7 Journeys in Non-Classical Computation

Robust, adaptable, powerful computation, as inspired by Nature

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How can we build complex computational systems - systems that are autonomous, adaptable, and robust - from millions of less reliable and simpler components? How can we build them to perform correctly and safely in an unpredictable, changing and hostile environment, and over long periods of time? Such tasks are currently well beyond the state of our computational art, and as our technology moves towards ever smaller and ever more numerous nano-scale and quantum devices, these tasks will get only more difficult.

And yet biological processes manage to do such things routinely. Living creatures are remarkably robust and adaptable. They can survive injury, damage, wear and tear, and continual attack from other creatures. Biology manages to take huge amounts of potentially unreliable matter and use self-checking, self-repair, self-reconfiguration, multiple levels of redundancy, multiple levels of defence, to develop adaptable complex biological organisms that continue to work for long periods of time in an extremely hostile environment.

So, in an attempt to cope with complexity, researchers are drawing inspiration from biology, which seems to have already discovered the answers, to develop a host of bio-inspired algorithms in evolution (genetic algorithms, genetic programming), neurology (artificial neural networks), immunology (artificial immune systems), plant growth (L-systems), social networks (ant colony optimisation), and more.

Researchers are also beginning to explore open complex adaptive systems, where new resources, and new kinds of resources can be added at any time, either by external agency, or by the actions of the system itself. Such new resources can fundamentally alter the character of the system dynamics, and so allow new possibilities, new adaptations. Our current computational systems are beginning to open themselves, for example, through the continuing dialogue between user and machine, through continued new connections to networks such as the Internet, and through robotic systems controlling their own energy sources.

One of the most exciting, and seemingly weird, recent developments is the nonclassical paradigm of quantum computing. This has emphasised the fundamental link between computation and its physical embodiment in the real world. Still in relative infancy, it holds out the promise of massive increases in computation power, of untappable communication channels, and of spooky effects such as quantum teleportation.

Classical physics did not disappear when modern physics came along: rather its restrictions and domains of applicability were made explicit. Similarly, these various forms of non-classical computation - bio-inspired algorithms, open complex adaptive systems, quantum computation, and more - will not supersede classical computation: they will augment and enrich it. This Grand Challenge seeks to explore, generalise, and unify all these many diverse non-classical computational paradigms, to produce a fully mature and rich science of all forms of computation, that unifies the classical and non-classical (natural) computational paradigms. This Challenge will additionally provide some of the infrastructure and context for sister Grand Challenges in Biological Modelling and in Ubiquitous Computing.

Such a mature computational science will allow us to design and build robust, adaptable, powerful, safe, complex computational systems. It will help researchers to uncover deep biological truths: which features of biology are necessary for correct robust functioning (so true of any living organism)? Which are necessary only because of the particular physical realisation (carbon-based terrestrial life-forms)? Which are merely contingent evolutionary aspects (and so could be different if ìthe tape were played againî)? And it will help researchers to uncover deep physical truths: what is the relationship between logical information (bits) and physical reality?