Could Procaryotic (as Well as Eukaryotic Cells) Provide Software and Hardware for P Systems Based Computers?

Ioan I. Ardelean

Institute of biology, Romanian Academy
Splaiul Independentei 296, Bucharest 060031
Romania
ioan.ardelean57@yahoo.com

Summary. The aim of this contribution is to re-stress that i) biological roots of P systems are the chemical reactions and physical processes performed by living cells, and to further hope/claim/argue(?) that microscopic structures and functions within Prokaryotic cells (as well as eukaryotic cells) could provide both the software and the hardware for true P computer.

1 Introduction

Prokaryotes (*Bacteria* and *Archaea*) are unicellular (there are few interesting exceptions without relevance for the topic of this paper, however), as compared with more developed organisms(plants, animals and humans, for example) in which case the biological individual is composed of billions of cells; furthermore the prokaryotic cell has a simpler structure than the eukaryotic cell, thus being a easier model to study (Ardeleam, 2006, Ardelean et al., 2006). The main problem is how to pass from am biological reality to a computer device.

Biological hardware and software for a P systems based computer

There are ultrastructures in prokaryotes which, in my opinion, could provide both hardware and software for a P systems based computer. The cell membrane in prokaryotes (the skin membrane in P system language) is an excellent example of how a biological entity could contribute to both the software and the hardware of a true P - Computer. The basic structure of Cell membrane found in all biological cells, either prokaryotes or eukaryotes is basically composed of a lipid bilayer forming a semifluid matrix in which the membrane proteins are floating. The huge diversity in CM belonging to different cells is related to the chemical composition of CM, namely the identity of proteins and lipids. The membrane proteins are

involved in chemical reactions and physical processes occurring at the biological membranes which are essential for the living bacterial cell to grow and to multiply; however. In Bacteria the cell is enclosed by a cell wall and a cell membrane and contains cytoplasm and nucleoid. Cell membrane is basically composed of a lipid bilayer forming a semifluid matrix in which the membrane proteins are floating. This model of CM is called fluid mosaic model and is universally accepted. This is the basic structure of CM found in all biological cells. The huge diversity in CM belonging to different cells is related to the chemical composition of CM, namely the identity of proteins and lipids.

The general biological functions of CM are basically the following:

1. CM serves as a selectively permeable barrier
2. CM contains transport systems used for such tasks as nutrient uptake, waste secretion and protein secretion
3. CM holds the enzymatic machinery for crucial metabolic processes: respiration and photosynthesis
4. CM synthesizes lipids and cell wall constituents
5. CM contains special receptor molecules that help bacteria detect and respond to signal in their surrounding thus affecting their behavior.

However, one main problem is determined by the fact that the ultimate biological output of a (prokaryote) cell is its transformation in two identical cells, whereas the ultimate informational output of a P systems based computer will be a calculus (here, in this presentation we do not take into account the interesting aspect/topic that now seems to be a pure science fiction dream/nightmare that the P systems based computer could be switched (by the operator or by it/himself – see Isaac Asimov's "I, the Robot") to an operational state when it performs calculations OR to another operational state when it performs self-duplication. In this last respect, the P systems based computer could behave in the real world as a virus behaves into a living cell, by changing drastically the output of the living cells: the living cells which is dying no more synthesize chemicals and nanostructures and microstructures for another living cell, but synthesizes exclusively chemicals and nanostructures needed for the auto-assembly of many new viruses). Even in the first case, the changes operated by the scientist in the cell function, should be dramatic in the sense that the cell programme will be changed drastically, in order to perform calculations and not organized chemical reactions which end into the process of cell division with the formation of two separate and (theoretically) identical cells. It would be interesting to try to think how a given biological process should be changed by the scientist in order to used that process (eventually integrated in other biological processes OR isolated functionally in a mechanically stable support) to perform a calculation needed by the scientist/human operator.

For any living cell, thermodynamically speaking, some of the energy and material processed by the living cells are for its own maintenance in the physical world and some for its multiplication; this is why the yield of a biological process is not 1, always is a mixture of anabolic processes and catabolic processes. What would be

the case with a P systems based computer, which should obey the laws of Physics and Chemistry... (and Biology?...

In my opinion/intuition a P systems based computer would not be simply basically composed of a cell (either prokaryote or eukaryote) which has some wiring to conduct inputs and outputs, but composed by a re-synthesized (artificial?) cell whose molecular components interact each other in a different way than *in vivo*, just to produce another type of output: NOT other two living (identical) cells but a computation.

It could be possible that the molecules and assemblages of molecules, the hardware produced by living cell, would be isolated and purified by the scientist, [after being synthesized *in vivo* by the living cell (or synthesized *in vitro* by the scientist)], assembled, connected each other in such a way the obtained device/artificial cell will be a true computing machine.

Probably, there are also physical constrains with respect to the physical stability in time of a such complicated proteic structure, as compared with the physical stability of a silicon based component (here, we have not to forget that Edison's first bulbs had a rather short working "life"). The ability of scientist/mankind to design chemicals, proteins first of al, with changed /desired chemical and physical characteristics has improved significantly in the last decade, and the hardware of a P systems based computer probably needs even more progress in this demiurgic (thus dangerous) activity.

The biological property of each living cell to synthesize (almost in some cells) and assemble all its chemicals, micro- and nanostructures and, in the case of genetically engineered bacterial cells for example, even foreign/alien components (*E coli* which produce human insuline) seems to be an attractive way for the scientist/humans to produce huge numbers of bio-components to act as basic elements in constructing a P systems based computer. This ability of living cells is already used in nanotechnology to synthesize nanomaterials such as S-layers.

The occurrence in cell membrane of protein assemblages active in respiratory electron transfer which perform logic functions (AND, OR logic gates) could be used to *ex vivo* implement basic processes in computers "physiology". Natural occurring or artificial assembly of these kind of proteic logic gates to perform not circular biochemical reactions leading to overall metabolism but linear biochemical reaction leading to output as a calculus could become a reality. One such biological process is respiration.

Respiration is the biological process that allows the cells (from bacteria to humans) to obtain energy. In short, respiration promotes a flux of electrons from electron donors to a final electron acceptor, which in most cases is molecular oxygen. Thus, during the last step of respiration shortly presented above water is formed from molecular oxygen, protons ($4H^+$) and electrons($4e^-$), and 4 protons are simultaneously transferred across membrane from inside to outside the cell contributing to energy conservation. Furthermore, the process of respiration involves a few other steps before that catalyzed by specific enzymes, each of these steps being an example of how given protein function as molecular logic gates. These

molecular logic gates, arranged *in vitro* in a different way than *in vivo*, could be for P systems based computer what electronic logic circuits are for "normal" computers. These logic gates active in vivo in respiration are diverse in the bacteria world, opening the possibilities that natural occurring biologic gates could be put to perform in vitro rather different operations.

For example, in *Escherichia coli*, cytochrome bd has a high affinity for oxygen and is involved in energy conversion with a medium efficiency: more exactly for every electron (passed through the cytochrome bd to molecular oxygen) one proton (one atom of bound hydrogen without its electron) is transported from inside the cell to outside the cell. Thus, because of these properties, the cytochrome bd works at relative low oxygen concentration in the growing medium. The cytochrome bo oxidase has a lower affinity for oxygen (and a higher efficiency in energy conversion); thus, cytochrome bo works at high oxygen concentration in the growing medium. Simply, but correctly, we can say that, at low oxygen concentration in the growing medium (lower than about 40% of oxygen saturation) the cytochrome bo oxydase is responsible for the entire respiratory activity of the cells: in other words, the flux of electrons to molecular oxygen proceeds 100high oxygen concentration in the growing medium (this means in between 90 and 100% of oxygen saturation), the cytochrome bd oxydase, is responsible for almost the entire respiratory activity of the cells. Furthermore, in between 40 and 90%, the two types of terminal oxidases contributes together to the respiration of cell.

Other type of proteins which could become physical substrate for the hardware of a P systems based computer are the proteins involved in the transport of ions and molecules across the plasma membrane. For example, the tripartite ATP-independent periplasmic (TRAP) transporter carriers are secondary uptake carriers requiring a periplasmic solute binding protein. They are active in prokaryotes (*Bacteria* and *Archaea*) and form a distinct family of transporters. They have been discovered in the anoxygenic phototrophic bacterium *Rhodobacter capsulatus*, its biological function being the unidirectional transport inside the cell of organic solutes such as succinate, malate, fumarate. These substances are needed by the bacterium for photosynthesis, respiration, growth and related biological processes. Other proteins form the so called efflux pumps. The efflux pumps for antibiotics and hydrocarbons work with exceptional efficiency in Gram-negative bacteria due to synergistic action of cytoplasmic membrane with outer membrane. In Gram-positive bacteria, the efflux pumps move the substrate across just one membrane. This is rather inefficient, as they have to compete with the rapid spontaneous influx of the lipophilic molecule back into the cytoplasm. A high rate of efflux is therefore required to produce significant levels of resistance. The efflux pumps in the Gram-negative bacteria traverse both the cytoplasmic and outer membranes. As the outer membrane is composed largely of lipopolysaccharides (LPS), it has different permeability properties compare to the membrane of Gram-positive bacteria. And the examples could be (mechanically) extended...

2 Conclusions and perspectives

We have not to forget that Turing was the first to notice/ to argue mathematically the possibility that nonuniform steady state could exist in chemical reaction (Turing, 1952), thus leading at bifurcations called by Prigogine, Turing bifurcations; these bifurcations are essentials for the complexity of biochemical reaction within a living cell as well as for the physical possibility of a living cell /systems to exists and to be used as a basic element in a computational (nonliving) device. (The function of many proteins as logic gates is also dependent on this property of bifurcation.)

The incorporation of different active (mainly) protein molecules in artificial membranes opens the possibility to move objects across these membranes, and to perform a calculus. This kind of experiments could lead to the construction of P systems-based computers. In conclusion, I claim that membrane proteins could provide both the software and the hardware for a P systems based computer

References

1. I. Ardelean: Biological roots and applications of P systems. Further suggestions. *Membrane Computing, WMC 2006* (H.J. Hoogeboom et al., eds.), LNCS 4361, Springer, 2006, 1–17.
2. I. Ardelean, D. Besozzi, M.H. Garzon, G. Mauri, S. Roy: P system models for mechanosensitive channels. *Applications of Membrane Computing* (G. Ciobanu, Gh. Păun, M.J. Pérez-Jiménez, eds.), Springer, 2006, 43–81.
3. A.M. Turing: Thechemical basis of moprhogenesis. *Philosophical Transactions of the Royal Society of London.* Series B, Biological Sciences, 237, 641 (1952), 37–72.