Capturing Emerging Complexity in Lenia

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Complexity and Open-Endedness

Complexification

- End Goal: How to solve a task?[Clune, 2019];
- Where Manual AI fails? [Stanley et al., 2017];
- Novelty, Task based and Hybrid approaches [Stanley et al., 2017];
- Open-endedness and Complexification goes together [Randazzo and Mordvintsev, 2023];

Why open-endedness?

- Endless variation implies complexification;
- Fundamental questions: initial conditions, selection pressure, etc;
- Endless variation + Sensitivity to initial conditions + Selection pressure = Complexification
  [Randazzo and Mordvintsev, 2023]
  OR
  Open-endedness allows AI systems to continue to learn and improve over time, adapting to changing environments and evolving to meet new challenges

Why Evolvability? [Randazzo and Mordvintsev, 2023]

- Heritable Genetics and Selectable Phenotype with variation;
- Without Evolvability there would be no discovery, no new behaviour;
- Dynamical task landscapes, adaptive mutations, novelty search;

Lenia [Chan, 2018]

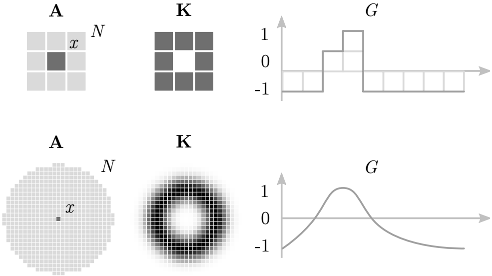

Figure: Discrete CA vs Continuous CA

Lenia Update Rule

Update function

The Lenia update rule is given by:

$$A_{t+1} = [A_t + \Delta t\, G(K * A_t)]$$

- A_t: Current State at t
- Δt: Step size
- G: Growth Function (for eg. Gaussian)
- K: Neighborhood Kernel
- $*$: Convolution operation

Kernel and Growth Function

Kernel Function

- Weighted importance to neighboring pixels and gradually reduced importance to distant pixels.
- Calculate the distances of each coordinate from the center and apply a mask to filter out values outside the desired radius.

Growth Function

- By adjusting the μ and σ parameters of the G, each cell's growth or decay can be controlled by taking input as Nh. sum array.

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Emerging Complexity and Behaviour in Lenia using standard Genetic Algorithm

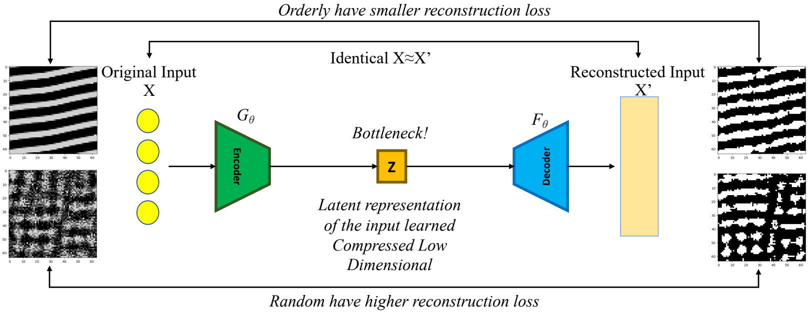

Figure: Compression based: AutoEncoder [Cisneros et al., 2019]

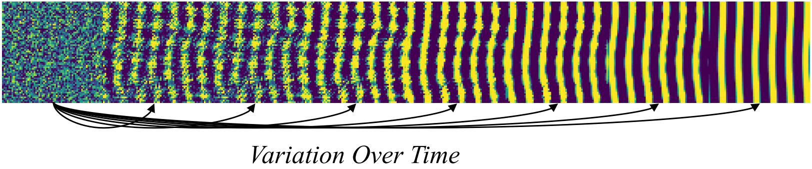

Figure: Variation based: Variation over Time

Algorithm 3. Auto-Encoder based Variation over Time (AEVoT)

Input : Input frames of Lenia patterns
Output: Population standard deviation (pstd) over list of alive cells count of each frame

1 **Begin**
2 Reconstruct the original frames using an auto-encoder (AE):; **For** *each input frame f* **do**
3 f_{AE} = AE(f); Calculate the number of alive cells in the reconstructed frame f_{AE} using a threshold:; $alive_f = count(p \geq threshold)$; Store the number of alive cells $alivef$ in a list;
4 Calculate the population standard deviation (pstd) of the list of alive cells counts:; $mean = \frac{1}{n} \sum i = 1^n alivei$; $variance = \frac{1}{n} \sum i = 1^n (alive_i - mean)^2$; $pstd = \sqrt{variance}$; **return** *Population standard deviation (pstd) over list of alive cells count of each frame*;

Figure: AEVoT Based: Combined Approach

Selection, Crossover, and Mutation

- Roulette Wheel Selection
- No Crossover
- Mutation by perturbation

Results from different experiments for AE, VoT and AEVoT

VoT based Experiments

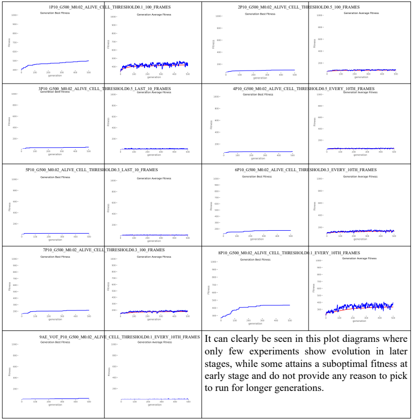

Figure: VoT experiments

AE based Experiments

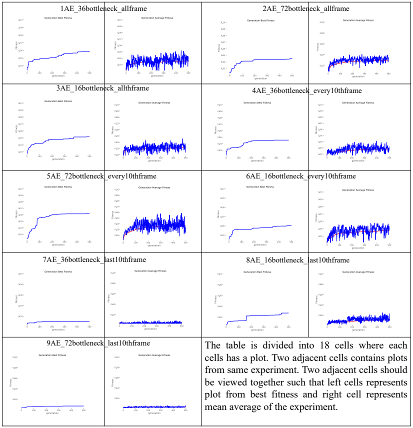

Figure: AE experiments

AEVoT based Experiments

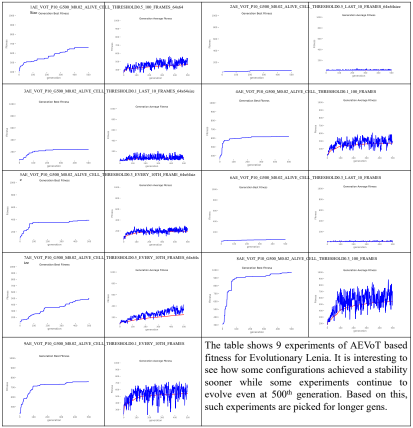

Figure: AEVoT experiments

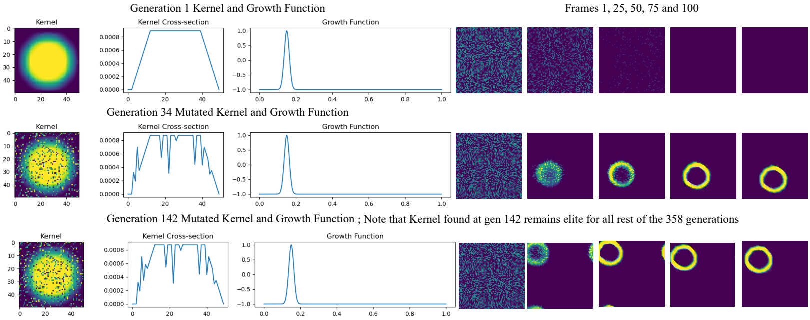

Figure: AEVoT experiment for known kernel: Adaptable mutations

Challenges, Learnings and Conclusion

- Automated Discovery, Emergent Agency, Open-Endedness [Chan, 2018];
- A strong hypothesis and supporting proofs for chosen parameters, yields good results (We discovered a ring forming bacteria);
- Evolution is time-taking!

Future Scope of Improvement

- Mutating Known Kernels.
- Particle Lenia, Flow Lenia, Sensorimotor Lenia
- Using JAX.

Major References

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Open-endedness: The last grand challenge you've never heard of.
While open-endedness could be a force for discovering intelligence, it could also be a component of AI itself.

Play with it:

`https://s4nyam.github.io/evolenia/`