Discrete Dynamics of Cellular Machines: Specification and Interpretation

Stefano Nichele Gunnar Tufte

NTNU
Norwegian University of Science and Technology

Norwegian University of Science and Technology
Faculty of Information Technology, Mathematics and Electrical Engineering
Department of Computer and Information Science
Sem Saelands vei 7-9, NO-7491 Trondheim, Norway
(nichele,gunnart)@idi.ntnu.no

Department of Computer and Information Science

Goal

Investigation of the correlations between Cellular Automata (CA) behavior (*development process*) and cellular regulative properties (*genome information*).

Background and Motivation

In the 1980s, Stephen Wolfram divided and enumerated CA rules producing similar behavior:

- *Class 1*: fixed configuration, not reversible, previous information is lost.
- *Class 2*: fixed point or temporarily periodic cycle, parts of the initial configuration are filtered out and others are propagated forever, not reversible, information is partially lost.
- *Class 3*: chaotic behavior, completely reversible, chaos is not random and produced data is not noise.
- *Class 4*: complex localized structures that are sometimes long-lived, the only class with non-trivial automata, complex behavior.

1. Is there any *relationship* between computation performed by CA and their regulatory input and cellular actions?
2. Is it possible to develop an organism of a given complexity?
3. Can we *predict* the developmental behavior of the phenotype from the genotype composition?

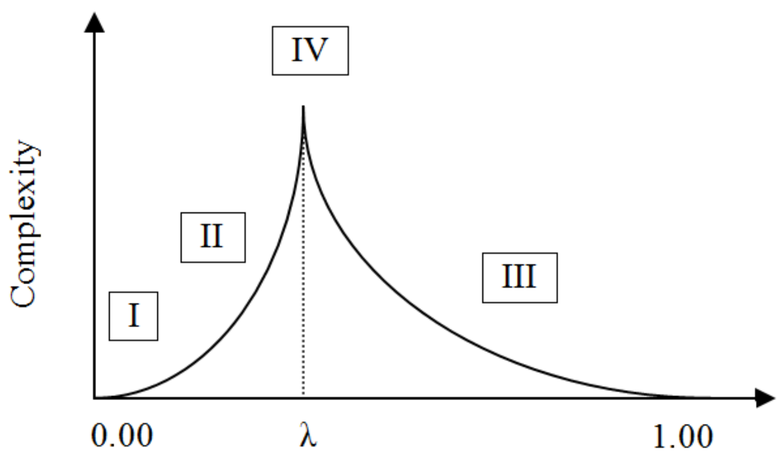
Computation at the Edge of Chaos

Langton [2] tried to find a relation between CA dynamics and a parameter λ. We propose a *new λ*, based on *genome and developmental properties*:

$$\lambda = 1 - \frac{q}{tot}$$

q = # transitions to quiescent states

tot = # total transitions in the rule-table for CA development



Possible location of the Wolfram classes in λ space [2].

Developmental System

A CA can be considered as a developmental system, in which an organism can develop (e.g. grow) from a zygote to a multi-cellular organism (phenotype) according to specific local rules, represented by a genome (genotype).

The genome specifications and the gene regulatory information control the cells' growth and differentiation.

The *behavior* of the CA is represented by the *emergent phenotype*, which is subject to shape and size modification, along the developmental process.

Experimental Setup

Minimalistic developmental model:

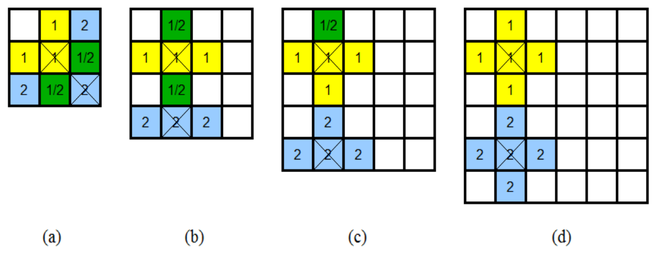
- 2D CA with Von Neumann neighborhood
- 3 cell types (type 0: quiescent, type 1 and type 2 for multicellularity)
- All possible 3^5 = 243 regulatory input combinations are represented
- If all neighbors are quiescent, the cell will be quiescent at the next step

L	R	U	D	C	$C_{(t+1)}$
0	0	0	0	0	0
0	0	0	0	1	{0,1,2}
0	0	0	1	0	{0,1,2}
0	0	0	1	1	{0,1,2}
0	0	1	0	0	{0,1,2}
		:			:
1	1	1	1	1	{0,1,2}
0	0	0	0	2	{0,1,2}
0	0	0	2	0	{0,1,2}
0	0	0	2	1	{0,1,2}
0	0	0	2	2	{0,1,2}
		:			:
2	2	2	2	2	{0,1,2}

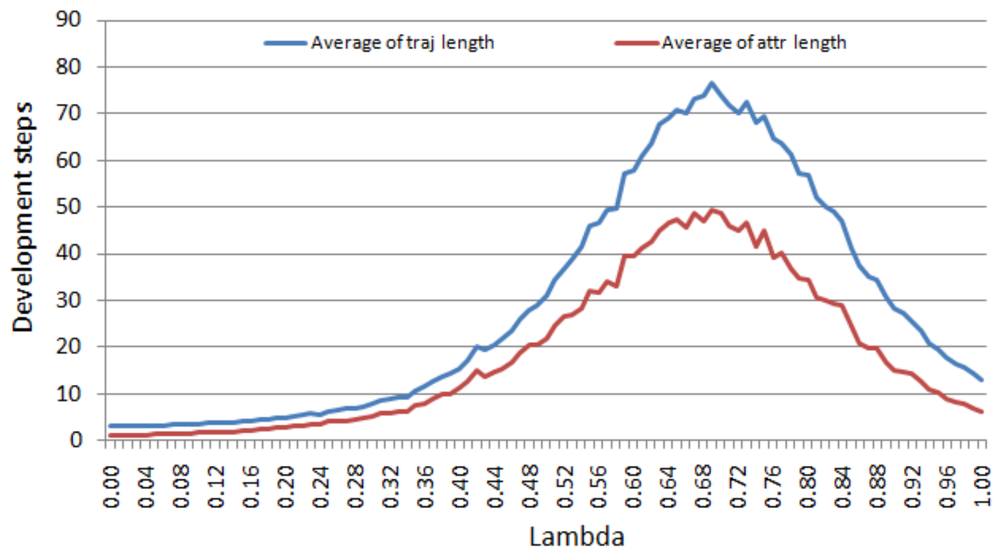
Preliminary Results

Investigation of *trajectory* and *attractor lenght* in all the λ space.

In a 3 by 3 grid there are 3^9 (= 19 683 possible states) but the development process is completely dependent on the neighborhood configuration of each other cell. Many neighborhoods are overlapping and the development process is annihilated. Not enough space for a "free" development.



Yellow / blue: neighborhoods of two cells (X), green: overlapping neighbors, from (a) 3 by 3 to (d) 6 by 6.



Results with 3 by 3 grid. Average trajectory and attractor length plotted as function of λ.

Conclusion and Future Work

Now running 4 by 4, 5 by 5 and 6 by 6. New results in [3].

Promising results: *λ can be an indicator of how the organism will develop*.

Other complexity measures? Gwowth rate, change rate, structural complexity.

λ can be used to drive evolution in desired parts of the seach space.

References

[1] S. Wolfram. Universality and Complexity in Cellular Automata. Physica D Vol 10 Issue 1-2 (1984) pp. 1-35

[2] C. Langton. Computation at the Edge of Chaos: Phase Transitions and Emergent Computation. Physica D Vol 42 (1990) pp. 12.37

[3] G. Tufte and S. Nichele . On the Correlation Between Developmental Diversity and Genomic Composition, to appear in GECCO '11: Proceedings of the 20th annual conference on Genetic and evolutionary computation, New York, NY, USA (2011). ACM. (IN PRESS)