Computation by competing patterns: Life rule $B2/S2345678$

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Abstract. Patterns, originating from different sources of perturbations, propagating in a precipitating chemical medium do usually compete for the space. They sub-divide the medium onto the regions unique for an initial configuration of disturbances. This sub-division can be expressed in terms of computation. We adopt an analogy between precipitating chemical media and semi-totalistic binary two-dimensional cellular automata, with cell-state transition rule $B2/S2\ldots8$. We demonstrate how to implement basic logic and arithmetical operations (computability) by patterns propagating in geometrically constrained Life rule $B2/S2\ldots8$ medium.

1 Introduction

Non-standard computation deals with implementation of programmable processing of information by unorthodox ways (e.g. computing with traveling localizations [2]) and in novel, or unusual, materials, (e.g. chemical reaction-diffusion media [4]). All non-standard computational systems can be classified as geometrically-constrained (fixed, stationary, architecure, e.g. wires, gates) and architecureles (collision-based, or 'free space'[4] [1]) computers.

[4] 'Free space computing' is a term coined by Jonathan Mills.

Conway's Game of Life [11] is the best-known example of a universal collision-based computer [8, 2]. Its universality [18] can be proved and demonstrated by many ways, either simple functionally complete set of logical functions, as in [8], or via construction of large and complicated simulators of Turing machine [9, 25] and register machine [8].

The Life, and Life-like rules, are know to support myriad of traveling localizations, or gliders; stationary localizations, or still lives; breathing stationary localizations, or oscillators [11, 29, 12, 20, 24, 5, 30]. In its original form, where transition from living state, '1', to 'death' state, '2', does exist, the Life automata resemble excitable media, including excitable reaction-diffusion systems. There is also a family of Life-life rules, where 'cells never die', or the state '1' is an absorbing state. This is the family of *Life without Death*, invented by Griffeath and Moore in [12]. In the Life without Death automata we can still observe propagating localizations, formed due to rule-based restrictions on propagation similar to that in sub-excitable chemical media and plasmodium of *Physarum polycephalum* [7], but no complicated periodic structures or global chaotic behavior occurs.

The Life without Death family of cell-state transition rules is the Game of Life equivalent of the precipitating chemical systems. This is demonstrated in our computational-phenomenological studies of semi-totalistic and precipitating CA [5], where we selected a set of rules, identified by periodic structures, which is named as Life $2c22$ [21].[5] The clans closest to the family $2c22$ are *Diffusion Rule* (Life rule $B2/S7$) [17], all they also into of a big cluster named as Life $dc22$.

A partial but important result was find an indestructible pattern into Life rules. The Life families with indestructible patterns allow us to study a computational potential of the propagating precipitating systems. We employ our previous results on chemical laboratory prototypes of XOR gates in precipitating chemical media [3], and design a binary adder in the CA equivalent of the precipitating chemical medium. In Sect. 2 we overview basic patterns emerging in rule $B2/S2\ldots8$. Logical gates and a binary full adder are constructed in Sect. 3.

2 Life rule $B2/S2\ldots8$

The Life rule $B2/S2\ldots8$ is described as follows. Each cell takes two states '0' ('dead') and '1' ('alive'), and updates its state depending on its eight closest neighbors as follows:

1. Birth: a central cell in state 0 at time step t takes state 1 at time step $t+1$ if it has exactly two neighbors in state.

[5] `http://uncomp.uwe.ac.uk/genaro/diffusionLife/life_2c22.html`

2. Survival: a central cell in state 1 at time t remains in the state 1 at time $t+1$ if it has more then one live neighbor.
3. Death: all other local situations.

Once a resting lattice is perturbed, few cells assigned live states, patterns formed and grow quickly. Most interesting behavior occurs when at least 20% of cells are initially alive. A general behaviour of rule $B2/S2\dots8$ can be well described by a mean field polynomial and its fixed points (see Fig. 1) [23, 14], as follow:

$$p_{t+1} = 28p_t^2q_t^7 + 28p_t^3q_t^6 + 56p_t^4q_t^5 + 70p_t^5q_t^4 + 56p_t^6q_t^3 + 28p_t^7q_t^2 + 8p_t^8q_t + p_t^9.$$

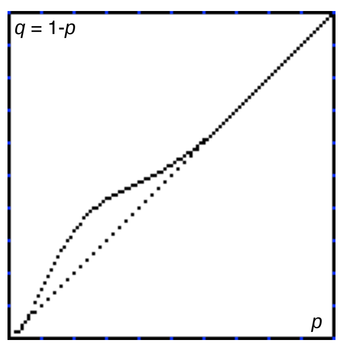

Fig. 1. Mean field curve for $B2/S2\dots8$.

High densities of domains dominated by state 1 correspond to $p = 0.9196$ to $p = 1$ (also we can consider $p = 0.6598$ to $p = 0.7252$, all they are stable fixed points). Interesting behavior can be found in extreme unstable fixed points when $p = 0.00036$ to $p = 0.001$. Thus unstable fixed points may represent gliders and small oscillators as show Fig. 1.

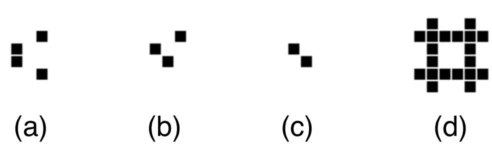

Fig. 2. Basic periodic structures in $B2/S2\dots8$: (a) glider period one, (b) oscillator period one, (c) flip-flop, and (d) still life configuration.

Minimal localizations, or basic periodic structures, in rule $B2/S2\dots8$ include gliders, oscillators, flip-flops, and still life (stationary localization) configurations (Fig. 2).

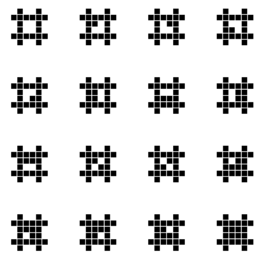

Fig. 3. Indestructible Still Life family patterns derived in rule $B2/S2\dots8$.

A relevant characteristic was that the rule $B2/S2\dots8$ supports *indestructible patterns*, which can not be destroyed from any perturbation, they belong to the class of stationary localizations, still lives [10, 22]. The minimal indestructible pattern is show in Fig. 2d. More heavier, in a number of live cells, patterns are provided in Fig. 3.

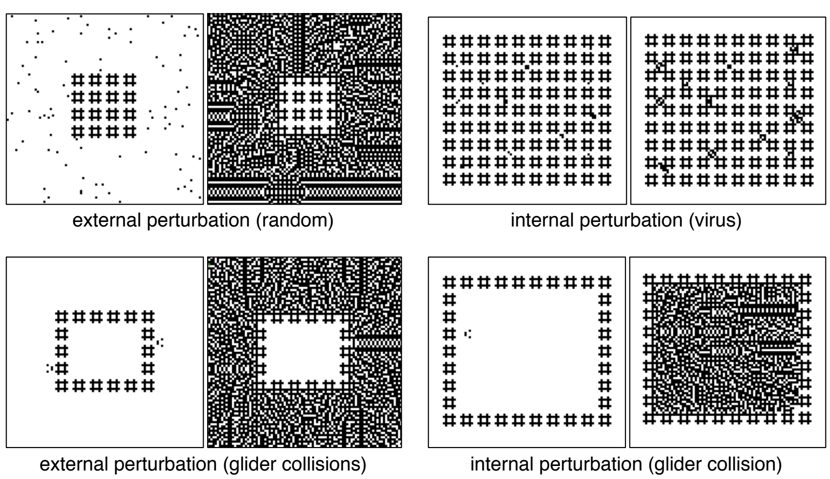

Fig. 4. Indestructible Still Life colonies ‘tested’ by internal and external perturbations. Each pair of snapshots represents an initial condition (on the left) and a final, i.e. stationary, configuration (on the right).

In CA rule $B2/S2\ldots8$ one can setup colonies of the indestructible structures as sets of block patterns, which are capable for resisting internal and external perturbations, see examples in Fig. 4. The indestructible patterns symbolize a precipitation in CA development. We use these patterns to architecture channels, or wires, for signal propagation.

The Still Life blocks are not affected by their environment however they do affect their environment. As demonstrated in Fig. 4, bottom scenarios, gliders colliding to the Still Life walls are transformed into propagating patterns, which fill the automaton lattice.

Localizations colliding to Still Life blocks become delocalised.

We use this feature of interactions between stationary and mobile localizations in designing logical circuits.

3 Computing with propagating patterns

We implement computation with patterns propagating in the Life rule $B2/S2\ldots8$ is follows. A computing scheme is build as channels, geometrically constrained by Still Life indestructible blocks, and T-junctions[6] between the channels. Each T-junction consists of two horizontal channels A and B (shoulders), acting as inputs, and a vertical channel, C, assigned as an output. Such type of circuitry have been already used to implement XOR gate in chemical laboratory precipitating reaction-diffusion systems [3, 4], and precipitating logical gates in CA [16]. A minimal width of each channel is calculated as three widths of the Still Life block (Fig. 2d) and width of a glider (Fig. 2a).

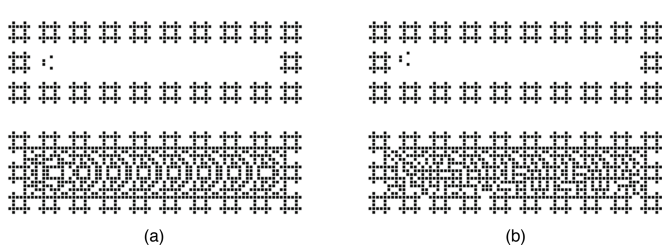

Fig. 5. Feedback channels constructed with still life patterns (a) show the initial state with the empty channel and a glider (top) and final state representing value 0 (low), and (b) show non-symmetric patterns representing value 1.

[6] T-junction based control signals were suggested also in von Neumann [28] works.

Boolean values are represented by gliders, positioned initially in the middle of channel, value 0 (Fig. 5a, top), or slightly offset, value 1 (Fig. 5b, top). The initial positions of the gliders determine outcomes of their delocalisation. Glider, corresponding to the value 0 delocalised into regular identified by a symmetric pattern, like frozen waves of excitation, patterns (Fig. 5a, bottom). Glider, representing the value signal value 1, delocalises into the less regular patterns (Fig. 5b, bottom) identified by a non-symmetric pattern although eventually it became periodic on a long channel but not symmetric.

The patterns, representing values 0 and 1, propagate along the channels and meet at the T-junctions. They compete for the output channel, and, depending on initial distance between gliders, one of the patterns win and propagates along the output channel. Figure 6 shows final configurations of basic logical gates.

The gates can be cascaded into more 'useful' circuits, e.g. binary adders. See a scheme representation based in T-junctions from its traditional circuit of a binary half-adder in Fig. 7.

Implementation of final configuration of the one-bit half-adder are shown in Fig. 8. Thus the circuity can be extended to a full adder (Fig. 9). Configuration of the adder, outlined with Still Life blocks, and description of computation stages are shown in Fig. 10. The full adder consists of 16 T-junctions, linked together by channels, and involve synchronization signals as well.

Finally the full adder was constructed on $1,118 \times 1,326$ cells lattice, and there were 66,630 live cells involved in 952 generations in total. A data-area of the full adder is shown in Fig. 11.

4 Conclusions

Result presented in the paper demonstrate how to implement computation at the systems with propagating precipitating patters based in T-junction system. Also, we shown universal computing in Life rules domain with the Life rule $B2/S2 \dots 8$ by implementing basic logical gates and full binary adder. Relevance of this result in CA literature specially into Life rules was besides showing universality in other evolution rule different to the Game of Life proposed in several works.

Problems related to configurations done a complete computation involucre space complexity and possible architecture of implementation, also of different orders of CA [27]. In this way it is possible look complex constructions in Life domain [9, 25] or using the isotropic neighborhood

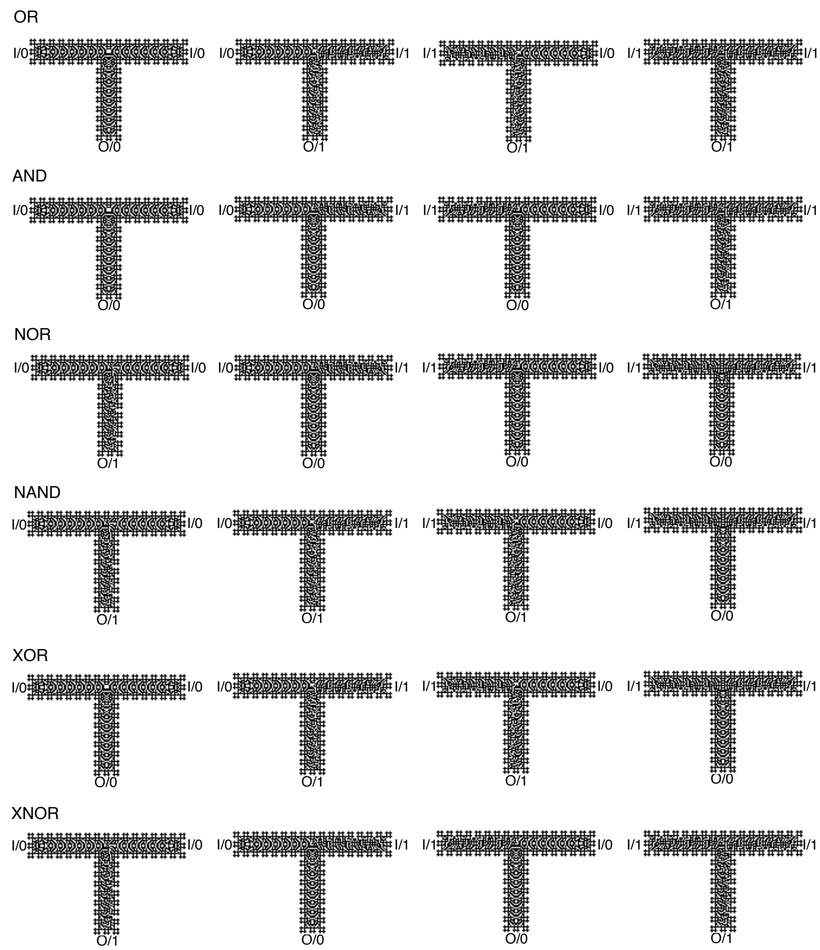

Fig. 6. Logic gates implemented at the Life rule $B2/S2\ldots8$. Input binary values A and B are represented for In/0 or In/1, output result C is represented by Out/0 or Out/1.

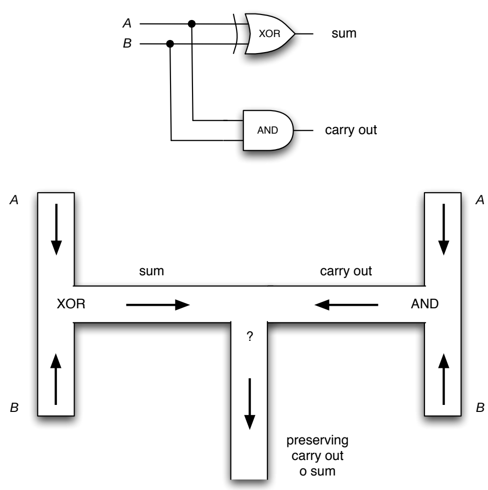

Fig. 7. Half adder circuit (top) and scheme of its implementation by propagating patterns geometrically constrained medium (bottom).

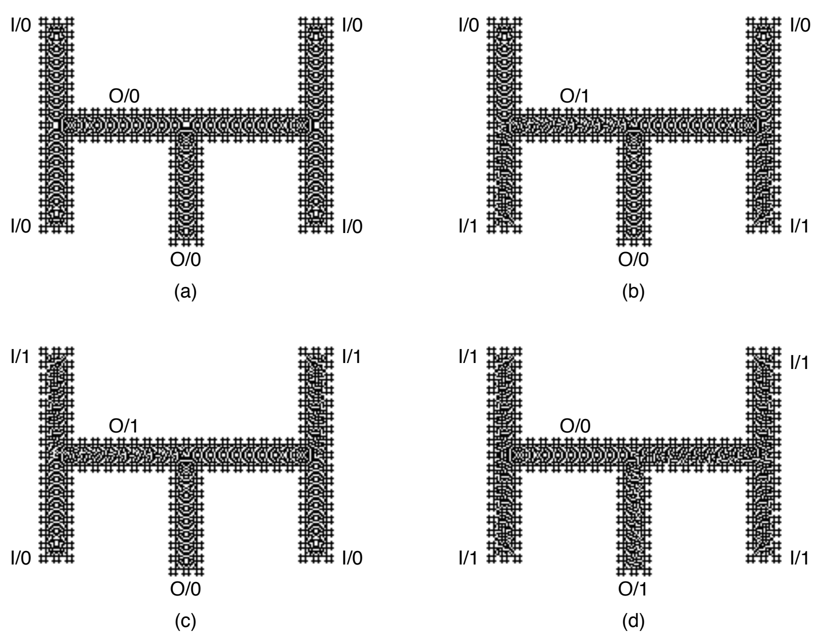

Fig. 8. Half adder implemented in *Life* rule $B2/S2\ldots8$. Operations represent sums (a) $0+0$, (b) $0+1$, (c) $1+0$, and (d) $1+1$ where besides its carry out is preserved in this case.

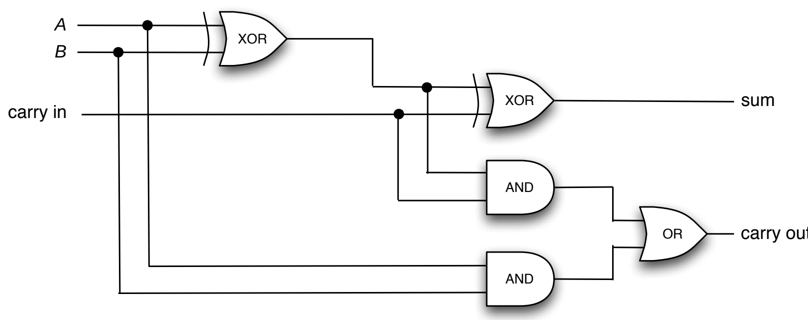

Fig. 9. Full binary adder circuit.

[26]. However in this case gliders were used to produce a propagation of patterns and not to produce new gliders or Life objects.[7]

Future work will concern with explicit construction of a Turing machine, computer design, solitons [15], systems self-copying [19] and detailed study and classification of indestructible still life patterns in Life *dc*22.

Sources, stuff and specific initial condition (.rle files)[8] to reproduce these results are also available from `http://uncomp.uwe.ac.uk/genaro/diffusionLife/B2-S2345678.html`

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References

1. Adamatzky, A. (2001) *Computing in Nonlinear Media and Automata Collectives*, Institute of Physics Publishing, Bristol and Philadelphia.
2. Adamatzky, A. (Ed.) (2003) *Collision-Based Computing*, Springer.
3. Adamatzky A. & De Lacy Costello B. (2002) Experimental logical gates in a reaction-diffusion medium: The XOR gate and beyond, *Phys. Rev. E* **66**, 046112.
4. Adamatzky, A., De Lacy Costello, B. & Asai, T. (2005) *Reaction-Diffusion Computers*, Elsevier.

[7] Lifeinfo `http://www.pentadecathlon.com/`

[8] Implementations and constructions were developed with Golly system available from `http://golly.sourceforge.net/`

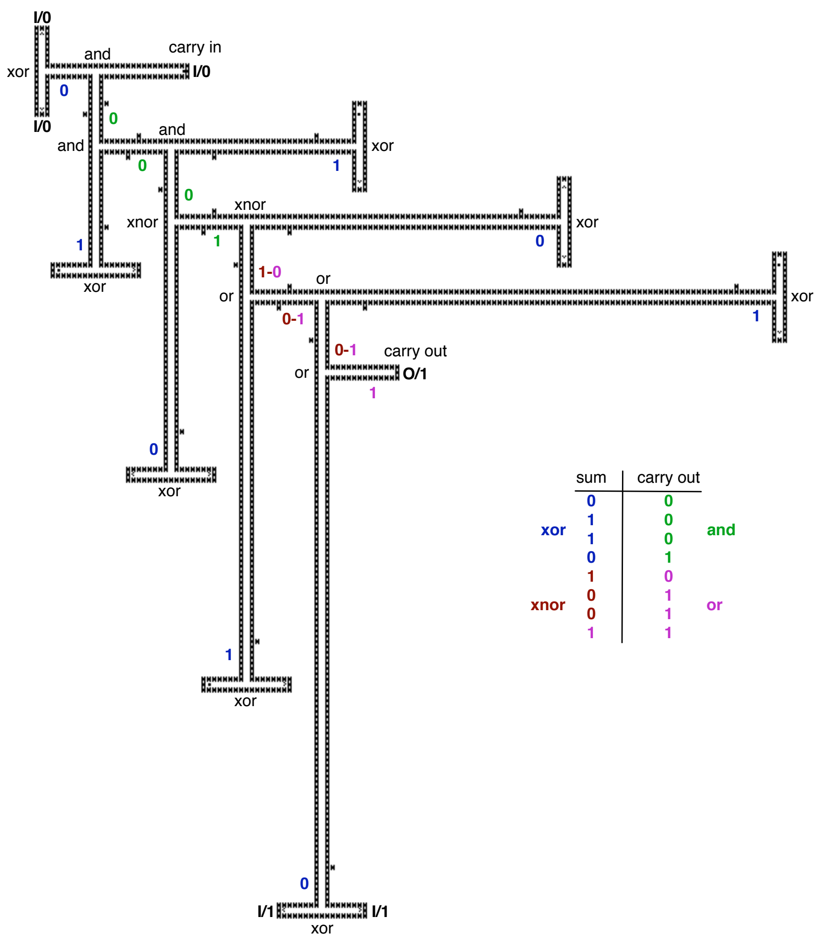

Fig. 10. Full binary adder description of stages in Life rule $B2/S2\ldots8$.

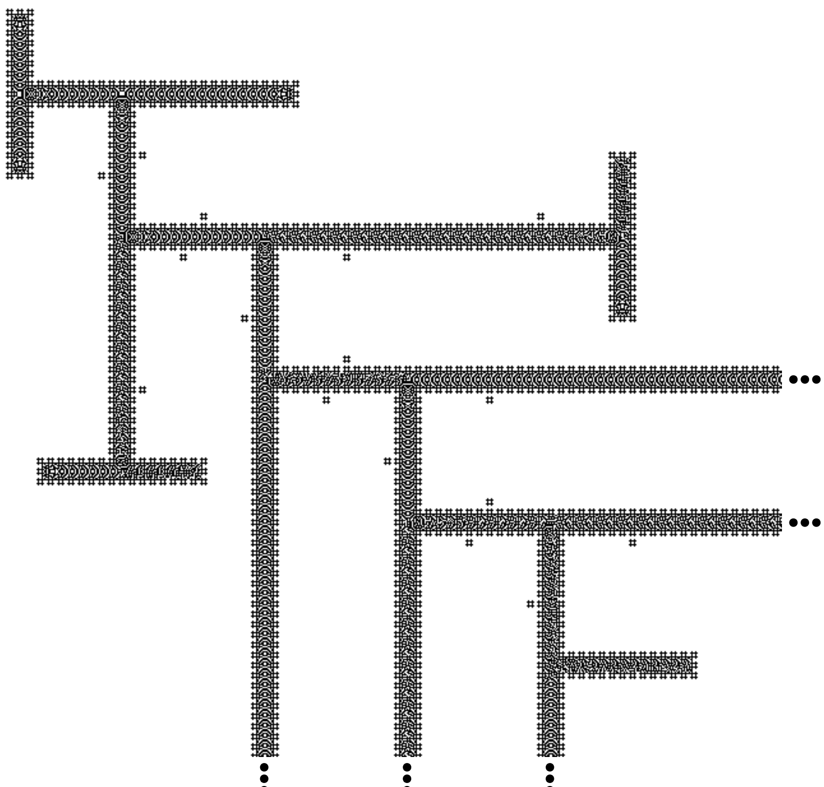

Fig. 11. Full binary adder serial implementation in Life rule $B2/S2\ldots8$ (zoom-in data area).

5. Adamatzky, A., Martínez, G.J. & Seck Tuoh Mora, J.C. (2006) Phenomenology of reaction-diffusion binary-state cellular automata, *Int. J. Bifurcation and Chaos* **16 (10)**, 1–21.
6. Adamatzky, A. & Wuensche, A. (2006) Computing in spiral rule reaction-diffusion cellular automaton, *Complex Systems* **16 (4)**.
7. Adamatzky A., De Lacy Costello B., Shirakawa T. Universal computation with limited resources: Belousov-Zhabotinsky and Physarum computers. Int. J. Bifurcation and Chaos (2008), in press.
8. Berlekamp, E.R., Conway, J.H. & Guy, R.K. (1982) *Winning Ways for your Mathematical Plays*, Academic Press, (vol. 2, chapter 25).
9. Chapman, P. (2002) Life Universal Computer, `http://www.igblan.free-online.co.uk/igblan/ca/`
10. Cook, M. (2003) Still Life Theory, (in ref. [13]).
11. Gardner, M. (1970) Mathematical Games — The fantastic combinations of John H. Conway's new solitaire game Life, *Scientific American* **223**, 120–123.
12. Griffeath, D. & Moore, C. (1996) Life Without Death is P-complete, *Complex Systems* **10**, 437–447.
13. Griffeath, D. & Moore, C. (Eds.) (2003) *New constructions in cellular automata*, Oxford University Press.
14. Gutowitz, H.A. & Victor, J.D. (1987) Local structure theory in more that one dimension, *Complex Systems* **1**, 57–68.
15. Jakubowski, M.H., Steiglitz, K. & Squier, R. (2001) Computing with Solitons: A Review and Prospectus, *Multiple-Valued Logic*, Special Issue on Collision-Based Computing, vol. 6, num. 5–6.
16. Martínez, G.J., Adamatzky, A. & De Lacy Costello, B., On logical gates in precipitating medium: cellular automaton model, *Physics Letters A*, accepted.
17. Martínez, G.J., Adamatzky, A. & McIntosh, H.V., Localization dynamic in a binary two-dimensional cellular automaton: the Diffusion Rule, *J. Cellular Automata*, in press.
18. Minsky, M. (1967) *Computation: Finite and Infinite Machines*, Prentice Hall.
19. Mitchell, M. (2001) Life and evolution in computers, *History and Philosophy of the Life Sciences* **23**, pages 361–383.
20. Magnier, M., Lattaud, C. & Heudin, J.-K. (1997) Complexity Classes in the Two-dimensional Life Cellular Automata Subspace, *Complex Systems* **11 (6)**, 419–436.
21. Martínez, G.J., Méndez, A.M. & Zambrano, M.M. (2005) Un subconjunto de autómata celular con comportamiento complejo en dos dimensiones, `http://uncomp.uwe.ac.uk/genaro/papers.html`
22. McIntosh, H.V. (1988) Life's Still Lifes, `http://delta.cs.cinvestav.mx/~mcintosh`
23. McIntosh, H.V. (1990) Wolfram's Class IV and a Good Life, *Physica D* **45**, 105–121.
24. Packard, N. & Wolfram, S. (1985) Two-dimensional cellular automata, *J. Statistical Physics*, **38**, 901–946.

25. Rendell, P. (2002) Turing universality of the game of life, (in ref. [2]).
26. Sapin, E., Bailleux, O., Chabrier, J. & Collet, P. (2007) Demonstration of the Universality of a New Cellular Automaton, *Int. J. Unconventional Computing* **3**, 79–103.
27. Tommaso, T. (2008) Background for the Quad Prize, EPSRC Automata 2008 Workshop, `http://uncomp.uwe.ac.uk/automata2008/prize.html`
28. von Neumann, J. (1966) *Theory of Self-reproducing Automata* (edited and completed by A. W. Burks), University of Illinois Press, Urbana and London.
29. Wainwright, R. (Ed.) Lifeline - A Quaterly Newsletter for Enthusiasts of John Conway's Game of Life, Issues 1 to 11, March 1971 to September 1973.
30. Wuensche, A. (2004) Self-reproduction by glider collisions: the beehive rule, *Alife9 Proceedings*, 286–291, MIT Press.