Chapter 11
Simple Collision-Based Chemical Logic Gates with Adaptive Computing

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ABSTRACT
We present a method that is capable of implementing information transfer without any rigidly controlled architecture using the light-sensitive Belousov-Zhabotinsky (BZ) reaction system. Chemical wave fragments are injected into a subexcitable area and their collisions result in annihilation, fusion or quasi-elastic interactions depending on their initial positions. The fragments of excitation both pre and post collision possess a considerable freedom of movement when compared to previous implementations of information transfer in chemical systems. We propose that the collision of such wave fragments can be controlled automatically through adaptive computing. By extension, forms of unconventional computing, i.e., massively parallel non-linear computers, can be realised by such an approach. In this study we present initial results from using a simple evolutionary algorithm to design Boolean logic gates within the BZ system.

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INTRODUCTION

Previous theoretical and experimental studies have shown that reaction-diffusion chemical systems are capable of information processing (Adamatzky, 2003; 2004a; Adamatzky, de Lacy Costello & Asai, 2005; Adamatzky & de Lacy Costello, 2007; de Lacy Costello & Adamatzky, 2005). “In the strict sense of the term, reaction-diffusion systems are systems involving constituents locally transformed into each other by chemical reactions and transported in space by diffusion” (Nicolis & De Wit, 2007). In our previous work, see overview in Adamatzky et al. (2005) we demonstrated that reaction-diffusion chemical systems are capable of implementing various kinds of computational procedures. Experimental prototypes of reaction diffusion processors have been used to solve a wide range of specialised computational problems, including image processing (Adamatzky, de Lacy Costello & Ratcliffe, 2002a; Rambidi, 2003), path planning (Adamatzky & de Lacy Costello, 2003a; Steinbock, Toth & Showalter, 1995), robot navigation (Adamatzky et al., 2004b), computational geometry (Adamatzky & de Lacy Costello, 2003b), counting (Gorecki, Yoshikawa & Igarashi, 2003) and implementing memory (Motoike & Yoshikawa, 2003). Logic gates were also constructed in excitable chemical systems (de Lacy Costello & Adamatzky, 2005; Sielewiesiuka & Gorecki, 2002; Toth & Showalter, 1995) and in simple inorganic precipitation reactions (Adamatzky & de Lacy Costello, 2002b). Several researchers have created prototype reaction diffusion processors. These implement logical computation mimicking a conventional hardware type approach with wires and gates in a fixed morphology (Adamatzky & de Lacy Costello, 2002b; Motoike & Adamatzky, 2005; Sielewiesiuka & Gorecki, 2002; Steinbock, Kettunen & Showalter, 1996; Toth & Showalter, 1995). In previous works we introduced the possibility of constructing gates using a dynamical architectureless approach based on collision-based computing. We demonstrated both in computational (Adamatzky, 2004a; Adamatzky & de Lacy Costello 2007) and experimental studies (De Lacy Costello & Adamatzky, 2005) using a subexcitable BZ system that under carefully controlled conditions compact wave fragments develop in the medium, they then travel for reasonably long distances when undisturbed and their collisions can be interpreted as the implementation of logical operations.

In the current experimental approach we utilise small chemical wave fragments propagating in a weakly excitable BZ medium (defined as a level set in experiment just above the critical subexcitable threshold) and study their interactions when they are collided whilst travelling on different trajectories. These interactions, i.e. collisions, produce dynamic structures which can be interpreted in terms of a computation. When two or more wave fragments collide, they may fuse, annihilate, generate new wave fragments or change their trajectories. We use the photosensitive BZ system (Gáspár, Bazsa & Beck, 1983) with tris(2,2'-bipyridine)ruthenium(II) ion catalyst immobilised on silica gel and immersed in the catalyst-free BZ solution. The excitability of the system is controlled by illumination of the reaction medium. Previous studies showed that two excitability limits define a subexcitable range where small wave fragments can form but they don’t exist for any significant period of time (Karma, 1991; Mihaliuk, Shakurai, Chirila & Showalter, 2002; Zykov & Showalter, 2005). Close to the upper excitability limit unbounded planar wave fragments (critical fingers) propagate for a relatively long time (Karma, 1991; Zykov & Showalter, 2005), providing the opportunity to use them as signals in unconventional computing methods.

Evolutionary Algorithms (EA) (e.g., DeJong, 2005) are being increasingly used in the design and analysis of complex systems. Example applications include data mining, time series analysis, scheduling, process control, robotics and electronic circuit design. Such techniques can be used for the design of computational resources
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