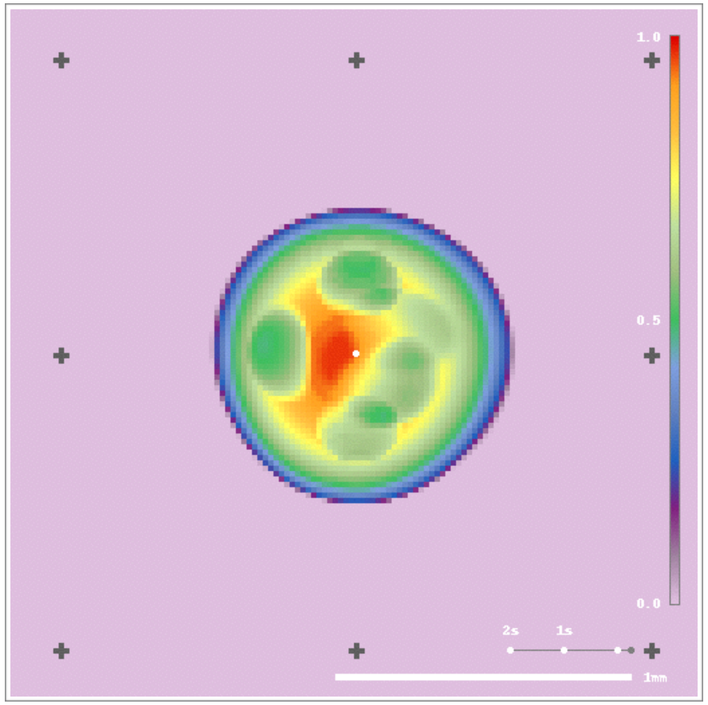
3D & 4D

3D glider



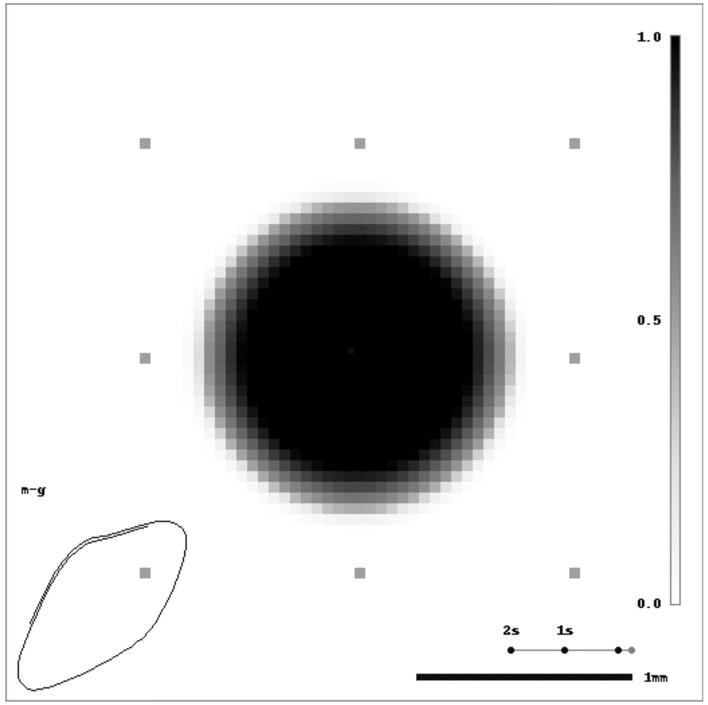
video: bit.ly/Lenia3DGlider

3D orbital



video: bit.ly/Lenia3DOrbital

4D pulsar



video: bit.ly/Lenia4DPulsar

Related Works

- Stephen **Rafler** - SmoothLife *(independent discovery)*
- Pierre-Yves **Oudeyer** - curiosity-driven exploration
- Kenneth O. **Stanley** - neuro-evolution, novelty search
- David **Ha** - neuro-evolution + deep learning
- Alex **Mordvintsev** (DeepDream) - neural CA *(TBA)*
- Nick **Kyparissas** - FPGA chip for CA

SmoothLife

Neural CA

SmoothLife: conwaylife.com. Neural CA: Twitter @zzznah

ALife Community

- **ALIFE 2020** conference @ Montréal
  “What can ALife offer AI”
  2020.alife.org

- **Quine** Association @ Lausanne
  - ALife, quines, creativity
  quine.ch

- **Twitter** List
  bit.ly/ALifeTwitter

Quine @ HK

Thank You

香港人 加油

Q & A

chakazul.github.io