Metabolic Systems as Computers, Theoretically and Practically

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Background

Original Problem

Is it possible to represent metabolical processes as electrical circuits?

Because some biological studies (e.g., Lømo's long-term potentiation [4]) generate responses and curves such as those of analog, electrical circuits (RLC circuits).

If so, let us make a electrical (or electronics) metabolism, after all that is the goal of Human Brain Project!

Intention

Find a both-way transformation between electrical circuits and metabolism,

so we could *engineer* Biology. Or, simply, use already existing and validated tools (analysis, design, prototyping, among others) to accelerate biological research.

Intermediate Problem

Is there a way to transform *any* metabolic representations into digital (discrete), electronic circuits (and vice-versa)?

Because some examples of metabolic systems were implemented in digital circuits using VHDL, but the boundaries of this implementation was unknown.

• There were digital circuits that could not be implemented as metabolism? (Is metabolism computationally universal?)

• Or metabolism that could not be implemented as digital circuits? (Is metabolism a continuous, analog system?)

Idea-Consequence-Suggestion

Prove the computational power of metabolic systems,

and infer the relation between them and (analog) electrical and (discrete) digital circuits.

It is a known strategy in diverse theoretical fields (including computability and automata theory) and came as a consequence of the unresolved (at that moment) commutative diagrams.

Achievement

Theory

Computational power of metabolic P systems.

Using a set of rules to transform register machine to metabolic systems [1], we have proved that *metabolic P systems are computationally universal.* Yes, Turing-complete! And, we also did the other way round (for equivalence reasons)! [2]

Minimalist, computationally universal class of membrane systems.

Called MP^+V, this class of membrane P systems requires solely two simple types of fluxes and solely one of rules in order to be equivalent to both register machine or feasible biological metabolism [1].

Software

Compilers, simulators and comparators

to MP^+V systems to register machine and vice-versa. Three (and more!) pieces of software bundled in a single, standalone, command-line application. (And soon a full-functional web version, also.) Completely written in Haskell, it presents more than 1700 lines-of-code and its latest release can be download at http://goo.gl/B6r56v

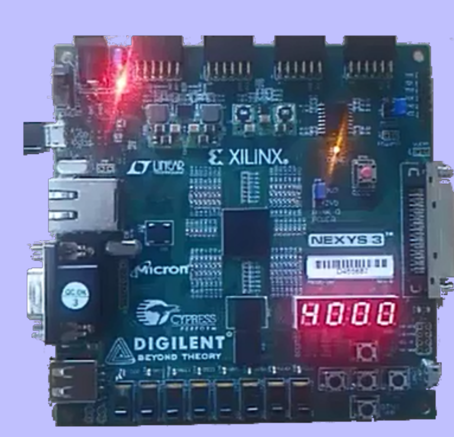
Metabolic Discrete Fourier Transform.

A DFT algorithm was developed to "test the power" of metabolic systems, providing more accurate results than the state-of-art FFT algorithm [3] used in most numerical applications with small penalty on run time.

Hardware

Digital circuits of metabolic systems.

Designed using VHDL hardware-specification language, the FPGA board implemented several metabolic systems to display the feasibility of "metabolism-on-circuits".



Reflections

• Metabolic systems aren't exactly biological metabolism. But a computer isn't a Turing machine also, nor your chocolate is a rational number. Abstraction, here, is the key concept.

> "[...] scientific work must not be considered from the point of view of the direct usefulness of it. It must be done for itself, for the beauty of science, and then there is always the chance that a scientific discovery may become [...] a benefit for humanity."
>
> Maria Skłodowska-Curie

• The work do span to delicate but great discussions such as discrete versus analog, Turing-equivalent versus super-Turing systems. It is probably a lifetime research and I want to address them. Someday.

• Practical and restricted ideas easily expand (with a little of creativity) to huge theoretical work. Breath slowly, keep yourself calm and meditate (a lot): you'll have to tame (the devils in) your mind and baby-step, problem after problem. But it is real fun and gratifying.

In the pick (of chaos), this work have stretched to:

dynamical systems, automata theory, computability, logic synthesis, control theory, algebraic groups, commutative diagrams and category theory, to name a few.

• There are more rocks in the shoes than simply the theoretical problems.

References

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The icons presented in this poster were acquired in the Noun Project website and I thank the following artists for allowing to use their art: Aha-Soft, Ema Dimitrova, Denis Klyuchnikov, Syafiqa Fickle, Laurène Smith, Juan Pablo Bravo and Luis Prado.