Complex Systems

As a Possible Path to AI

Strong AI

should be able to:

- reason
- have a good memory
- transfer knowledge between tasks
- always keep on learning and adapting to its environment

A Possible Path to AI

biological evolution

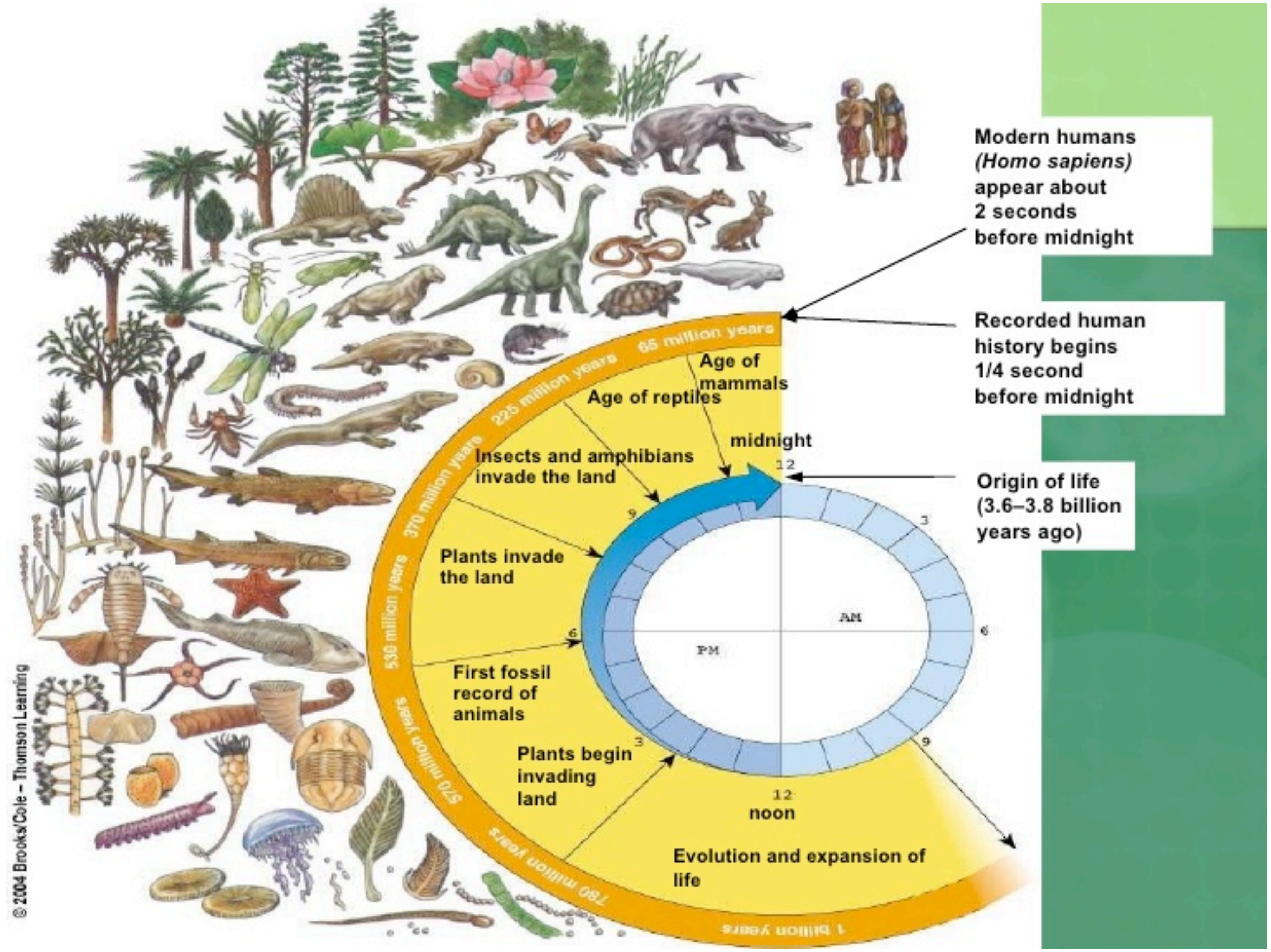
↓

intelligent organisms

A Possible Path to AI

biological evolution

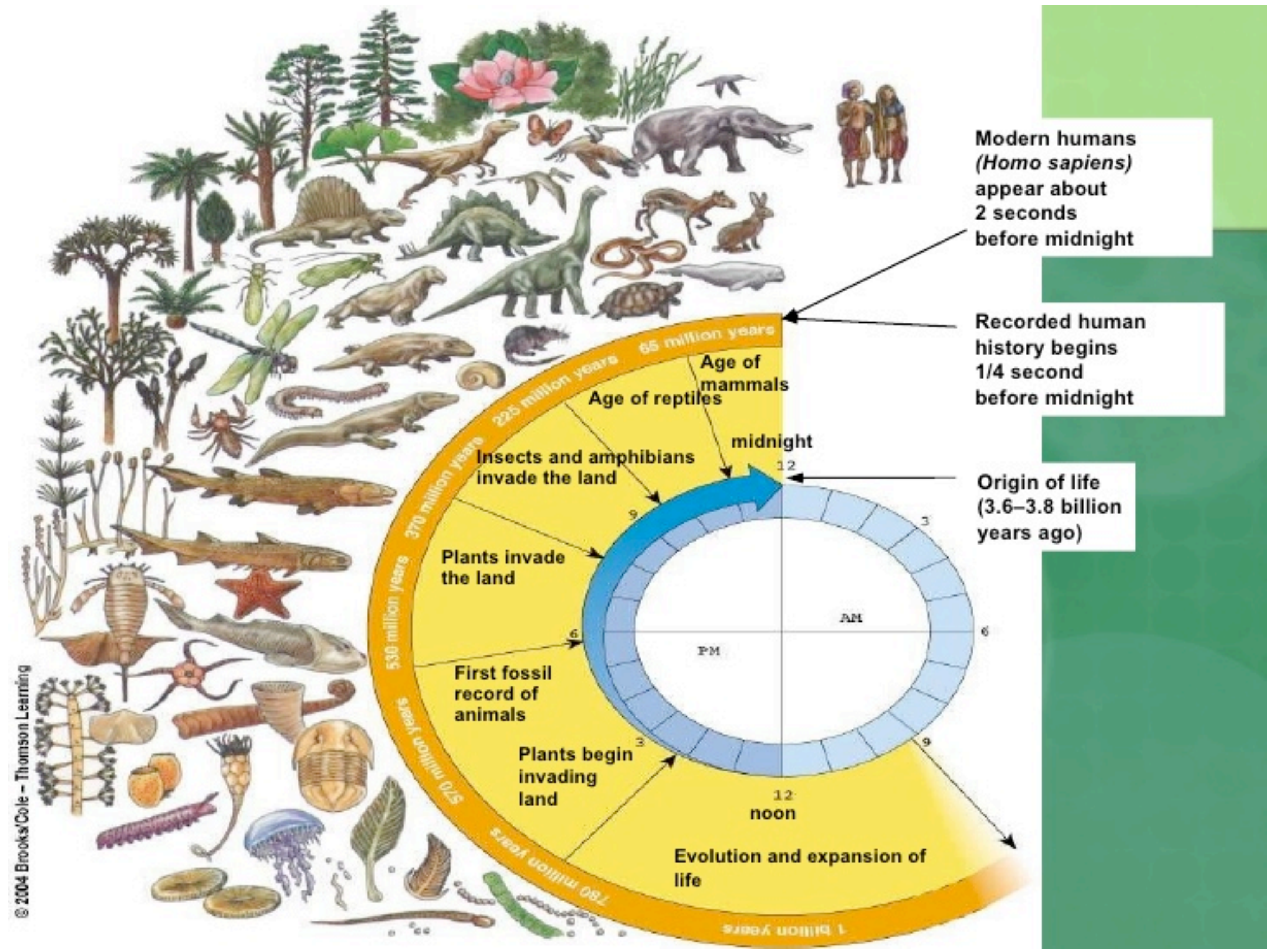
intelligent organisms



A Possible Path to AI

biological evolution

intelligent organisms



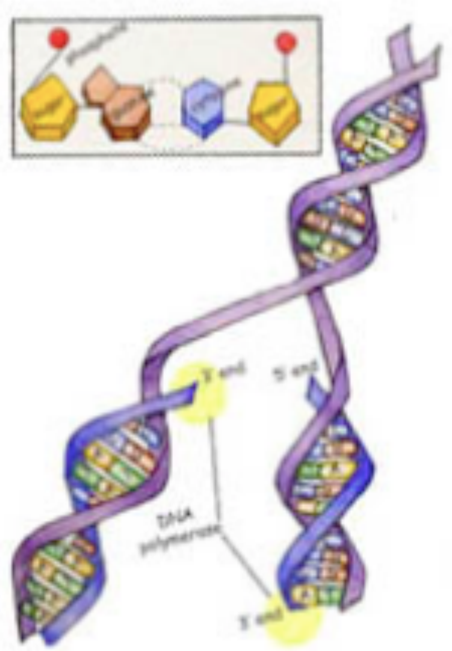
- *What we observe in nature might be only one instance of a whole class of possible open-ended systems.*
- *It might be simpler to design an evolutionary process than all the details of an intelligent system itself.*

A Possible Path to AI

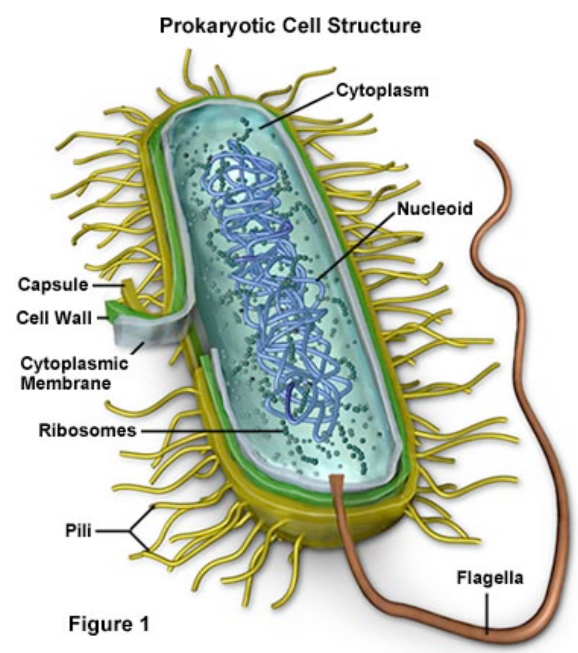
biological evolution	≈	artificial evolution
↓		↓
intelligent organisms	≈	artificial intelligence

Artificial Evolution

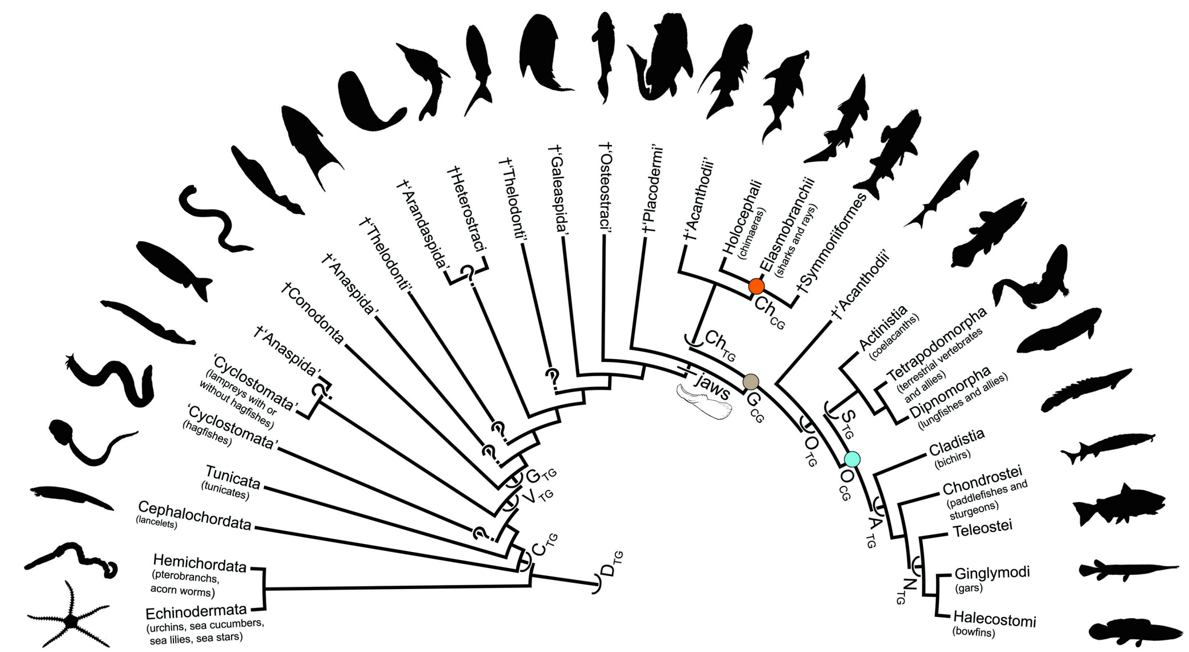
is a dynamical system where



structures emerge



and further grow in **complexity**



in an open-ended manner

Artificial Evolution

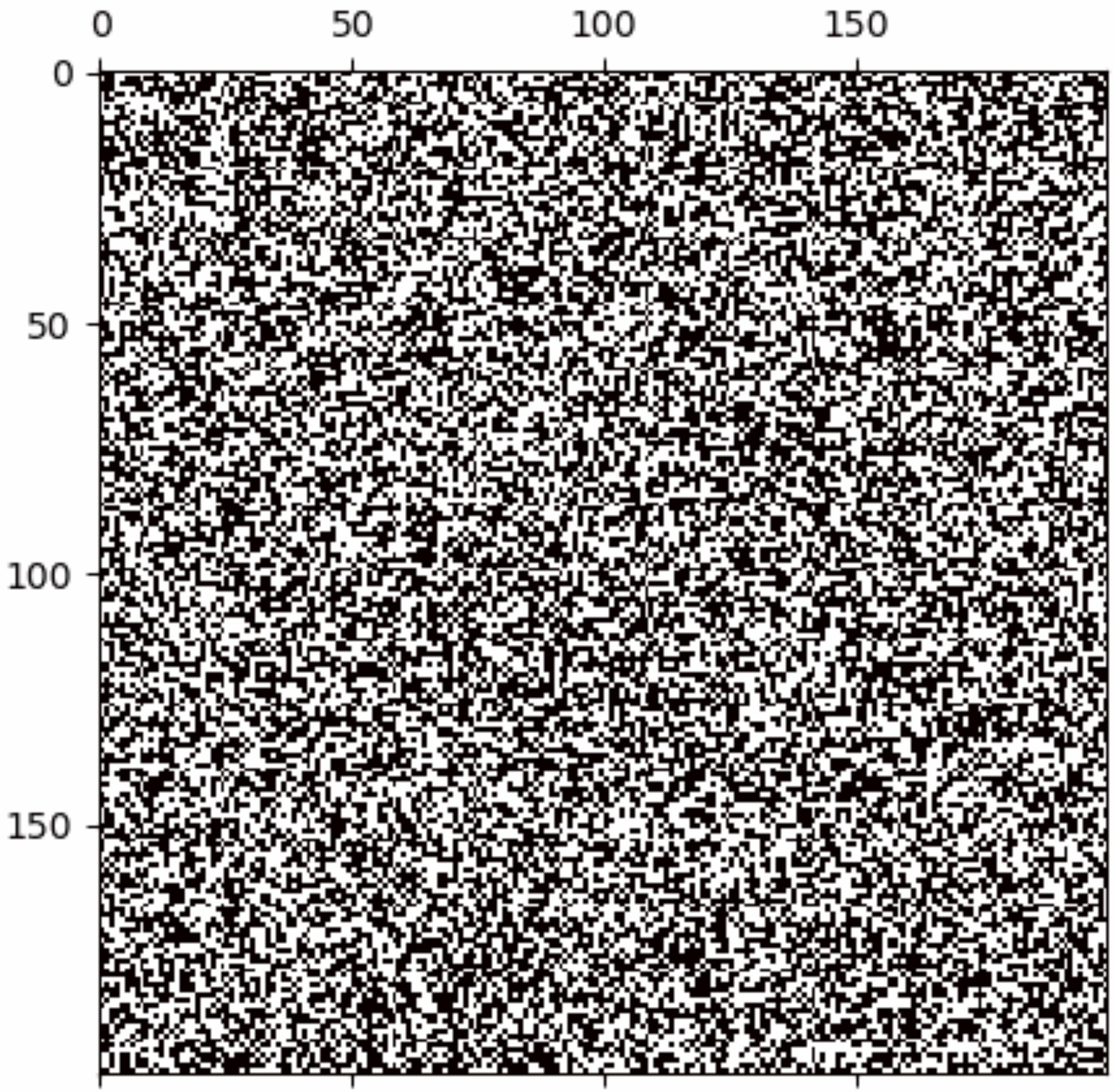
Designing artificial systems evolving in an open-ended way is an open problem for the Artificial Life community.

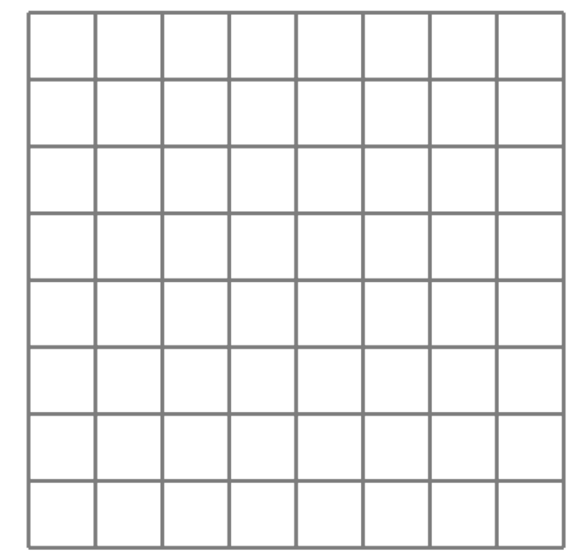
Possible mathematical models of AE:

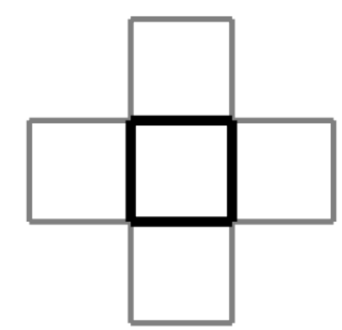
- cellular automata (Game of Life), Turing machines, random Boolean networks, neural nets,…

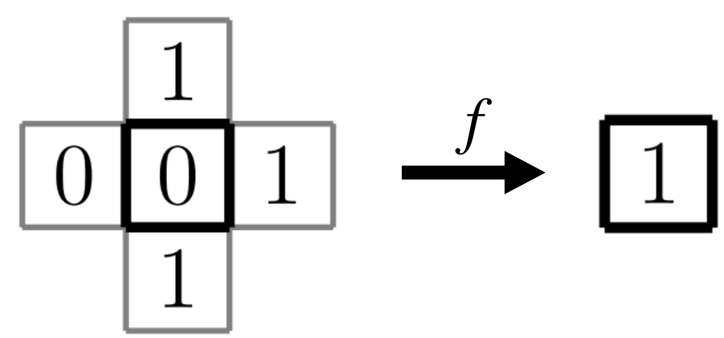
Cellular Automata

As Models of Artificial Evolution

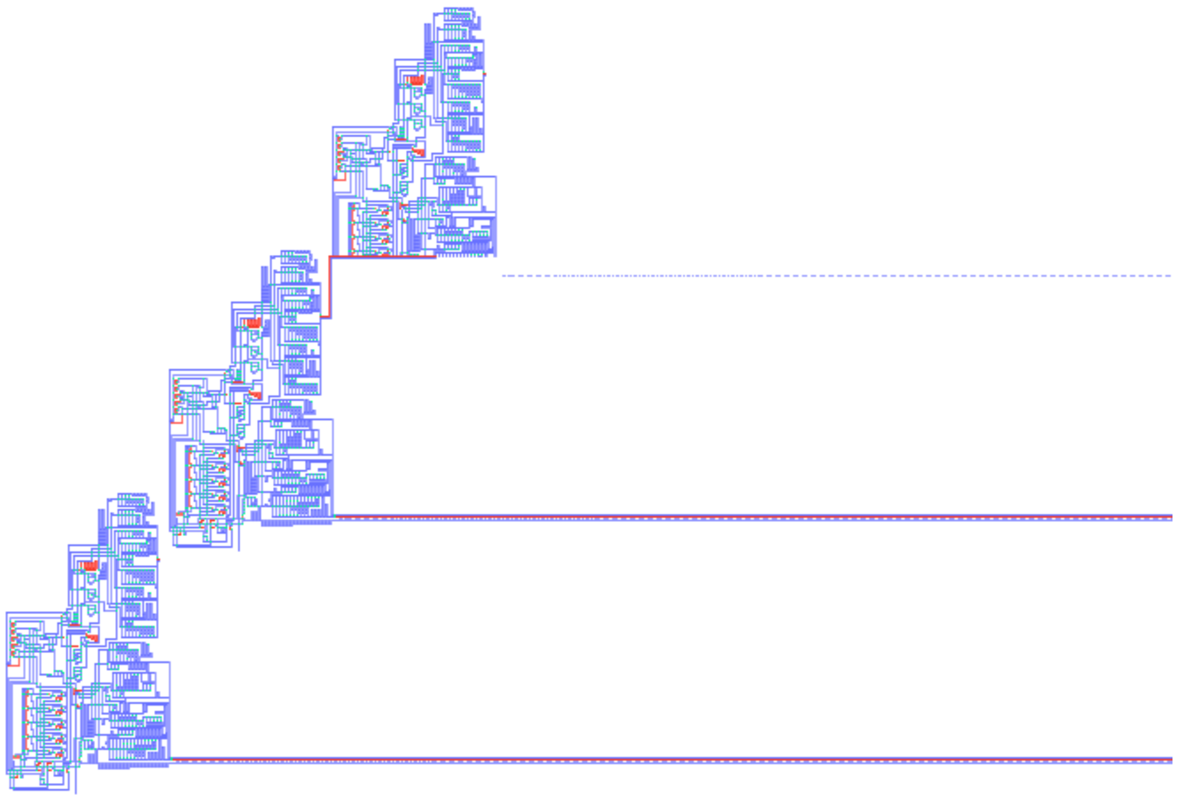


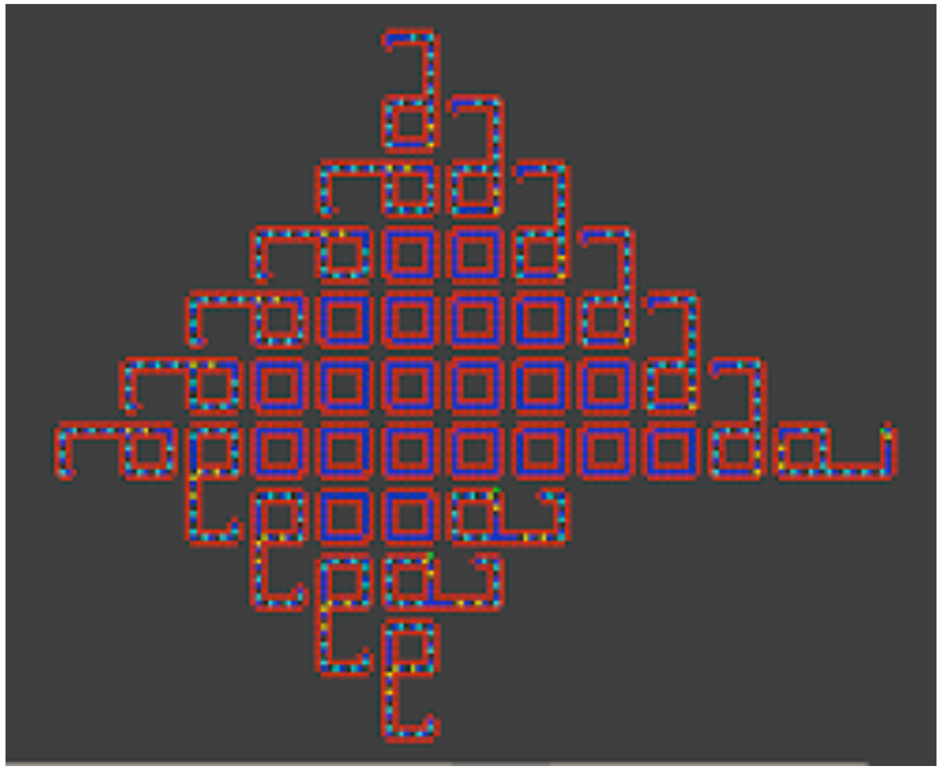




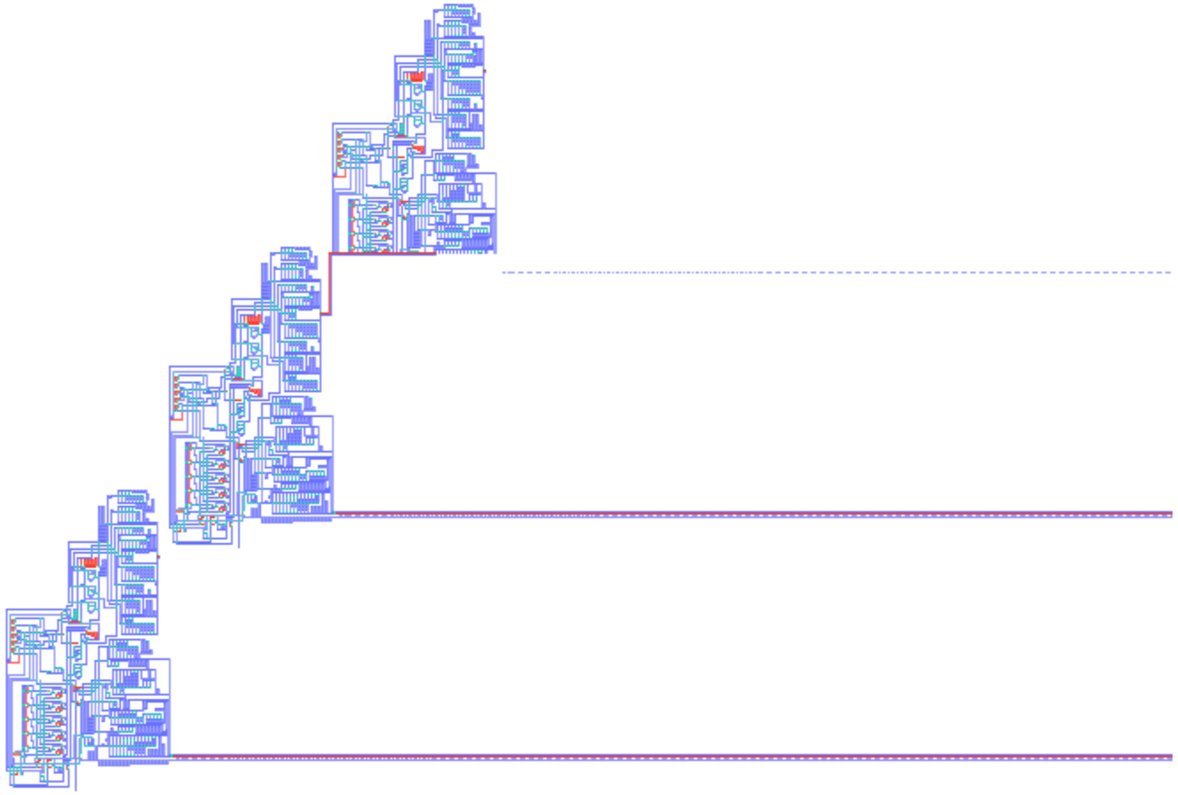


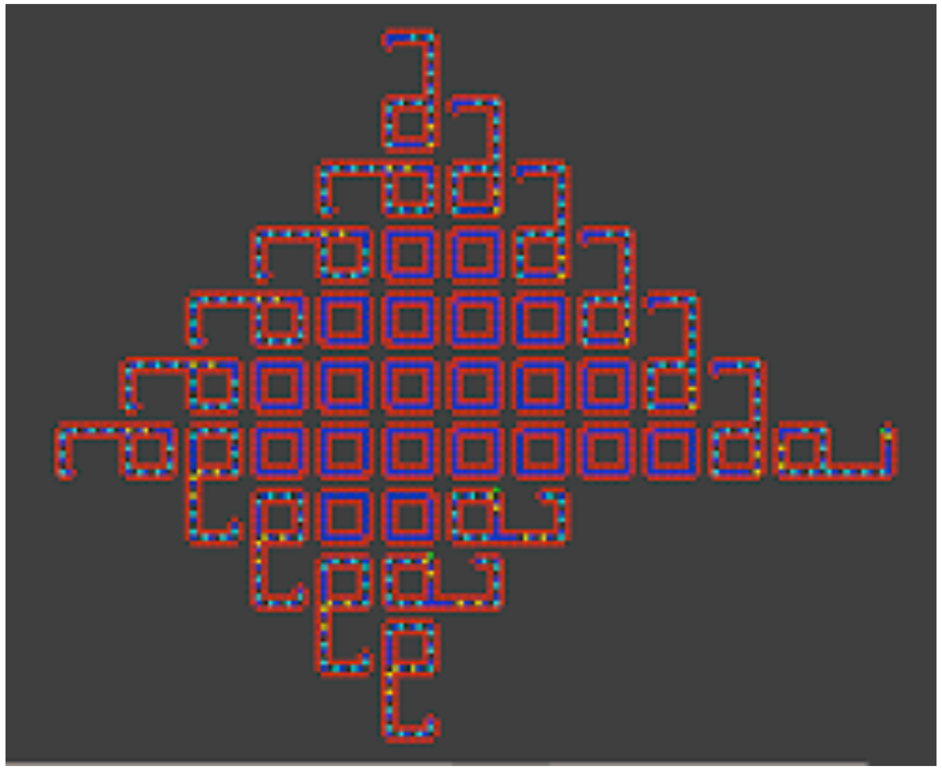
Cellular Automata





Cellular Automata



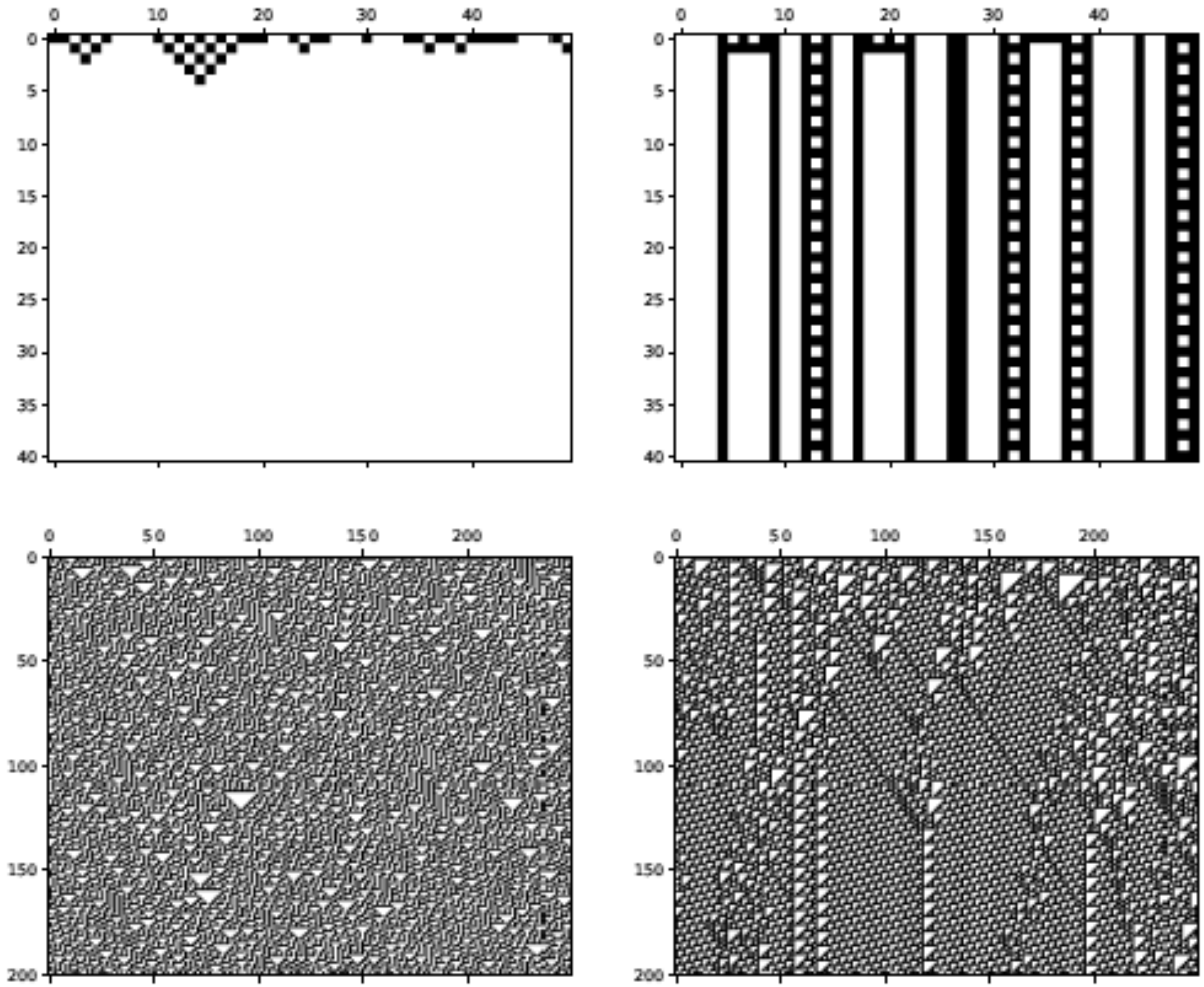


- simple
- fast to simulate
- fascinating visualisations

Complex Systems

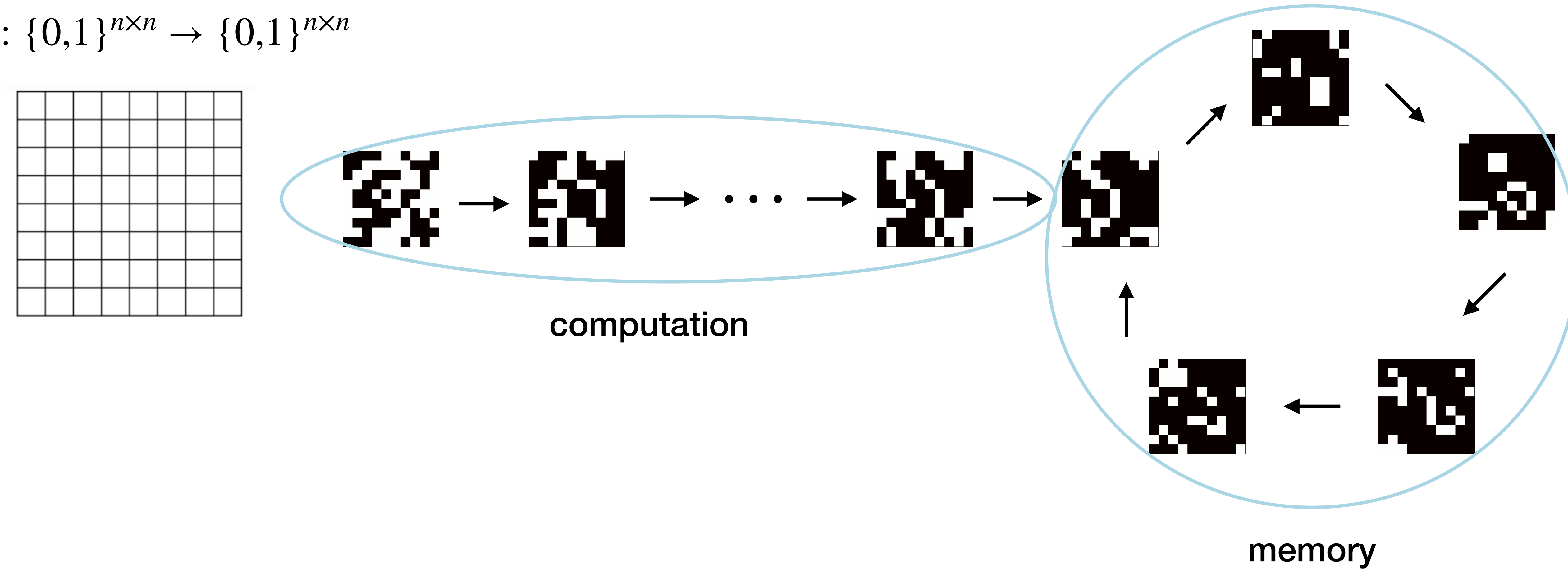
- How do we detect the emerging structures?
- How do we measure the complexity of the system?
- A classification method is needed

Classification of CA Dynamics



Transient Classification
of CA Dynamics

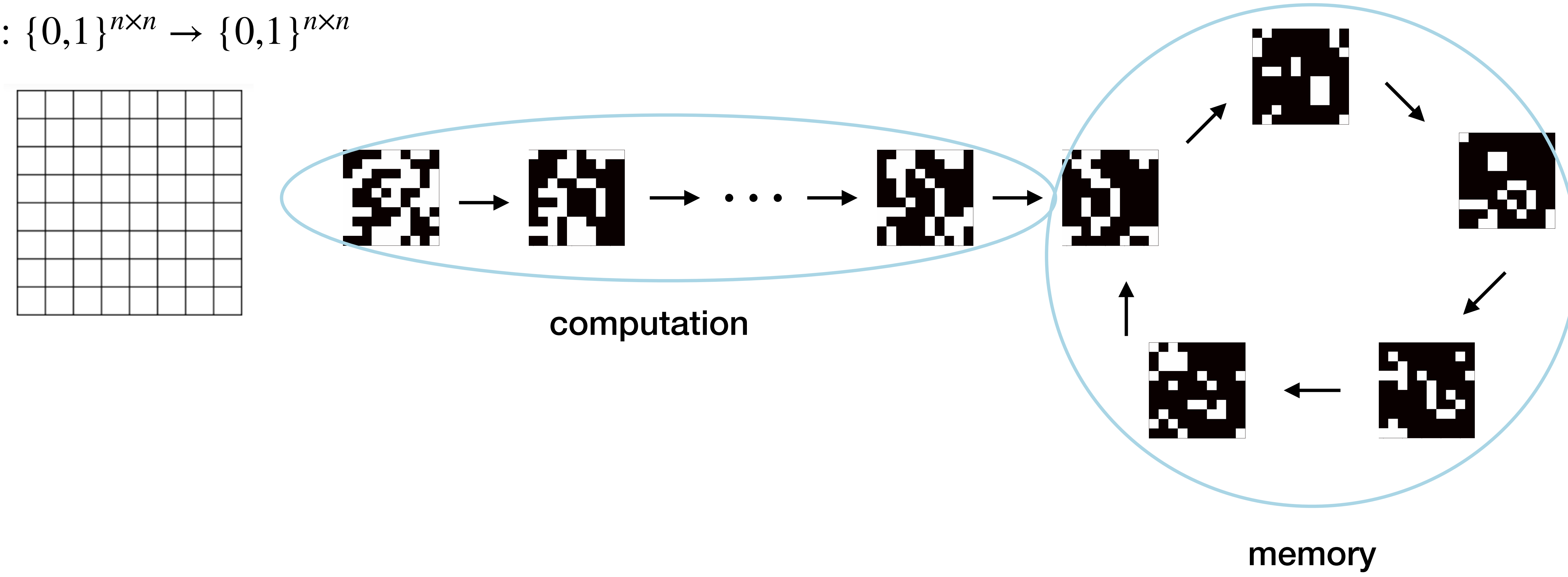
$F : \{0,1\}^{n \times n} \to \{0,1\}^{n \times n}$



transient length = time before the CA enters a loop

goal 1: measure the average transient length of a CA

$F : \{0,1\}^{n\times n} \rightarrow \{0,1\}^{n\times n}$



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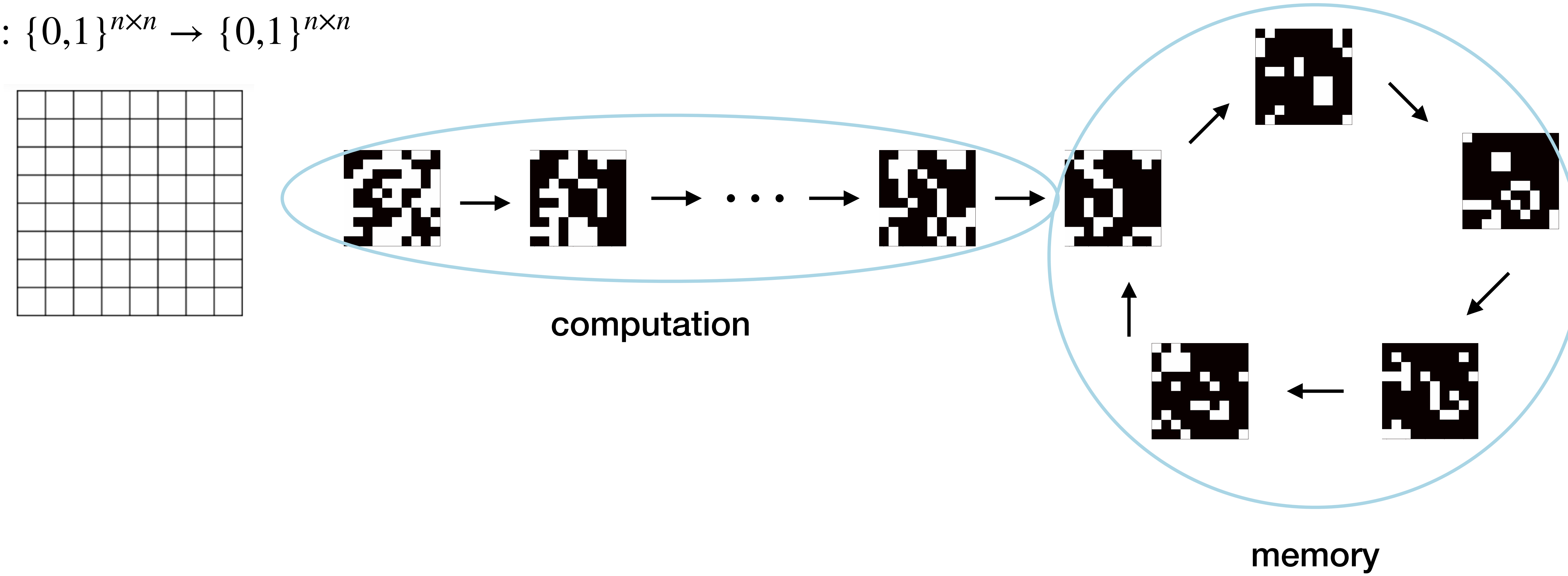
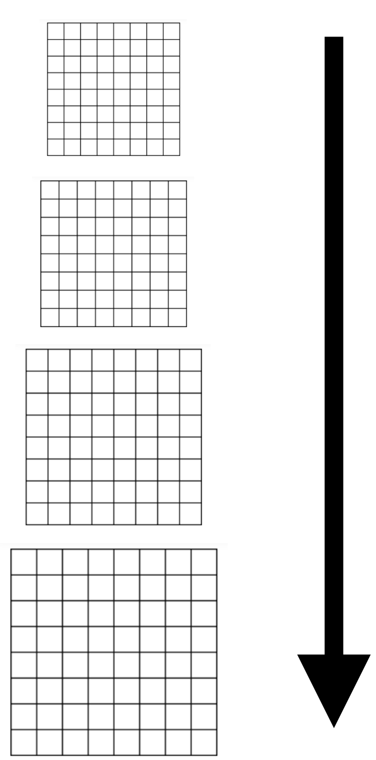
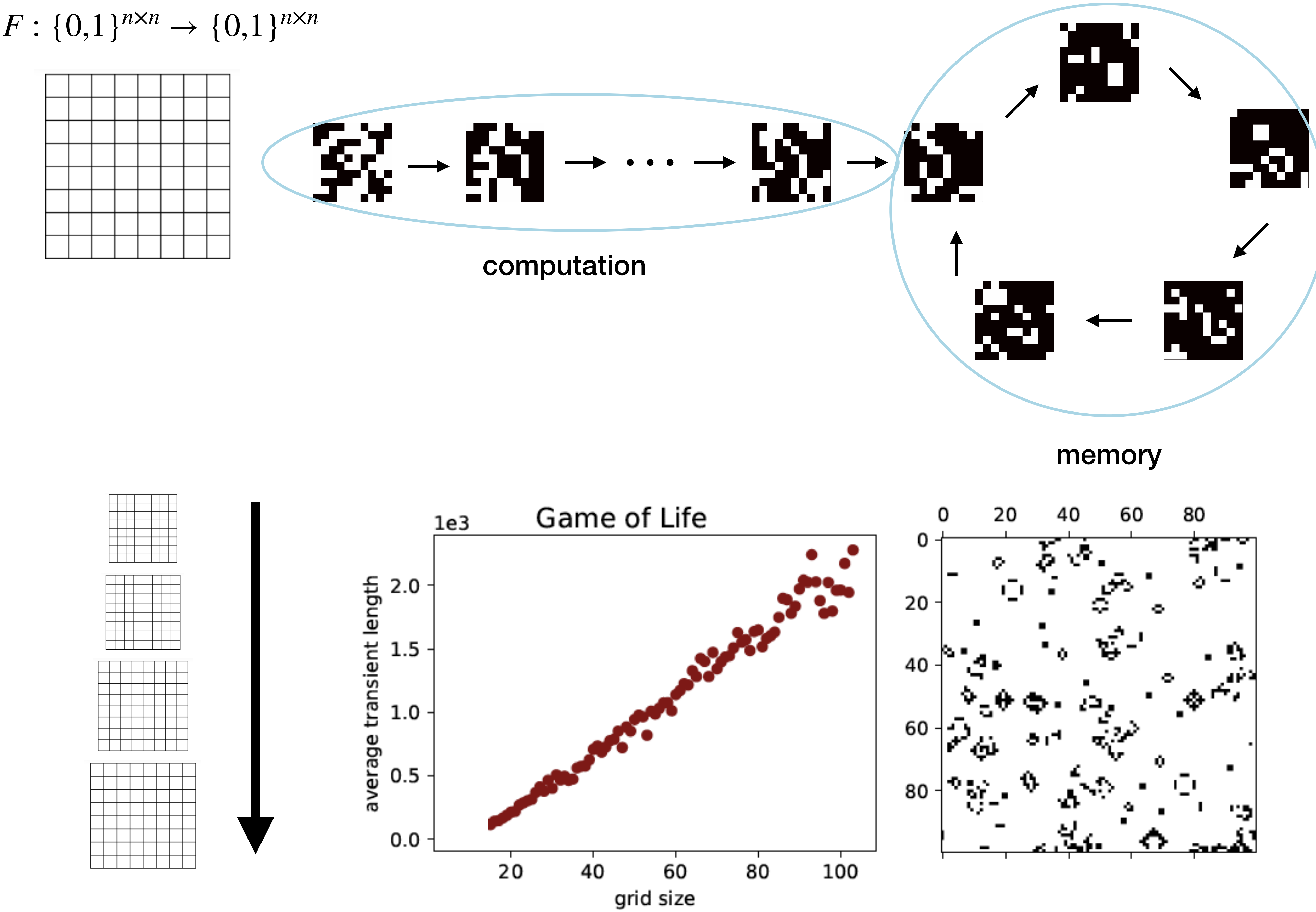


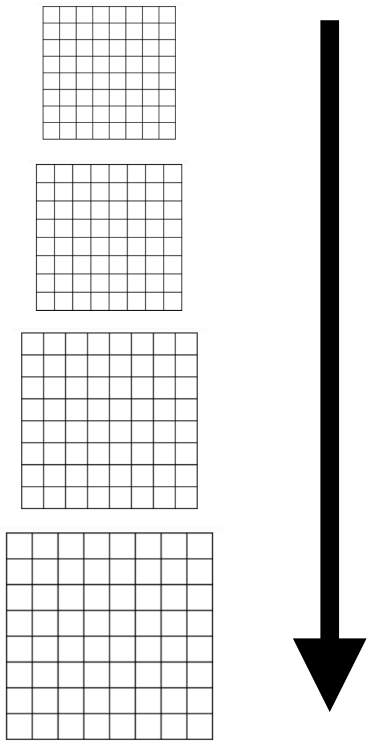




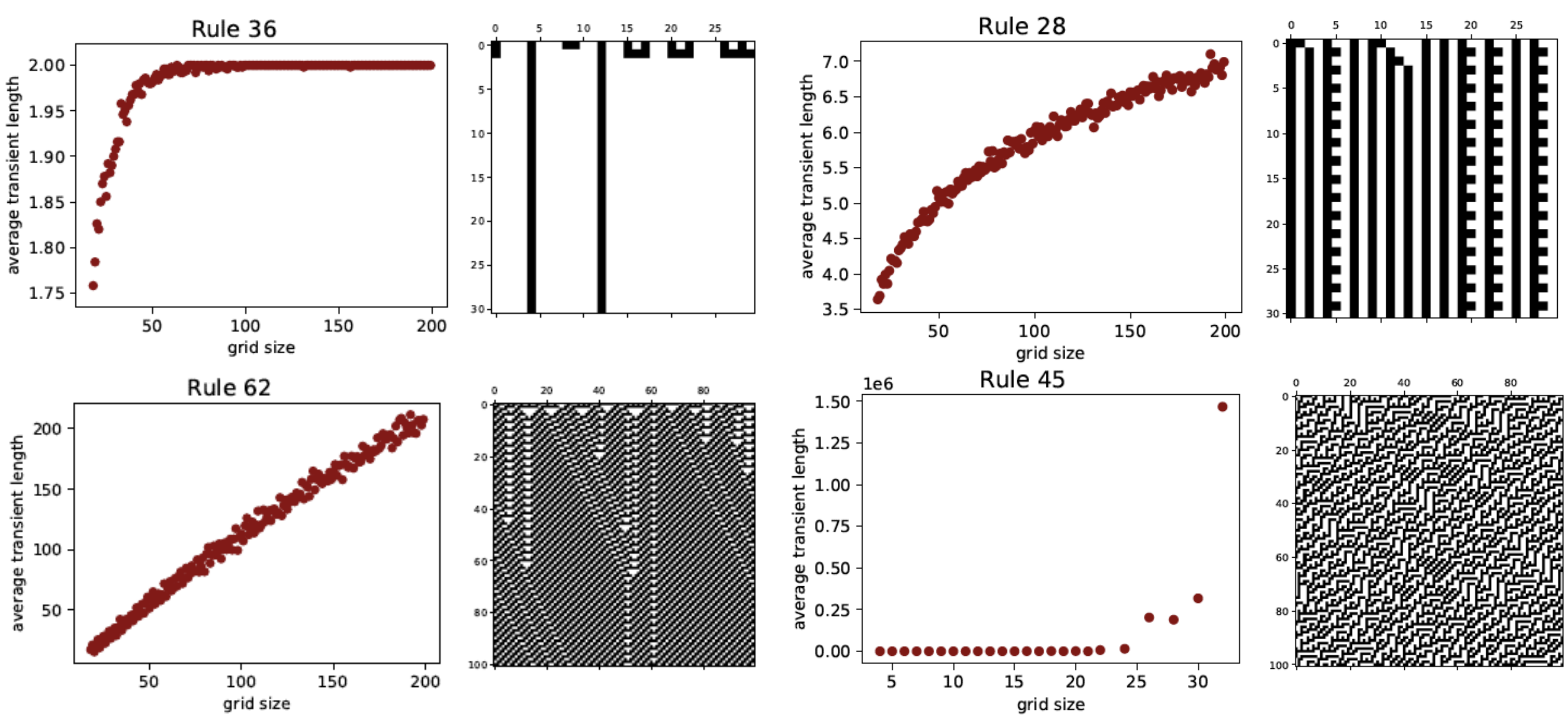
$F : \{0,1\}^{n \times n} \to \{0,1\}^{n \times n}$
computation
memory
Game of Life
1e3
average transient length
grid size
0.0
0.5
1.0
1.5
2.0
20
40
60
80
100
0
20
40
60
80

Transient Classification

of CA Dynamics



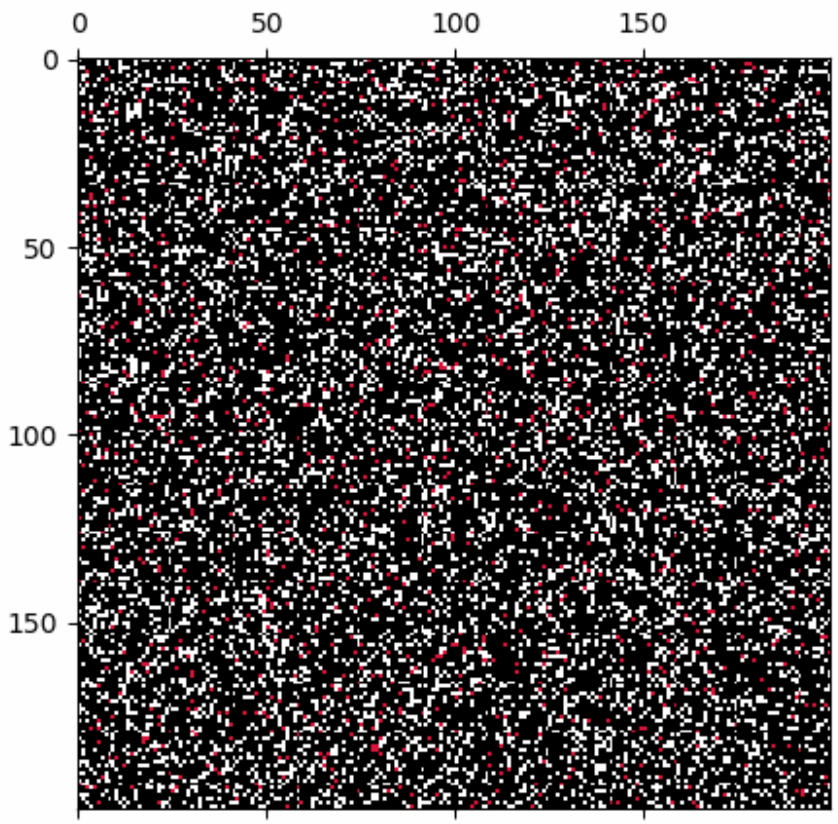
goal 2: measure the asymptotic growth
of the average transient length
of a given CA



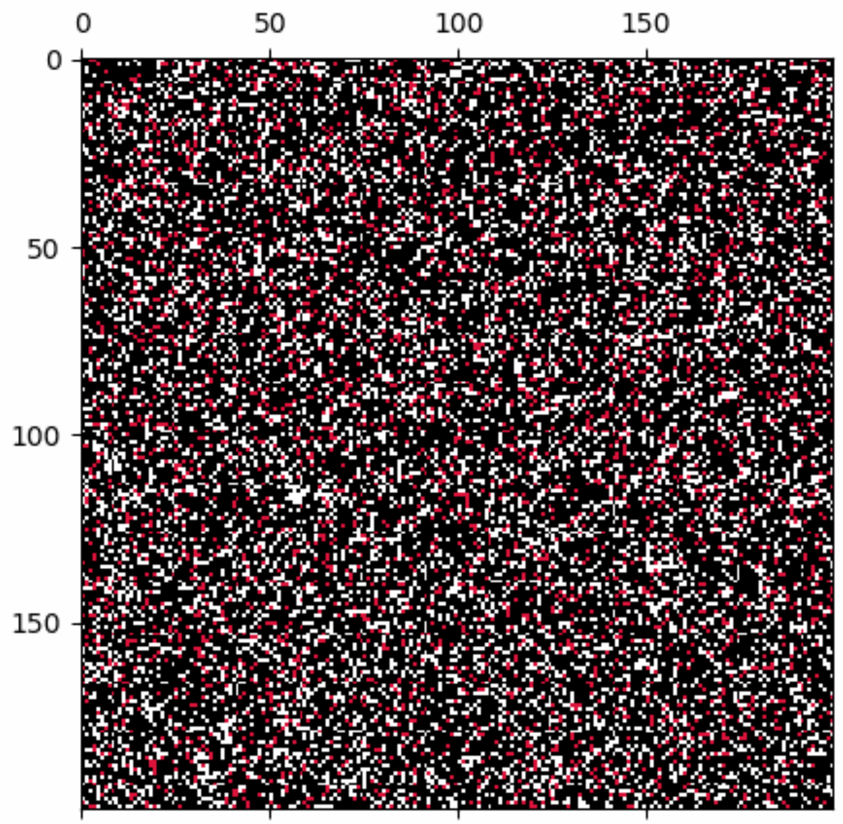
Transient Classification

Results

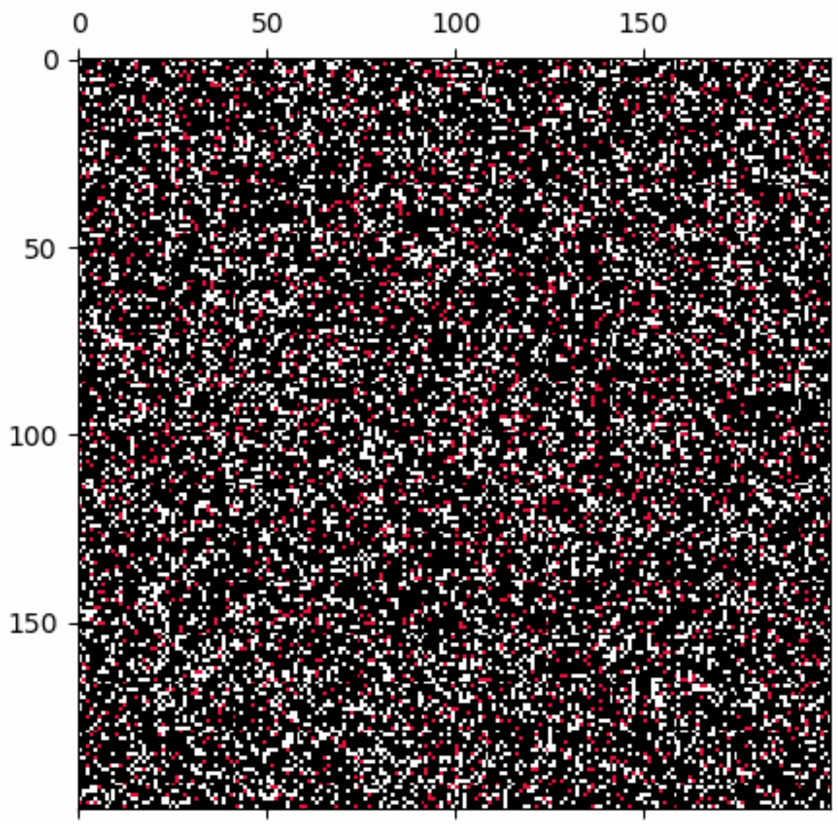
logarithmic growth



polynomial growth



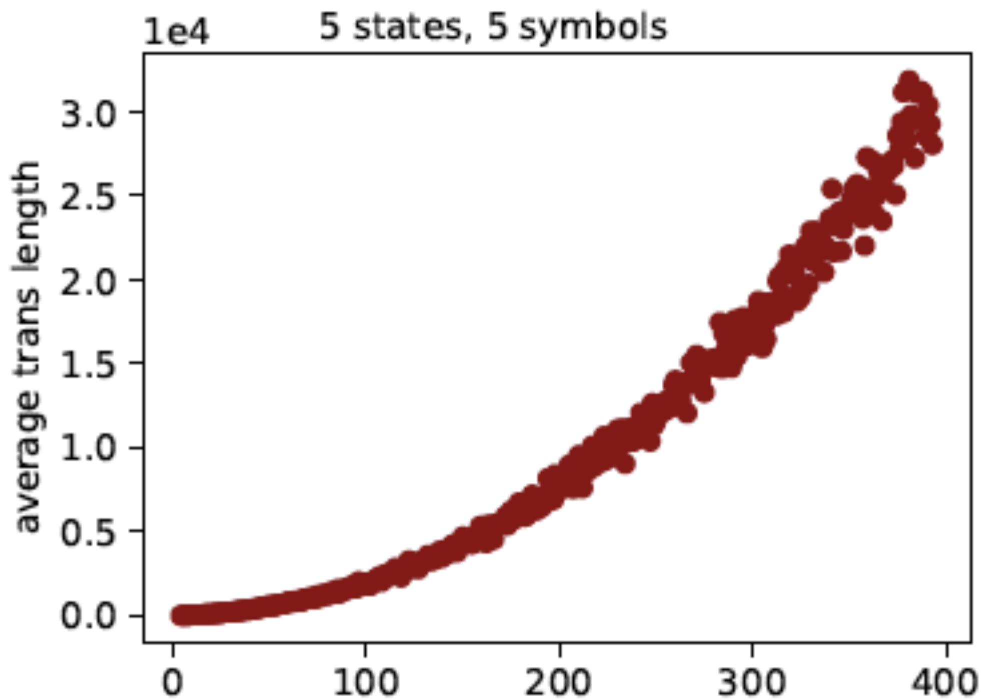
exponential growth

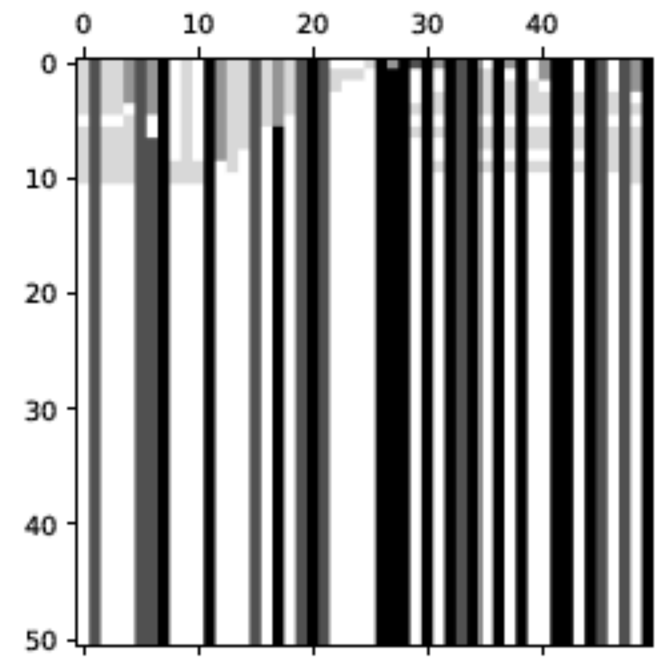


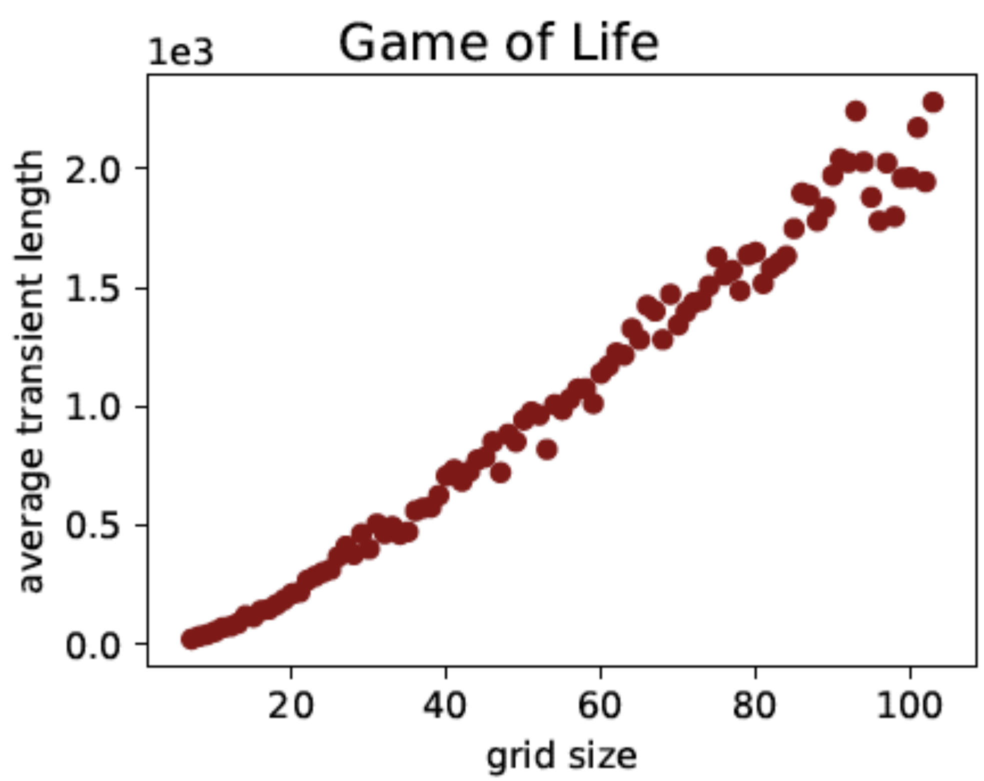
Transient Classification

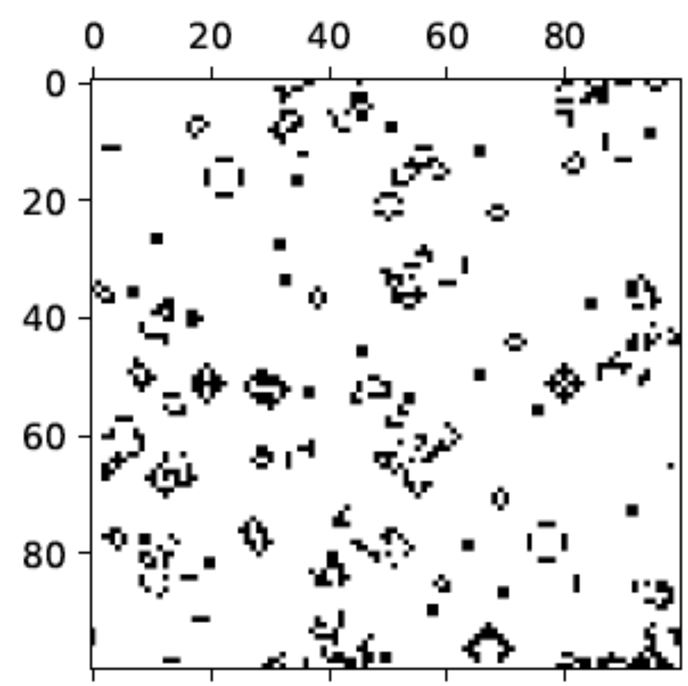
Results

Hypothesis: complex systems belong to the Lin/Poly Class





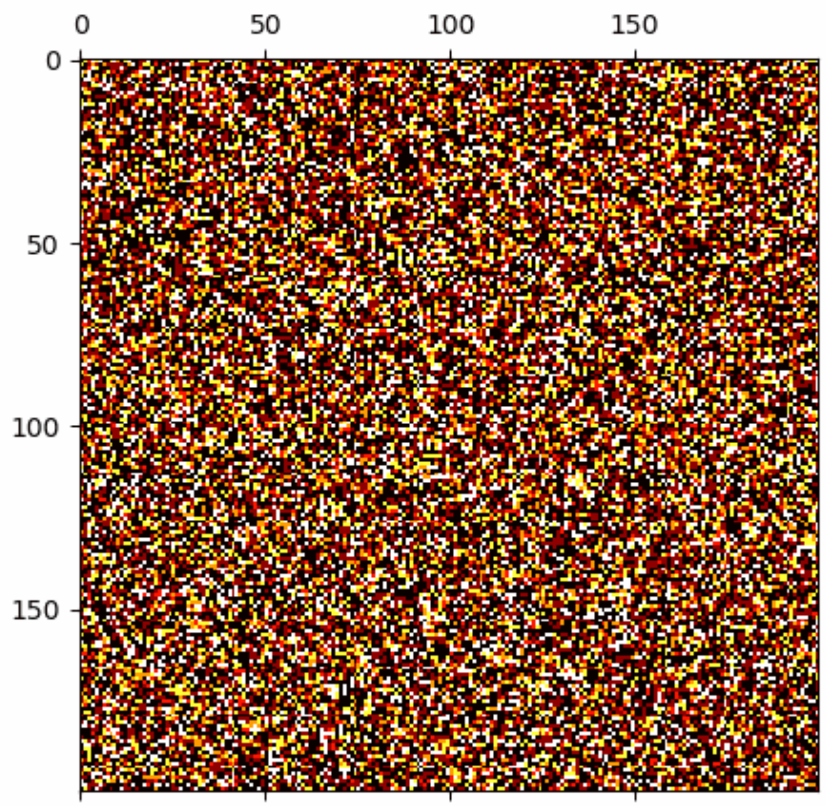


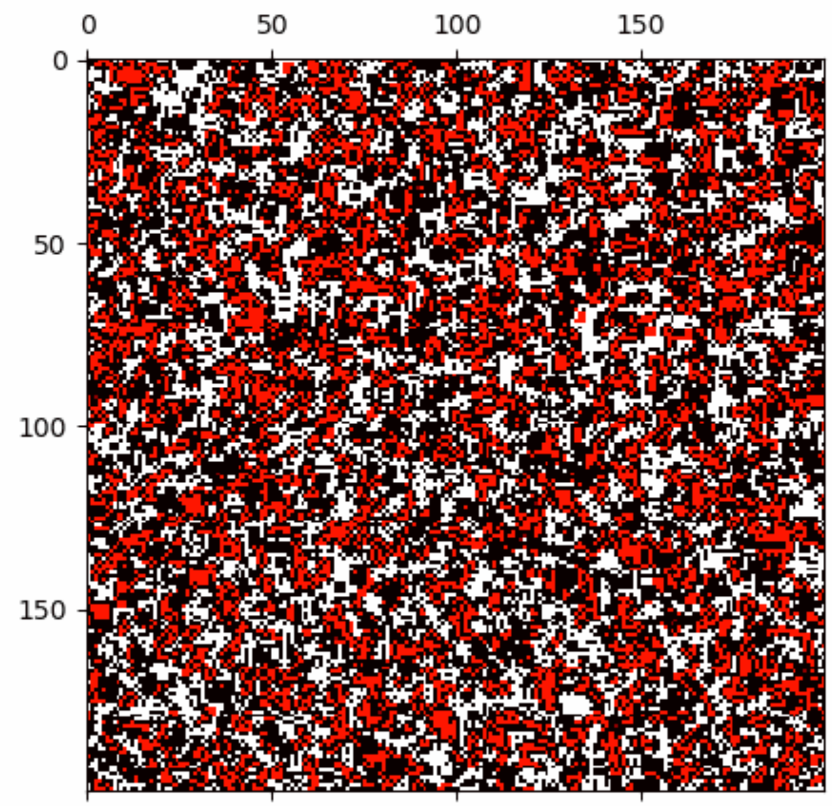


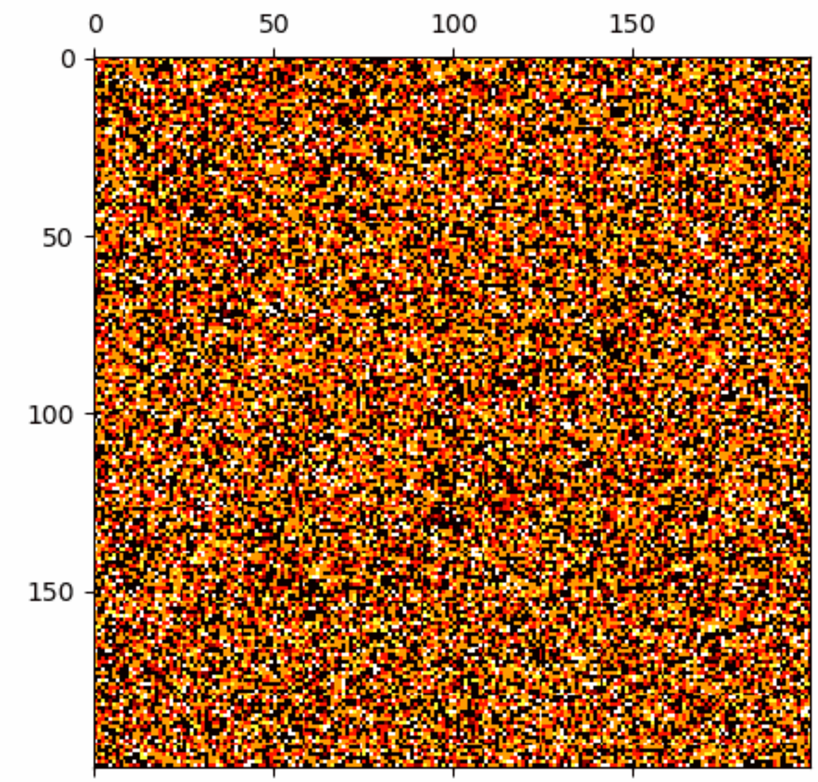
Transient Classification

Results

Cellular Automata with Complex Behavior:



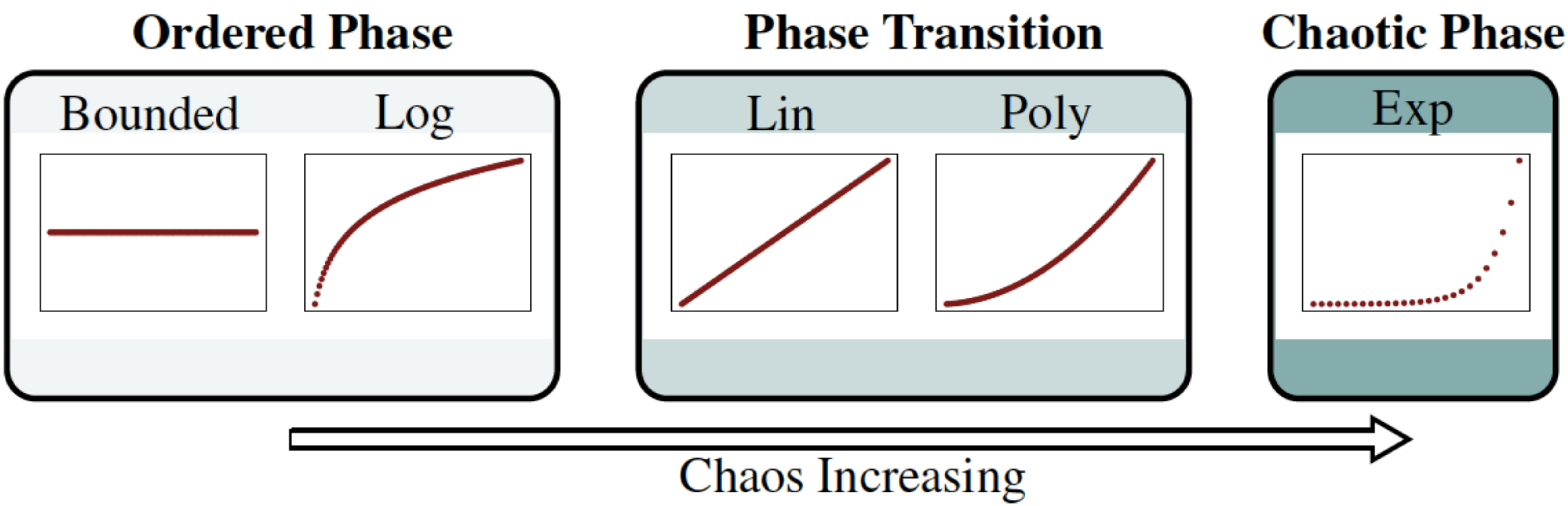




Transient Classification

Results

General trend in the results of the transient classification:



Summary

- complex systems $\longrightarrow$ artificial evolution $\longrightarrow$ AI
- no formal notions of emergence, **complexity**, evolution
- Transient Classification

    1) measure the average time before a CA enters a loop

    2) classify the asymptotic growth of this value

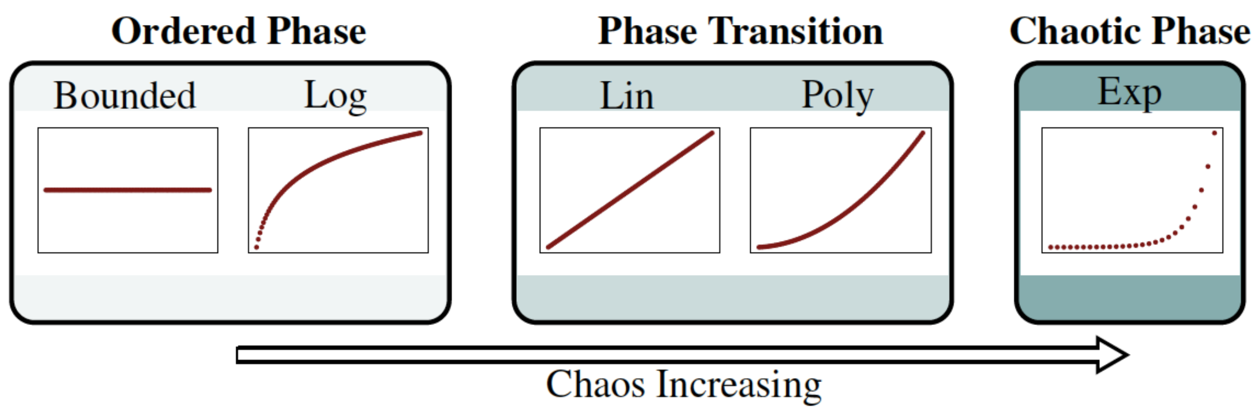
    3) Bounded/Log/Lin/Poly/Exp classes

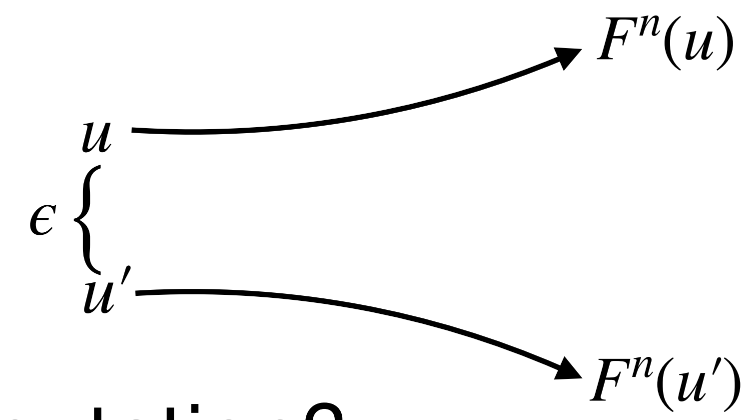
Classical ML Context

- in ML we set a goal and seek an algorithm minimizing the corresponding error
- in AE we use no supervision and simply let the systems evolve; we search for ones producing diverse, novel structures which further increase in complexity

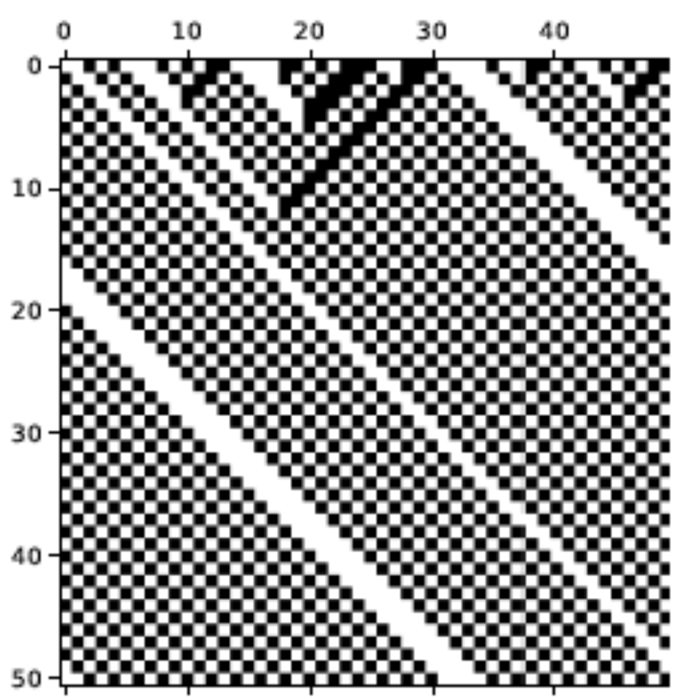
It might turn out that NN are a better model for artificial evolution than CA.

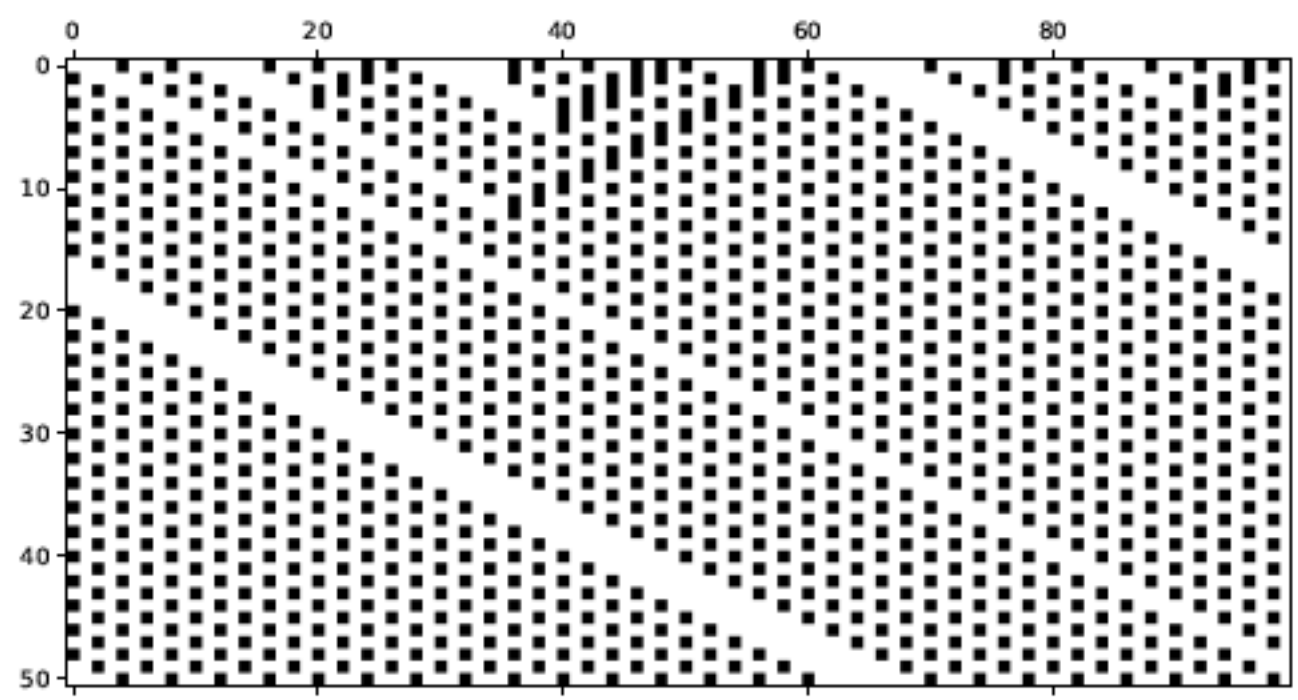
Chaos in Discrete Systems





- How to define chaos in discrete systems?
- Can chaotic CA perform any nontrivial computation?





Future Work

- formalize chaos in discrete systems
- find hyperparameter values corresponding to a phase transition in CA

  2 states, 2 dim, neigh size 7

  2 states, 2 dim, neigh size 8

  2 states, 2 dim, neigh size 9

- explore the dynamics of neural nets, study what initializations yield the most complex dynamics