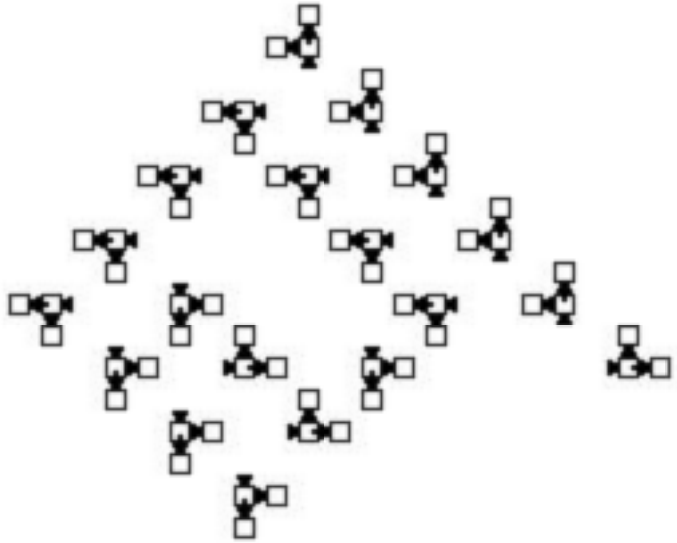

Self-Replicating Worms That Increase Structural Complexity through Gene Transmission

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Looking Backward...

Universal constructor-computer, J. von Neumann (1950's), E. F. Codd (1968)

Sexually reproducing cellular automata, P. M. B. Vitanyi (1973)

Self-replicating loop, C. G. Langton (1984), J. Byl (1989), J. A. Reggia *et al.* (1993), M. Sipper (1994)

Self-replicating loop with finite computational capabilities, G. Tempesti (1995)

Evolutionary discovery of self-replicating structures, J. D. Lohn and J. A. Reggia (1995)

Self-replication in reversible cellular automata, K. Morita and K. Imai (1995)

Self-replication with shape-encoding mechanism, K. Morita and K. Imai (1996)

Self-replicating loop capable of universal computation, J. Y. Perrier *et al.* (1996)

Spontaneous emergence of self-replicating loops, H. H. Chou and J. A. Reggia (1997)

Problem solving during artificial selection of self-replicating loops, H. H. Chou and J. A. Reggia (1998)

Structurally dissolvable self-reproducing loop, H. Sayama (1998)

Evoloop: An evolving SDSR loop, H. Sayama (1999)

Five Questions Posed by von Neumann

(1) Universal computation

(2) Capability of construction

(3) Universal construction

(4) Self-reproduction

} solved by von Neumann himself

(5) Complexity-increasing evolution remains unsolved

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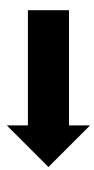
What keeps evolution in CA so simple?

Too simple mechanism which requires a simple square (or rectangular) shape



Remove this restriction using another more flexible mechanism to realize complexity-increasing evolution

Shape-Encoding Mechanism

Morita and Imai (1996)

Organisms dynamically and continuously encode phenotype into genotype by self-inspection (Laing 1977)

My Model

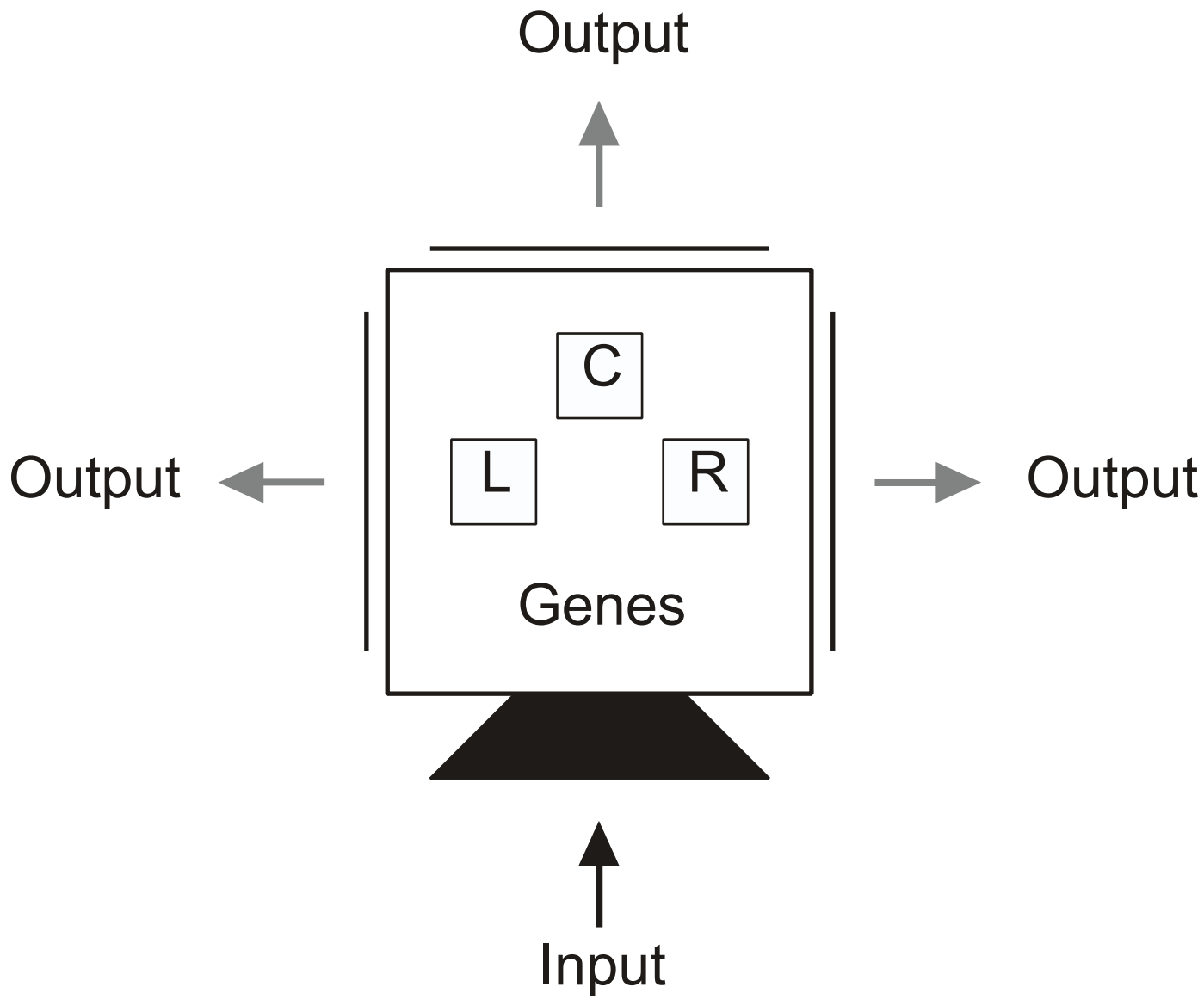
Deterministic 2D CA
(65-state 5-neighbor)

Shape-encoding mechanism

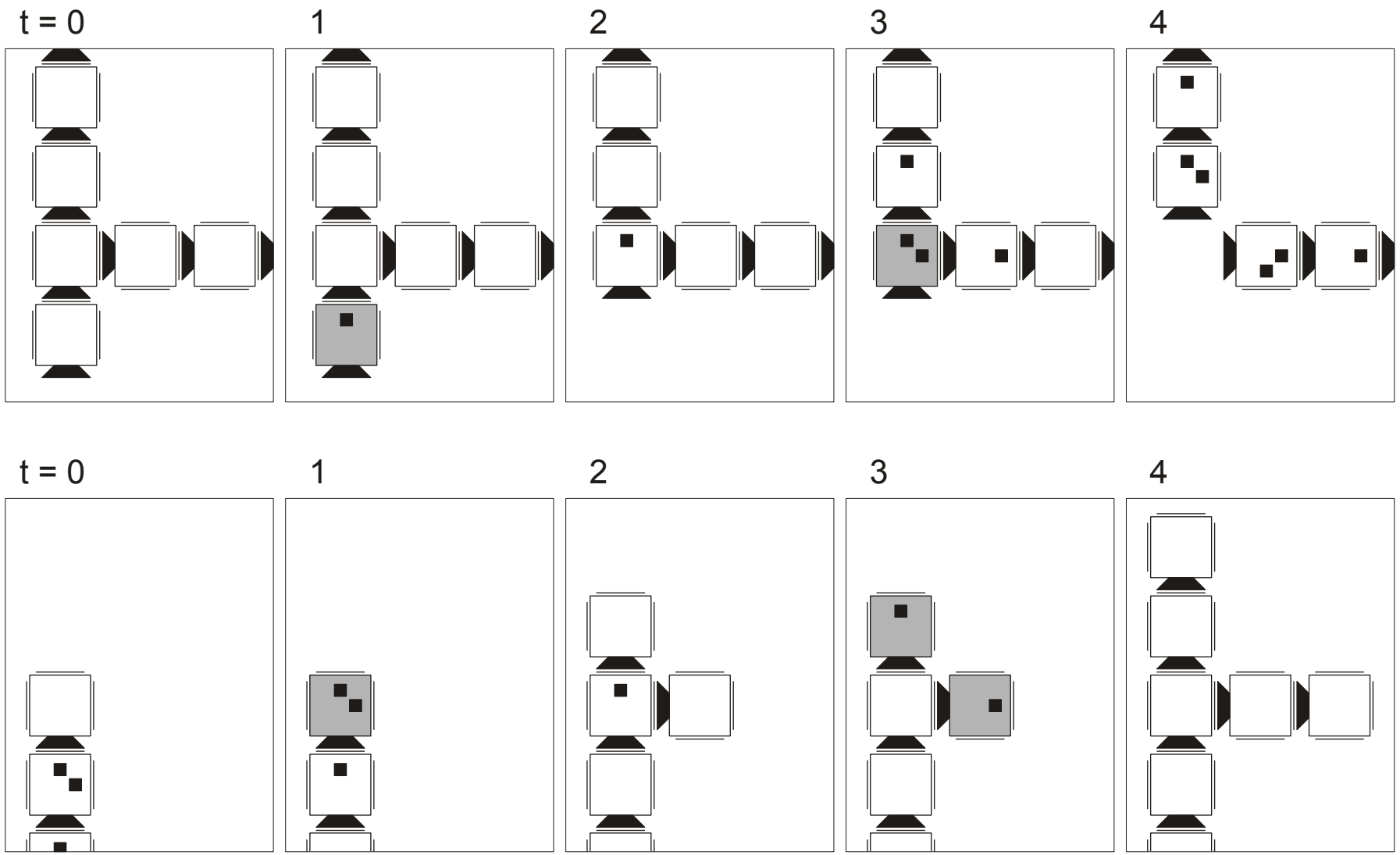
Finite size of resource (space)

Collision of organisms gives rise to variation

Design of Structure Cells



Shape Encoding / Decoding



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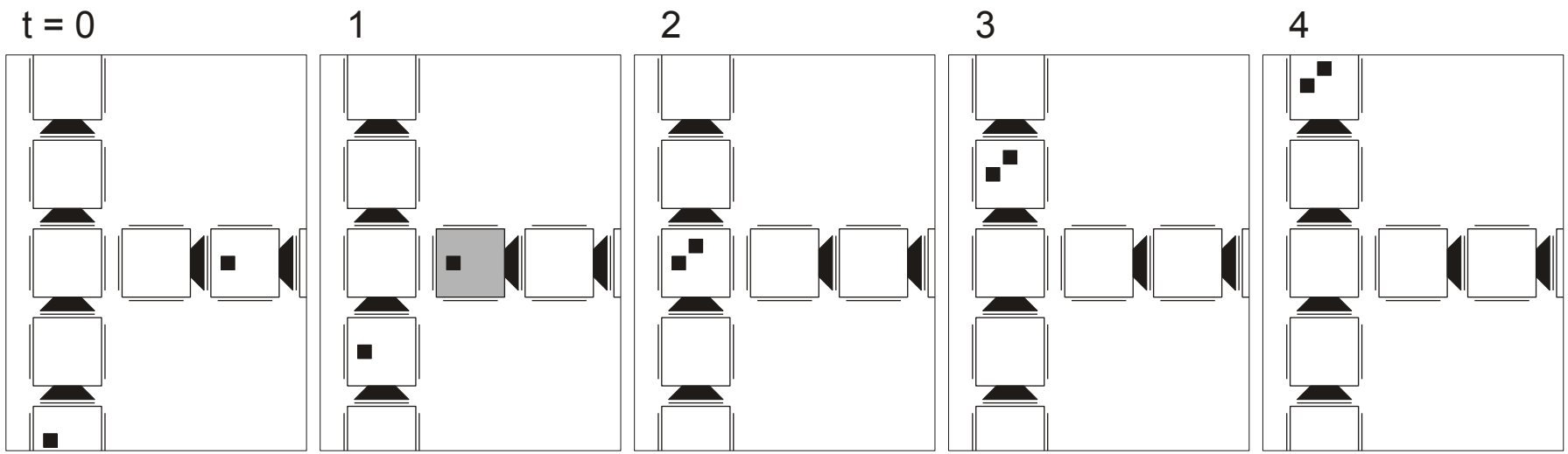
Gene Transmission



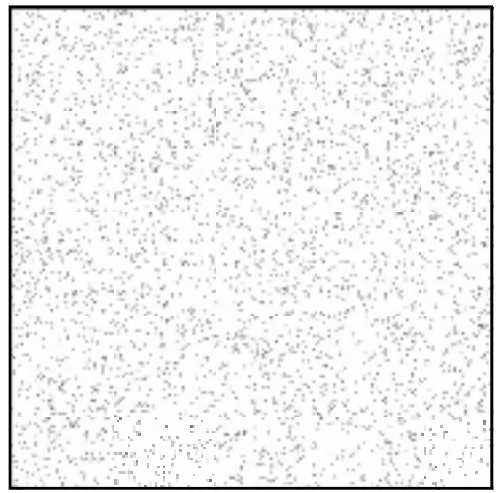
Experiment Settings

Space:

200x200 sites with cutoff boundary conditions

Initial configuration:

Blank structure cells randomly distributed at some specified density



Macrolevel behavior

Short transient period

↓

Growing colonies of self-replicators

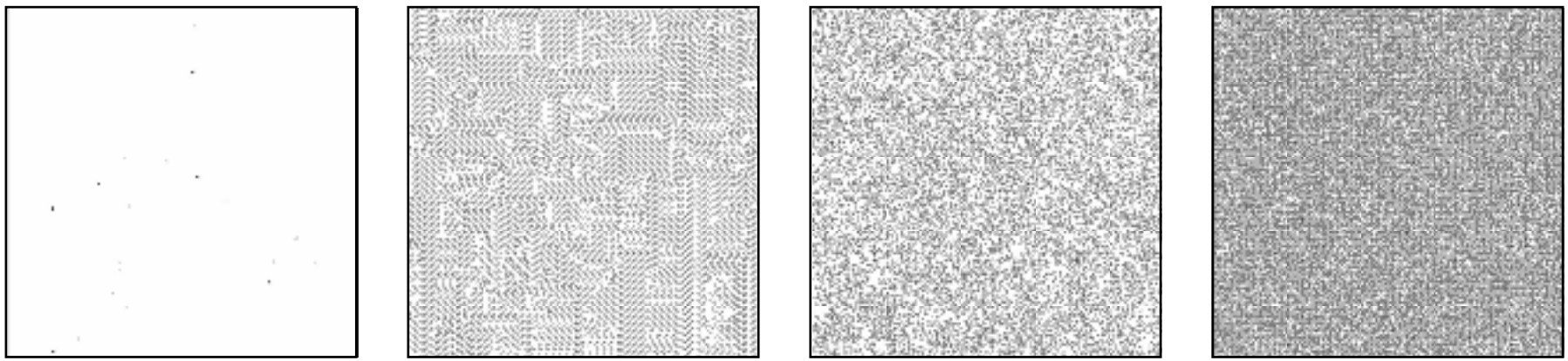
↓

Interaction among the clusters

↓

Four possible final states:

Type I **Type II** **Type III** **Type IV**



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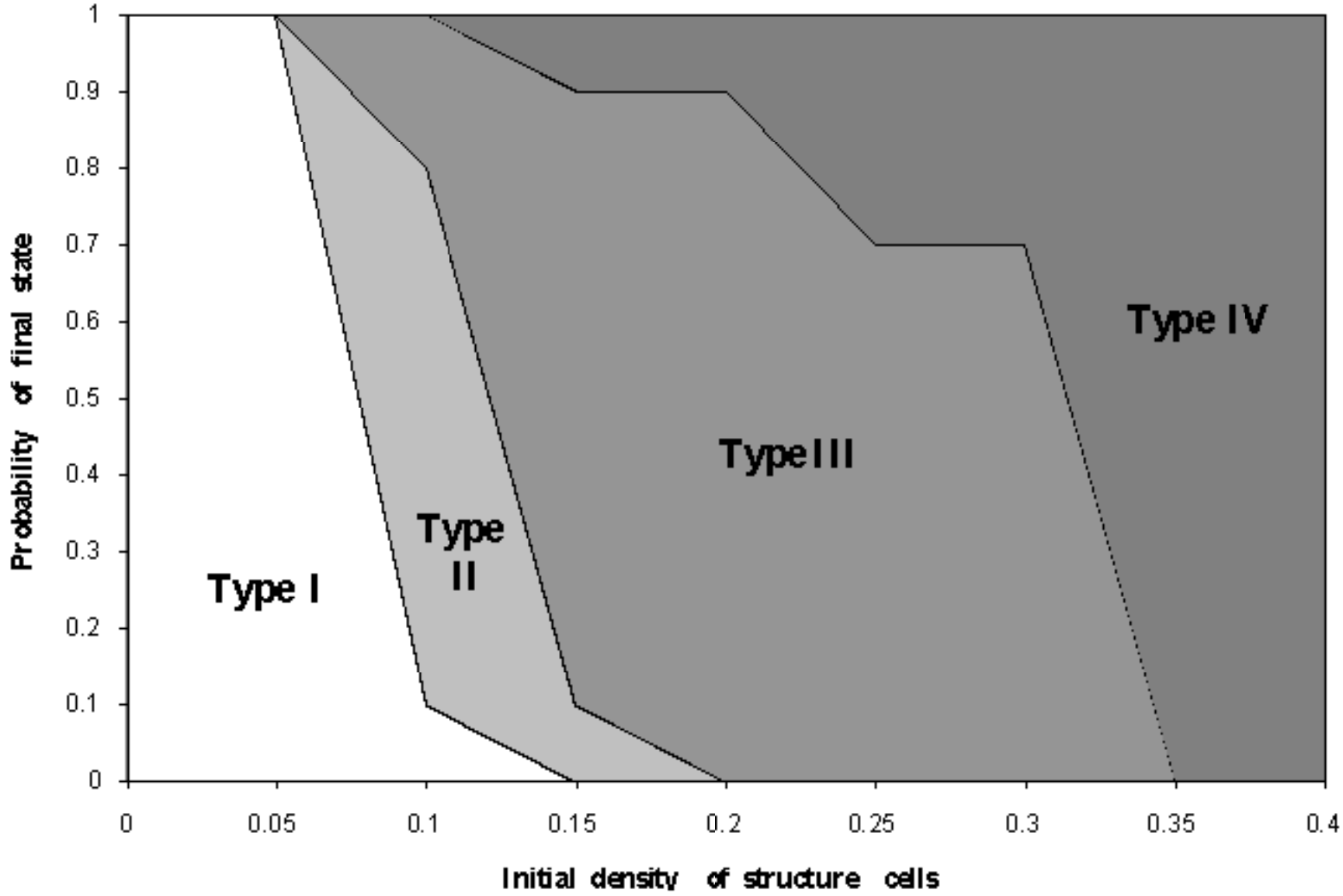
Probabilities of Four Types



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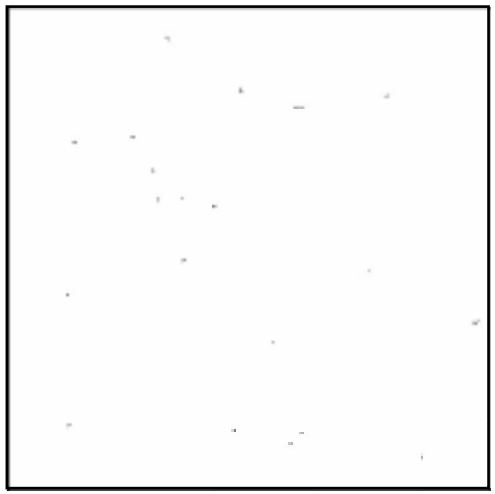
Evolution in Type III

Principal behavior for a regime with initial cell density 0.15 - 0.3

Dense clouds of complicated self-replicators are formed and dominate simpler ones

Evolution in Type III

t=5



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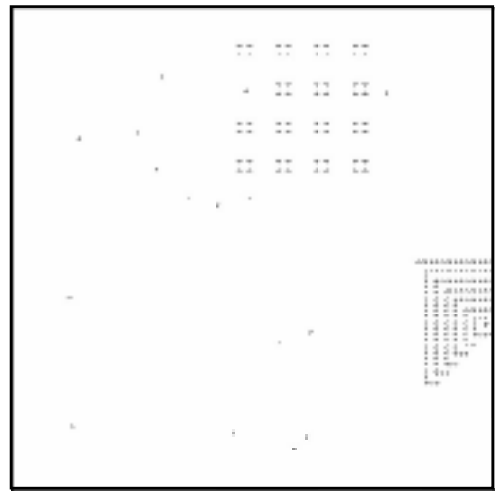

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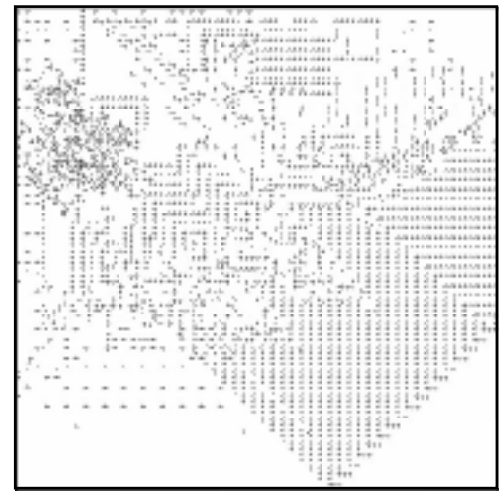

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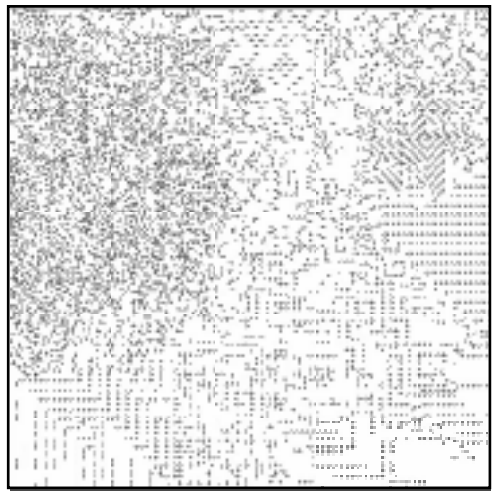

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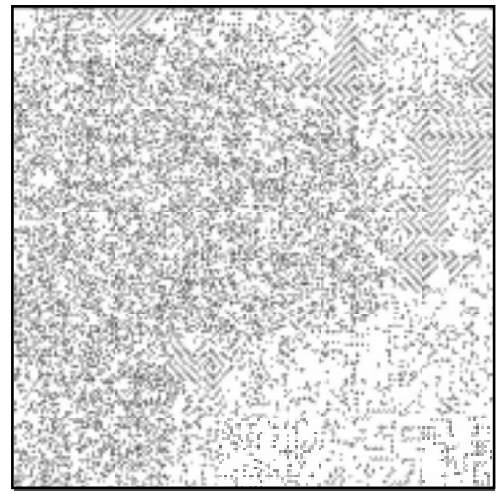

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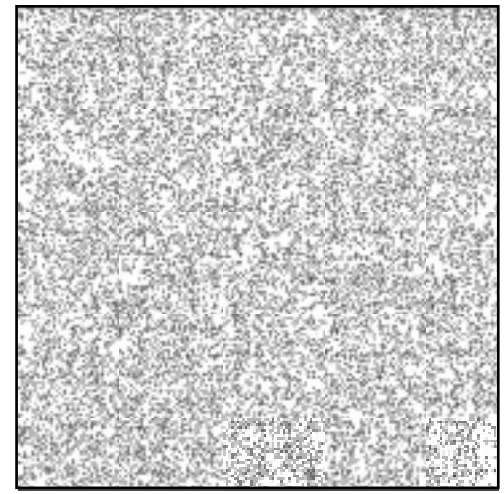

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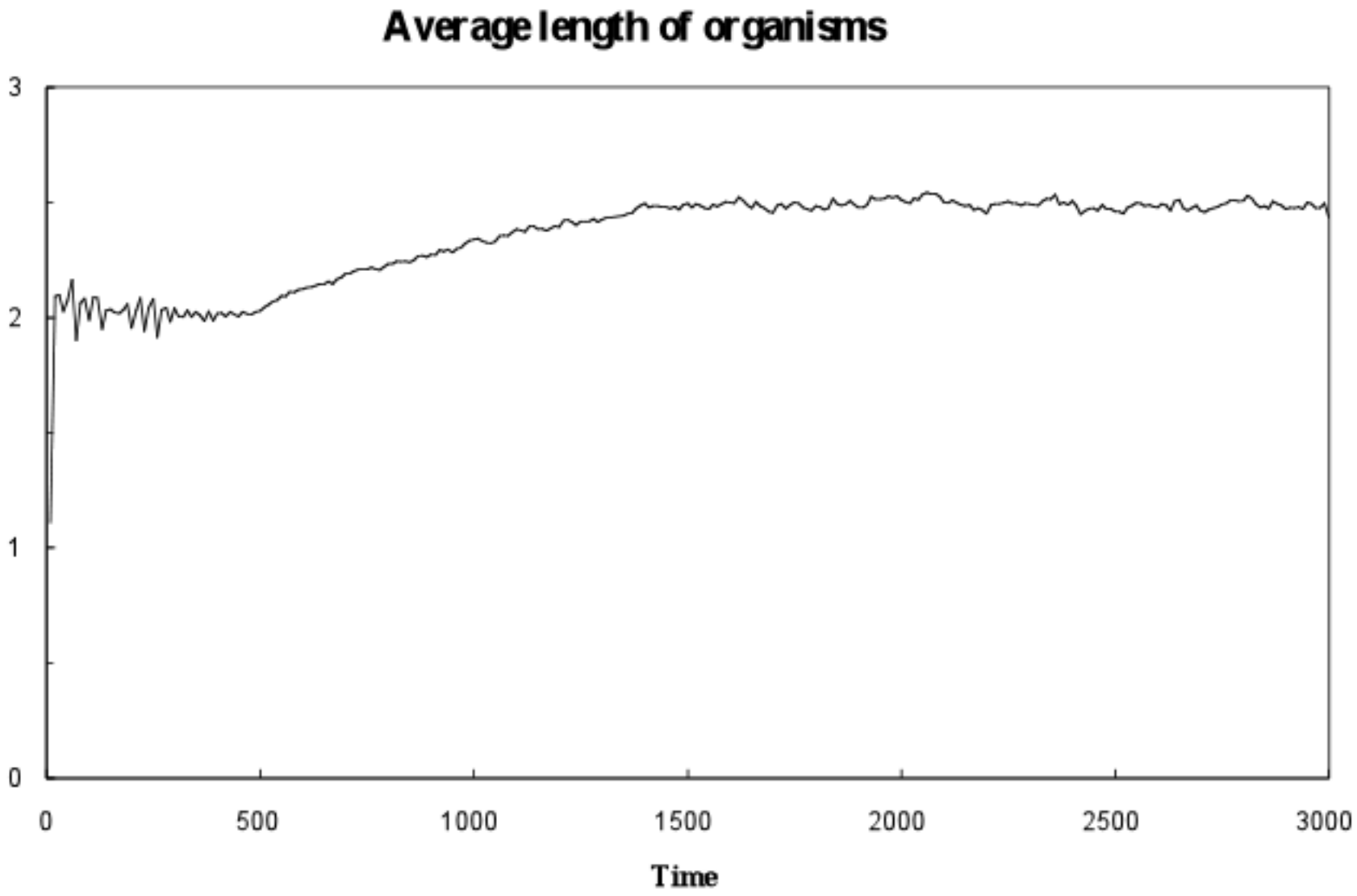
Increase of Structural Complexity (1)



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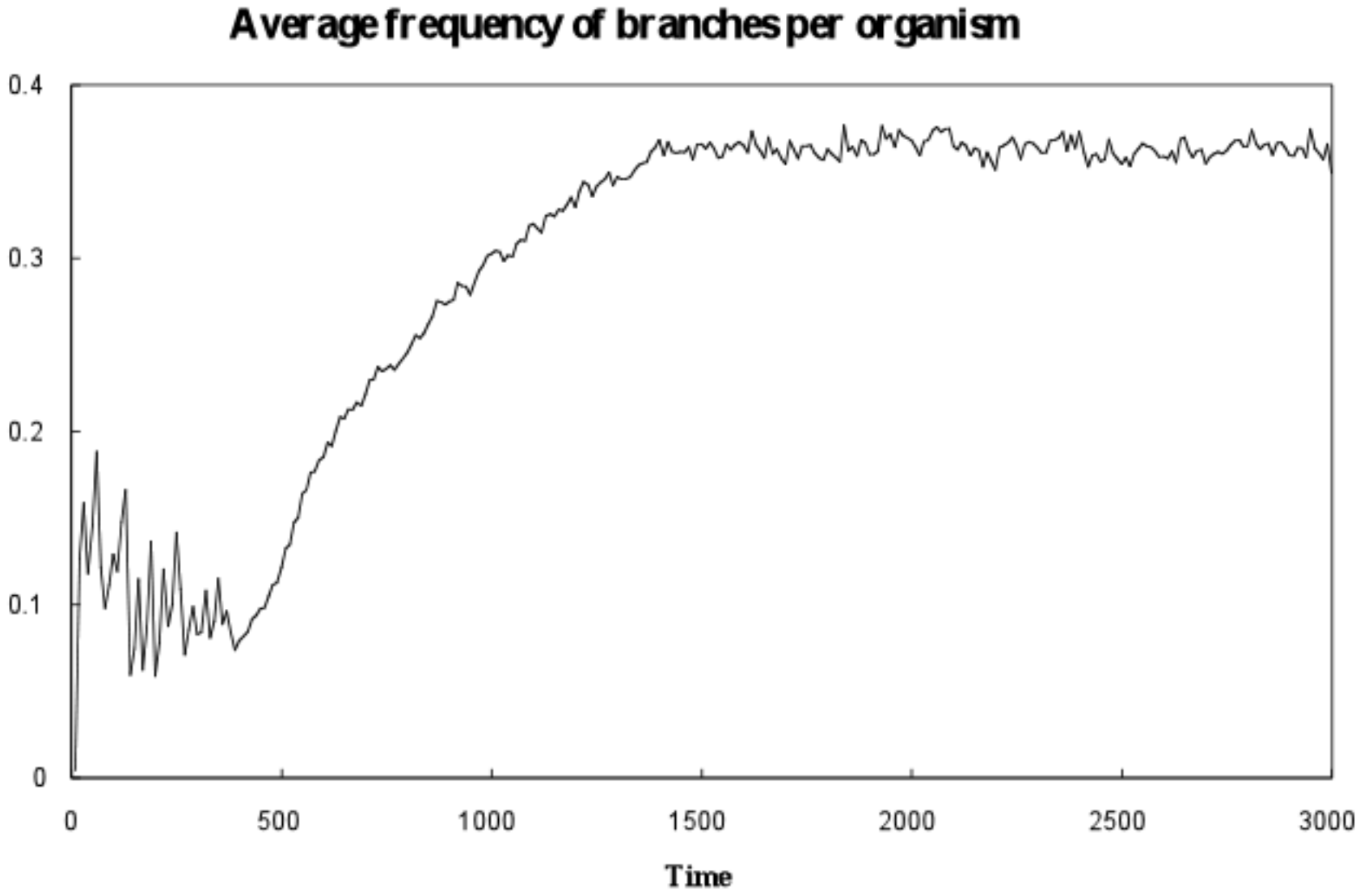
Increase of Structural Complexity (2)



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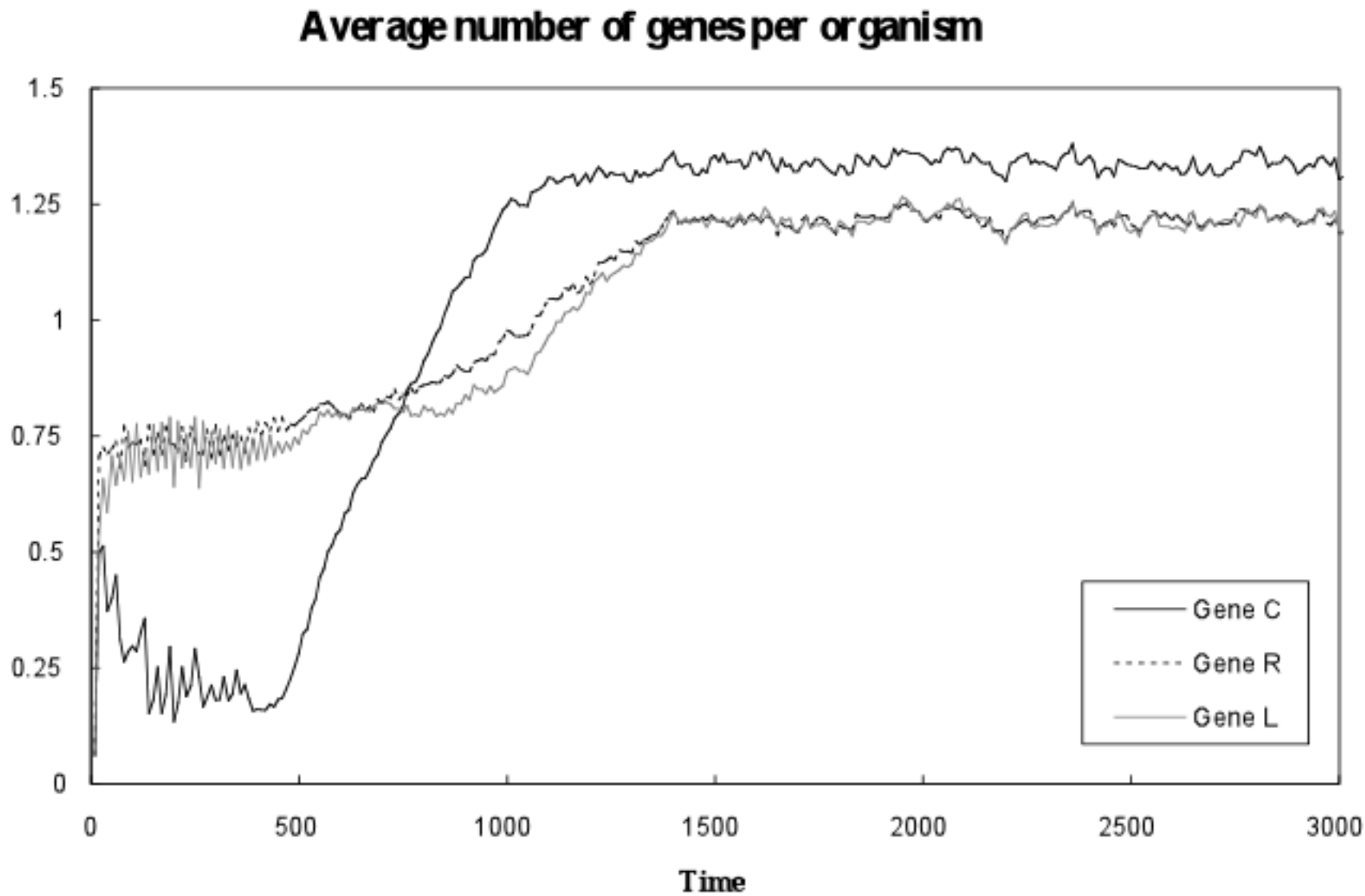
NECSI

Increase of Structural Complexity (3)



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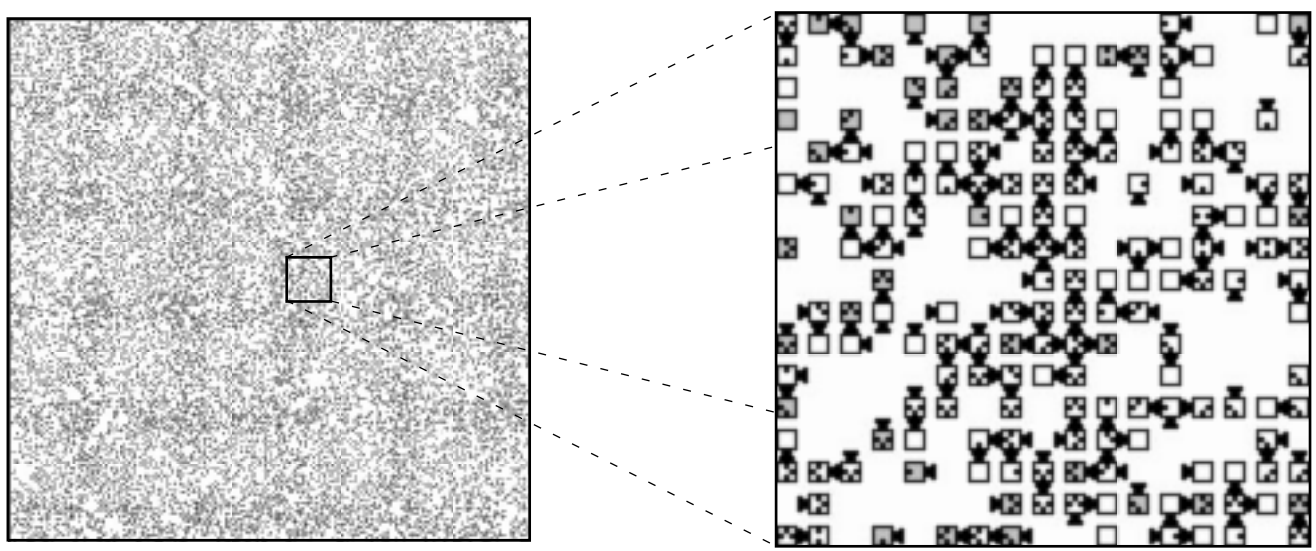
Complexity Saturation

Evolution of complexity always saturates

Organisms cannot make use of local empty areas since they are fixed onto particular sites



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Limitation of Classical CA-Based ALife

Space equals material

⬇

Spatially fixed structures
Strong locality
Feasibility for handling

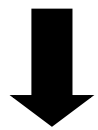
} **Why von Neumann used CA**

But simple strategies to quickly fill up the space always dominate others

(may be applicable for core memory based systems too)

Suggestions

Separate space and material
Make space very large



Kinematic model of self-replication

Limited materials
Fluidity of structures
Interaction in distance

} **What von Neumann abandoned**

Complex structure would be viable thanks to low spatial pressure

Looking Forward...

Go beyond von Neumann!

Project website:

`http://necsi.net/projects/sayama/artificial.html`

Java applet for experiments:

`http://necsi.net/postdocs/sayama/worms/`

Special thanks to:

Kenichi Morita, Katsunobu Imai, Yaneer Bar-Yam, Barry McMullin

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