Press Release: Living Cells Show Scientists How to Compute with Symmetry and Interaction, rather than Bits and Logic

BIOMICS

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Bits and binary logic have served engineers well as the foundation for building computers. It has worked so well in fact that we came to accept that human brain is analogous to a computer. But Mother Nature is not limited to simple 1 or 0 logic: Symmetry and interaction are harnessed in biology and in the brain to do things the most powerful computers can't do, like surviving, adapting and reproducing in a rich and dangerous ecology. Binary logic often falls short of describing the workings of living things and human intelligence accurately. So the scientists have been wondering: might the kind of complex interactions like those of biological networks be harnessed in the computers of future? There is now a reason to think so.

Scientists in the UK, Hungary, and Germany from the European Commission-funded Future and Emerging Technologies project BIOMICS studied whether cells might be using SNAGs ("Simple Non-Abelian Groups") to carry out complex computations based on interactions. SNAGs are commonly used in mathematics and physics, and are based on the principles of symmetry and interaction. There are infinitely many kinds of SNAGs. They were conjured by a brilliant 19th century French mathematician Évariste, whose tragic death at age 20 in a fatal duel over a romantic interest was preceded by a feverish night of writing his ground-breaking theory. SNAGs offer a potentially powerful alternative to binary logic for computation.

The BIOMICS team of systems biologists, computer scientists, and mathematicians established the presence of SNAGs within common biological networks. By analysing gene regulation and metabolism of cells mathematically and computationally, the researchers found a SNAG in the p53-mdm2 gene network, a regulatory pathway important in the cell's response to stress (such as ionizing radiation) and intimately involved in regulating cellular responses to damage, cell 'suicide' (apoptosis) and cancer. Their findings are reported in a paper appearing in *Philosophical Transactions of the Royal Society A*.

"Binary logic is a powerful tool-kit for computation, but it's only one possibility. Living organisms don't live in a world of 0s and 1s. By harnessing interaction, living things could be doing much more powerful kinds of computation with very different basic sets of primitives," said lead study author Professor Chrystopher L. Nehaniv of the Wolfson Royal Society Biocomputation Research Laboratory at the University of Hertfordshire in the U.K. "It's like finding a new planet in the sky where no one was looking. The presence of SNAGs in the computation of cells has not been observed before. We've now found evidence in living things of A5, the smallest SNAG. This SNAG uses interactions of 60 elements to compute rather than binary logic's 0 and 1. This demonstrates that living cells have access to computational mechanisms, like SNAGs, that are never used in conventional computers." Nehaniv and Prof. Gábor Horváth of the University of Debrecen, Hungary, outlined mechanisms of how living things may be computing with SNAGs.

This week in BIOMICS Deliverable D3.1.2, Chapter 3, published 14 May 2016, Horváth, Nehaniv, working together with Dr. Károly Podoski of the Alfréd Rényi Institute of Mathematics in Budapest, Hungary have shown mathematically that nearly all biological reaction networks must have numerous embedded SNAG components that could be harnessed for computations instead of bits and binary (or Boolean) logic. "Maybe it's Galois, not Boole, who presages understanding how to compute via interaction as the secret to success of living things. It's not only in the p53 gene regulatory network that SNAGs appear, but we know we can expect to find them in most genetic and many metabolic networks," said Nehaniv.

In collaboration with BIOMICS partner the University of Passau in Germany, the team is working to translate their findings to self-regulating interaction computing applications for internet services. The resulting paradigm of "interaction machines" that grow or die away their structure like living things in response to their environments provides new ways for computers to respond adaptively and harness SNAG symmetry. Dr. Vivien Kendon, Reader in Physics at Durham University, and Professor of Computer Science Susan Stepney at the University of York, both experts in unconventional computing, who were not involved in the research, wrote in an email to the authors of the *Royal Society* paper, "it is exciting and very significant that you've created such a nice, natural model for systems that can alter their own state space. [The work is] impressively well-underpinned with solid mathematical analysis and proofs too. We are already thinking about how we can make use of interaction machines in our own work."

Empirical labwork is still needed to confirm the theory and elucidate details of how cells harness SNAGs for computation. "In the future, new kinds of computer and software systems, that work using interaction and SNAGs, may deploy resources like some living organisms do in robust adaptive responses: Driven by interaction with their environment including human users, they could grow new cells or structures, divide up tasks among different types of cells, allow old structures to whither and be reabsorbed if unused, while other cells specialize to meet computational needs," said Prof. Nehaniv. Dr. Paolo Dini, senior research fellow at the University of Hertfordshire and the coordinator of BIOMICS stated, "The project has developed a very general mathematical and computational framework to connect biological behaviour to software engineering. As biochemical problems are solved mathematically in the future, this framework will enable us to explore ways to map biological behaviour to computational behaviour and, conversely, to develop new dynamic and interaction-based modelling approaches for systems biology."

Understanding how living things and brains use interaction-based computations, which are all around us, may radically reshape not only our computers and the internet, but the existing models of the brain and living organisms. After all, we know that we are not simple 'all' or 'none' computational devices. Now scientists are catching up by introducing more interactional complexity into modeling living organisms, the human brain, and their analogue – computers.

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