Reaction-diffusion computers: Wet, Weird and Wonderful

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What is a reaction-diffusion computer?

Reaction-diffusion (RD) chemical systems are well known now for their unique ability to efficiently solve combinatorial problems with natural parallelism. In RD processors, both the data and the results of the computation are encoded as concentration profiles of the reagents. The computation *per se* is performed via the spreading and interaction of wave fronts. The RD computers are parallel because the chemical medium's micro-volumes update their states simultaneously, and molecules diffuse and react in parallel.

What they can do?

RD information processing in chemical media became a hot topic of not simply theoretical but also experimental investigations since implementation of basic operations of image processing using the light-sensitive Belousov-Zhabotinsky (BZ) reaction. During the last decade a wide range of experimental and simulated prototypes of RD computing devices have been fabricated and applied to solve various problems of computer science, including image processing, path planning, robot navigation, computational geometry, logical gates, counting, memory units.

Why are they so cool?

RD computer is a super-computer in a goo. Liquid-phase chemical media are wet-analogs of massive-parallel (millions of elementary — 2-4 bit — processors in a small chemical reactor!) and locally-connected (a kind of "natural parallelism": every micro-volume of the medium changes its state depending on states of its closest neighbours), parallel I/O (e.g. optical input – control of initial excitation dynamics by illumination masks, output is parallel because concentration profile representing results of computation is visualized by indicators), fault-tolerance and automatic reconfiguration (cause if we remove some quantity of the liquid phase, the topology is restored almost immediately).

Design problems to be solved

Despite promising preliminary results in RD computing, the field still remains art rather then science, most RD processors are produced on an *ad hoc* basis without structured top-down approaches, mathematical verification, rigorous

methodology, relevance to other domains of advanced computing and computer hardware (this will be wet-ware for sure!) design. There is a need to develop a coherent theoretical foundation of RD computing in chemical media, and adapt new computational substrates.

Programmability

Controllability is inherent constituent of programmability. How do real chemical media respond to changes in physical conditions? Are they controllable? If yes then what properties of the media can be used most effectively to program these chemical systems? In programming RD processor we can use electric field (e.g. change velocity of waves), temperature (e.g. transitions between types of oscillations), substrate (e.g. types of mobile patterns formed), illumination (e.g. reflection of waves, wave splitting). RD programming languages and compilers is what we are also looking for!

Universality

Logical universality — both architecture-based and dynamical, or collision, based is demonstrated recently in laboratory experiments, however implementation of constant TRUTH remains an open problem. Simulation universality is almost untouched: Turing machine is still waiting its turn to be "fabricated" in wet-lab.

Smaller, faster and . . . harder

Real-life RD processors are slow indeed, due to limitations on speed of diffusion and phase waves traveling in a liquid layer or a gel. Future applications lie in the field of micro-scale computing devices and soft robotic architectures, e.g. gel-made robots, where RD medium forms an integral part of robot body, and speed may not be so critical. A silicon fabrication is another way — this may be seen as a betrayal of the "all-wet-world" idea — to improve speed of RD computers. CMOS design and analog emulation of RD systems have demonstrated feasibility of mapping chemical dynamics onto silicon architectures. Semiconductor devices based on minority carrier transport may succeed in upcoming designs of nano-scale RD processors and single-electron RD circuits.

Affective goo

Thinking is nothing without emotions. Interpreting chemical reactions in terms of emotional interaction is yet another challenge. Some theoretical work is done hence experimental implementations are on the way.

Further reading

- Adamatzky A. *Computing in Nonlinear Media and Automata Collectives* (IoP Publishing, 2001).
- Adamatzky A., De Lacy Costello B., and Asai T. *Reaction-Diffusion Computers* (Elsevier, 2005).