Self-Replication and Evolvable Hardware

Prabhas Chongstitvatana
Department of Computer Engineering
Chulalongkorn University

prabhas@chula.ac.th

- Self-replication
    - Cellular Automata
        - Basic
        - Game of Life
        - Langton Loop
    - Mechanical
    - Electronics
- Evolvable Hardware

Cellular Automata

History

1940 Stanislaw Ulam

- The evolution of graphic constructions generated by simple rules in 2-D cell.
- Starting from a given pattern, the following generation was determined according to neighbourhood rules.
- Self-reproduce
- Extremely simple rules permitted to build very complex patterns.

The following question was asked:

- *Can these recursive mechanisms explain the complexity of the real ?*
- *Is this complexity only apparent, the fundamental rules being themselves simple?*

1960 John von Neumann

The theory of self-reproductive automata
That machine was supposed to be able to reproduce any machine described in its programs, including a copy of itself.

- *"what kind of logical organization of an automaton is sufficient to produce self-reproduction"*

1970 John Conway

Game of life

The rules:

- One inactive cell surrounded by three active cells becomes active
- One active cell surrounded by 2 or 3 active cells remains active
- In any other case, the cell "dies" or remains inactive.

1980 Christopher Langton.

Langton considered that to study living systems inside a computer one only needs to consider *necessary* elements not *sufficient* one.

Langton's basic idea is that it is possible to conceive a cellular automaton supporting a structure whose components constitute the information necessary to its own reproduction. This structure is then both itself and representation of itself.

The structure that reproduces itself is a loop constituted of a sheath within which circulates the information necessary to construct a new loop i.e. necessary to reproduction.

Like von Neumann's automata, Langton's loops show that

- *"one of the fundamental properties of living organisms, self reproduction, can be explained in terms of interactions of simple elements and that it can be studied in its logical principles independently of its physical realization"*

Langton Loop

	2	2	2	2	2	2	2	2					
2	1	7	0	1	4	0	1	4	2				
2	0	2	2	2	2	2	2	0	2				
2	7	2					2	1	2				
2	1	2					2	1	2				
2	0	2					2	1	2				
2	7	2					2	1	2				
2	1	2	2	2	2	2	2	1	2	2	2	2	2
2	0	7	1	0	7	1	0	7	1	1	1	1	1
	2	2	2	2	2	2	2	2	2	2	2	2	2

The cells in state 2 constitute the sheath, inner cells contain the information for reproduction. They are, in some way, the DNA of the loop. The sequences 7-0 and 4-0 propagate toward the tail. When they reach the extremity, the first ones extend the tail, the second ones construct a left-hand corner.

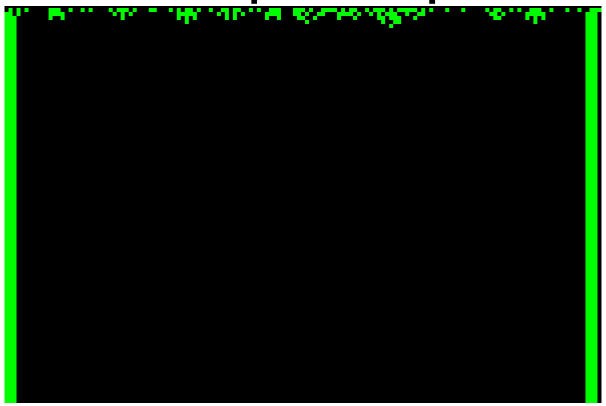
1984 S. Wolfram

Wolfram studied one dimensional automata, with two states and a neighbourhood of 2. He only considered as "legal" the automata that firstly eliminate any cell without neighbour, and secondly, are symmetric. There are then only 32 "legal" automata that Wolfram systematically studied.

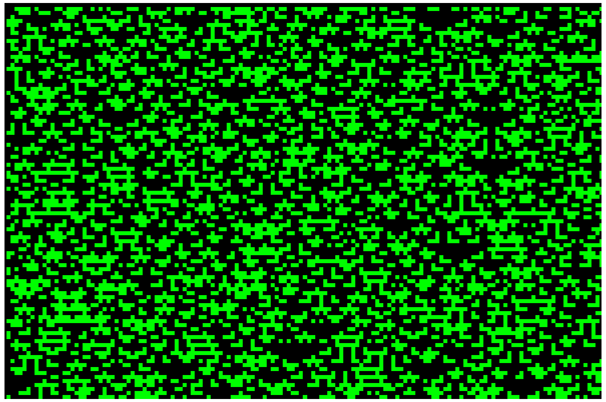
Numerous cellular automata, and maybe all of them, fall into four basic classes.

Class I- evolution leads to an homogeneous state.

Class II- Evolution leads to simple or periodic structures.



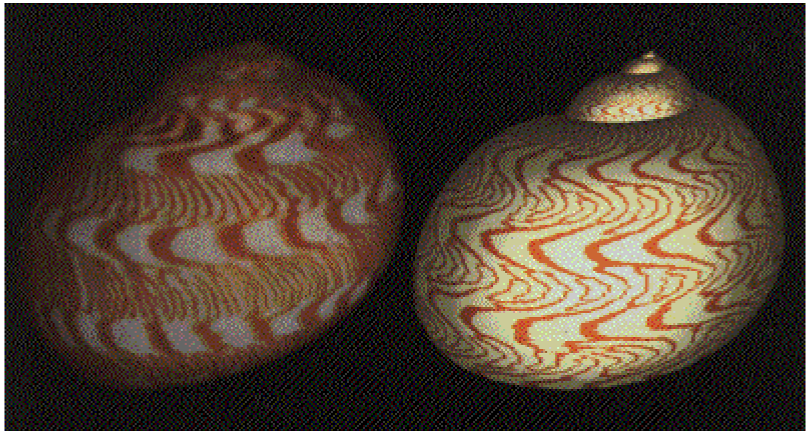
Class III- Evolution leads to chaotic states.



Class IV- Evolution leads to complex global structures.

"Cellular Automata may be viewed as computers, in which data represented by initial configurations is processed by time evolution. Computational universality implies that suitable initial configurations can specify arbitrary algorithmic procedures"

He puts forward the hypothesis that class IV characterizes the automata having universal computation capability. In order to let this capability emerge, the cells must be able to communicate and to transmit information.



Langton ed., *Artificial Life an overview,* MIT press, 1997.

MOVE processors that Self-preplicate and Differentiate

Joel Rossier, Yann Thoma, Pierre-Andre Mudry, and Gianluca Tempesti, "MOVE Processors That Self-replicate and Differentiate", A.J. Ijspeert et al. (Eds.): BioADIT 2006, LNCS 3853, pp. 160–175, 2006, Springer-Verlag.

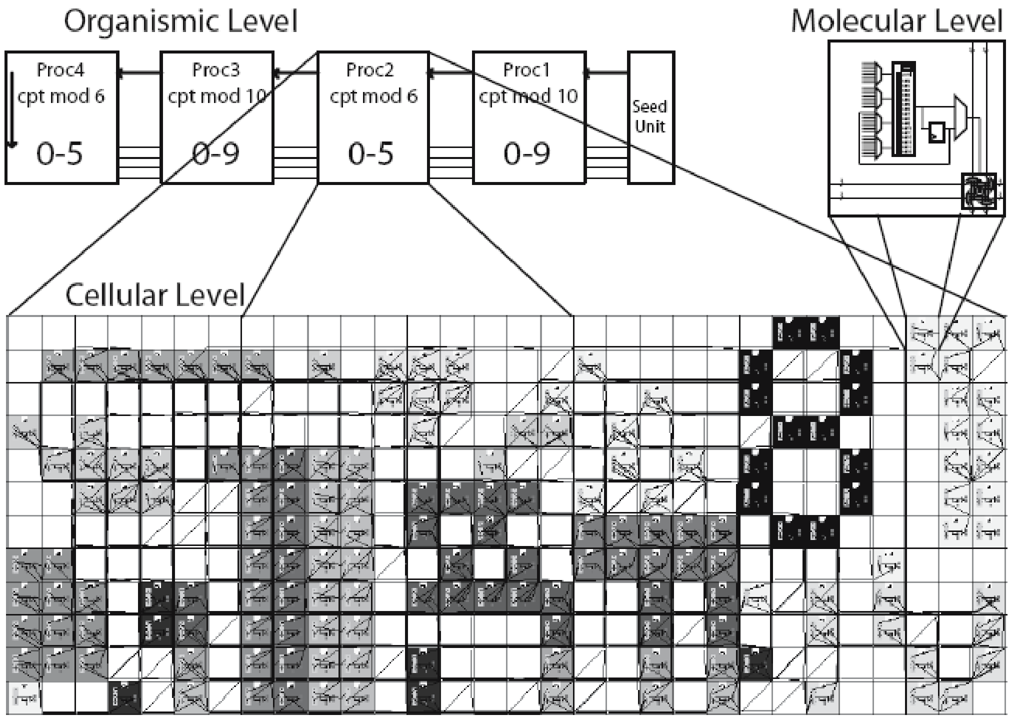


Fig. 4. The three hierarchical levels of our system: organism/counter final configuration, cell/processor mapping on POEtic, molecule/POEtic element

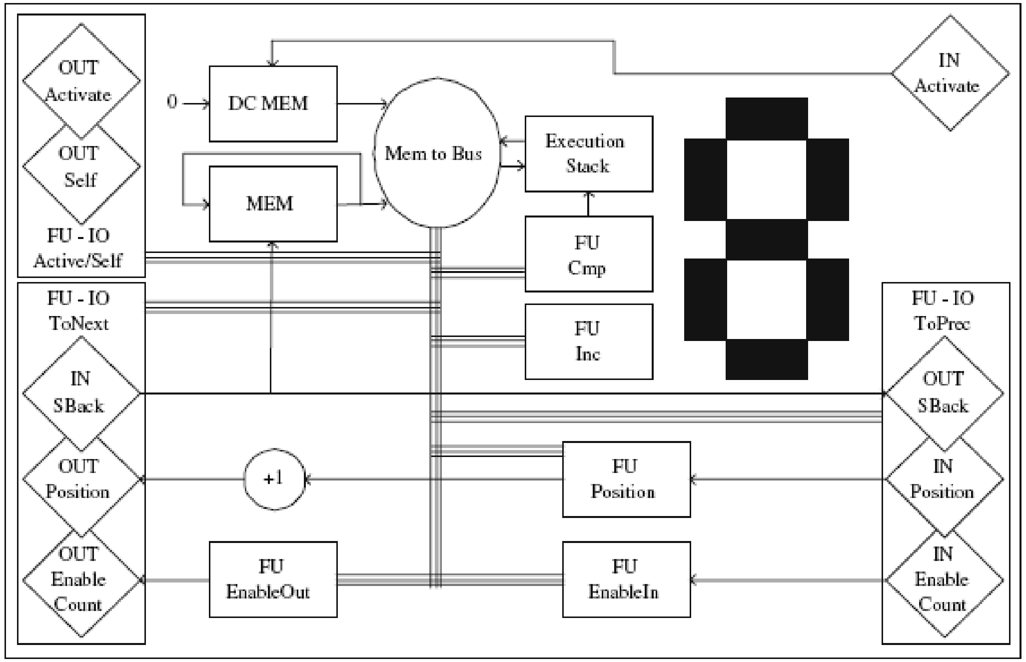


Fig. 5. Detailled architecture of the processor

A self-replication process

1) The cell that wants to replicate itself has to emit the configuration bits of every one of its molecules.
2) These bits are routed to their destination, i.e. the place where the copy will be constructed.
3) These configuration bits are then injected into molecules that are not yet configured. These molecules receive their new configuration and become copies of the initial molecules.
4) When all the configuration bits of each molecule of the initial system have been emitted, routed and injected in their new place, the cell has replicated itself.

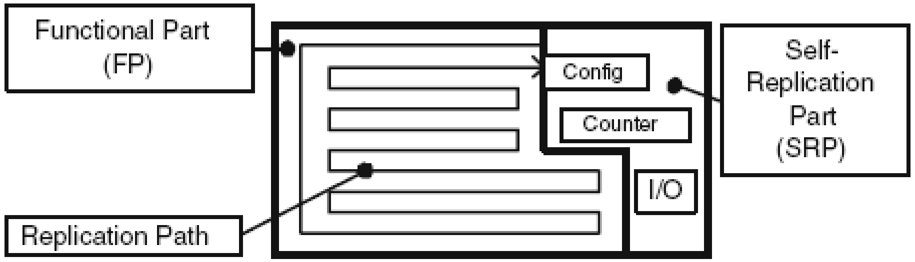


Fig. 6. Mandatory parts for a POEtic self-replication

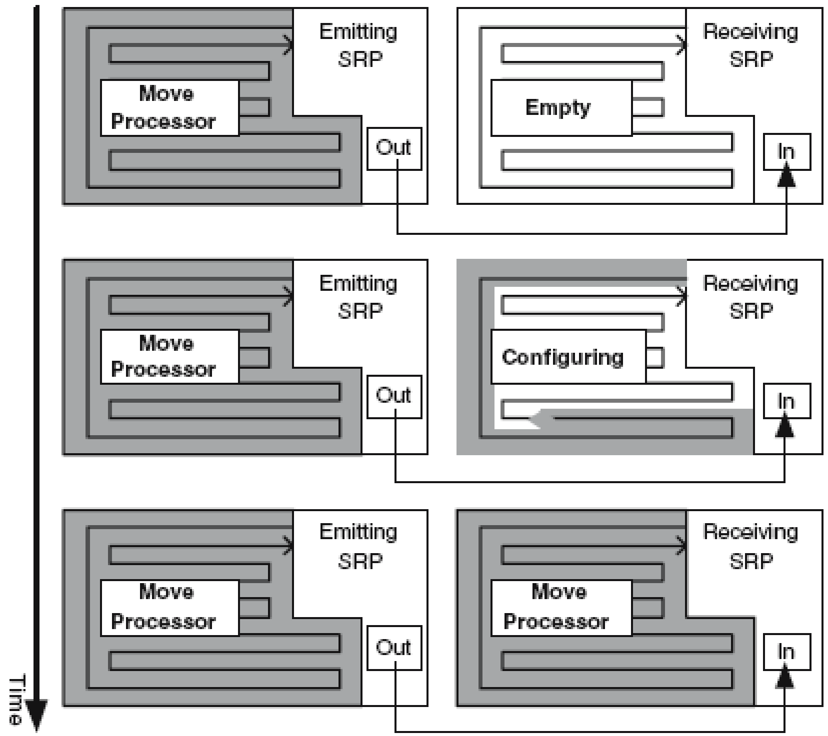


Fig. 7. Three steps of the self-replication process

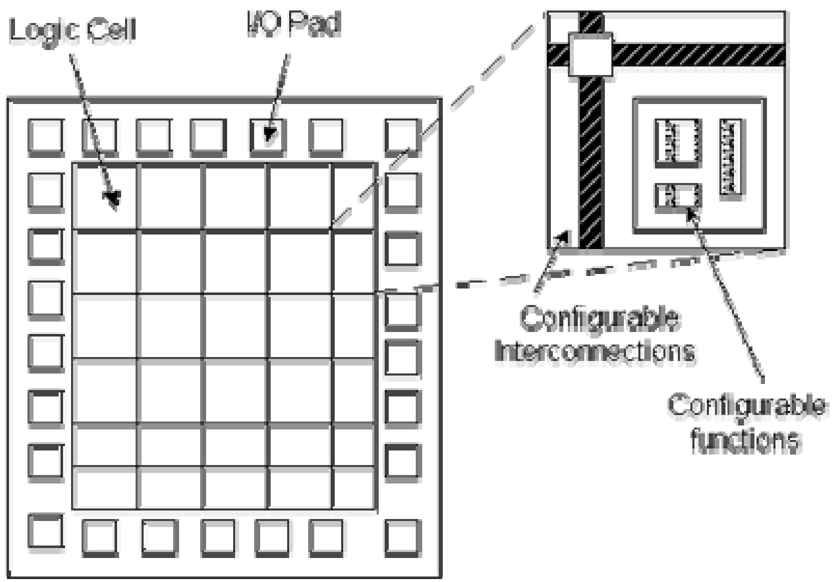
Connect and Differentiate

1) Seed unit activates connections.
2) The nearest replicated processor accepts connections.
3) The processor to activate its differentiation and connection memory and start the shifting and the execution of its instructions.
4) The spatial position of the processor inside the chain, defined through the differentiation process, is used to select the appropriate functionality.

Evolvable Hardware

Based on Reconfigurable circuits (usually Field Programmable Gate Array, FPGA)

FPGA has configuration bits



Parameters	1985	1998
Transistor width	3 um	0.25 um
Die size	25 mm2	400 mm2
Clock Frequency	20 MHz	350 MHz
Pins per package	48	630
Number of cells	64	8,464
Size of configuration bits	11,360	5,433,888
Power supply	5 volts	2.5 volts

Evolutionary Algorithms are used to create the configuration bits.

Two types, two modes:

Intrinsic – Hardware in the loop
Extrinsic – Hardware is simulate
Online – Hardware is used in evaluating candidates
Offline – EDA is used.

Examples of EHW

Evolving digital circuits
Evolving analog circuits
Evolving robot controller
EHW as an Adaptive System
Evolving an ATM traffic shaper
Evolving an adaptive equalizer
Artificial brains

Conclusion

– Self-replication is an exciting field that will lead to deep understanding of information processing systems.

– EHW is a promising medium to realize self-replication.