Chapter 15
Towards Arithmetical Chips in Sub–Excitable Media: Cellular Automaton Models

Liang Zhang
University of the West of England, UK

Andrew Adamatzky
University of the West of England, UK

ABSTRACT

We discuss a theoretical design of an arithmetical chip built on an excitable medium substrate. The chip is simulated in a two-dimensional three-state cellular automaton with eight-cell neighborhoods. Every resting cell is excited if it has exactly two excited neighbors, the excited cells take refractory state unconditionally. A transition from refractory back to resting state also happens irrelevantly to a state of the cell neighborhood. The design is based on principles of collision-based computing. Boolean logic values are encoded by traveling localizations, or particles. Logical gates are realized in collisions between the particles. Detailed blue prints of collision-based adders and multipliers presented in the article pave the way to future laboratory experimental prototypes of general-purpose chemical computers.

INTRODUCTION

Excitable chemical media are amongst most promising ‘wet’ computing devices capable for solving a wide ranging of tasks from optimization, computational geometry, image processing and robot control. The excitable media can also implement functionally complete sets of logical gates thus qualifying as (logically) universal computing systems. See theoretical background and details of laboratory implementations of reaction-diffusion computers in (Adamatzky, De Lacy Costello, Asai, 2005).

So far all experimental laboratory prototypes of reaction-diffusion chemical computers are in fact specialized, or task oriented purposed processors. They are capable for solution of only one problem or family of problems. When logical universality is concerned the experimental implementations do usually deal with one or two logical gates, just as a matter of demonstration (Adamatzky, 2004; De Lacy Costello and Adamatzky, 2005; Adamatzky and De Lacy Costello, 2007; Toth et al, 2008). To move from abstract computational
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universality to general-purpose machine we must demonstrate how we can cascade simple logical gates in more complicated circuits able to execute sensible computational tasks. An implementation of arithmetical chip in reaction-diffusion medium would be enough to convince laymen that excitable chemical computing devices are not just a matter of curiosity but viable candidates for a role of future non-silicon computers.

We envisage that novel arithmetic chip, to be built in an excitable medium, will be based on principles of collision-based computing. The proposed chips will be based on logical schemes of computation in Conway’s Game-of-Life (Berlekamp, Conway, Guy, 1982), Fredkin-Toffoli’s conservative logic (Fredkin and Toffoli, 1982) and Margolus’s physics of computation (Margolus, 1984). In collision-based computing (Adamatzky, 2003), quanta of information are represented by compact patterns traveling in an ‘empty’ space and performing computation by colliding with each other. The absence or presence of traveling patterns encodes values of Boolean logical variables. The trajectories of patterns approaching a collision site represent input variables, and the trajectories of the patterns ejected from a collision, and traveling away from the collision site, represent the results of logical operations, output variables.

A sub-excitable Belousov-Zhabotinsky medium (Sedina-Nadal et al, 2001) is an ideal substrate to build collision-based arithmetical chips in chemical systems. In a normal, excitable, mode the Belousov-Zhabotinsky medium responds to local perturbations by forming target or spiral waves, which propagate in all possible directions away from perturbation site. In a sub-excitable mode, we observe generation of a localized excitations, or wave-fragments that preserve their shape and travel like dissipative solitons (Bode et al, 2002) in one pre-determined direction for a substantial amount of time. We have demonstrated (Adamatzky, 2004; De Lacy Costello and Adamatzky, 2005; Adamatzky and De Lacy Costello, 2007; Toth et al, 2008) that it is possible to implement logical gates by colliding excitation wave-fragments. In present article we use a cellular-automaton sub-excitable lattice (Adamatzky, 1995; Adamatzky, 1998) to simulate a sub-excitable chemical medium. We integrate together our previous results (Zhang and Adamatzky, 2008; Zhang and Adamatzky, 2008) on arithmetical operations in collision-based media.

CELLULAR-AUTOMATON MODEL OF SUB-EXCITABLE MEDIA

We employ a two-dimensional three-state cellular-automaton model of an excitable medium — the 2⁺-medium, originally introduced in (Adamatzky, 1995; Adamatzky, 1998). The 2⁺-medium consists of an orthogonal array of finite automata, where every automaton, called a cell, takes three states: resting, excited ‘+’ and refractory ‘-’ and updates its state depending on the states of its eight neighbors. All cells update their states simultaneously and in discrete time, using the same rule. A resting cell becomes excited if it has exactly two excited neighbors. The transitions from excited state to refractory state, and from refractory state to resting state are unconditional.

Most common, and also minimal in size, localizations observed in 2⁺-medium, are particles traveling along horizontal and vertical directions of the cellular lattice (e.g. Figure 1a) and along diagonals of the lattice (e.g. Figure 1b). A 2⁺-particle consists of two excited cell-states and two refractory cell-states (Figure 1a). The particle can travel in four possible directions: East, West, North and South, and the particle conserves its configuration. A 3⁺-particle consists of three cells in excited states and three cells in refractory states (Figure 1b). The 3⁺-particle travels in the direction of North-East, South-East, North-West and South-West. Its topology changes in a cycle of four configurations.

There is the only one stationary localization in 2⁺-medium. The stationary oscillator (Figure