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ERCIM NEWS

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Special theme:
Unconventional Computing Paradigms

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IN BRIEF

New Robustness Paradigms: from Nature to Computing

by Giancarlo Mauri and Ion Petre

In the intracellular and the intercellular environment we observe architectural designs and dynamical interactions that are very different to those in human-designed systems: particles that are partly transported and partly move chaotically; fierce competition for resources; a vital need to respond fast, yet efficiently, to external stimuli; etc. Many details about the system-level motifs responsible for robustness, performance, and efficiency in living cells have been discovered in the last decade within computational systems biology. We are currently working on applying the lessons learned from the robust organization, functioning, and communication strategies of living cells to computing, and on integrating them into the design of a novel computing paradigm.

Computing resources in modern society, especially in Europe, are widely available and range from fixed resources (such as desktop computers, servers, game consoles, infrastructure systems), to mobile resources (such as portable computers, smartphones, car navigation systems), to virtual resources (also called cloud-based resources). Computer science is taking notice of these new technological developments and has started adapting its central computing paradigms from centralized, pre-programmed solutions to decentralized, emerging solutions, able to take advantage of the variety of resources that may be available during computations.

The goal of this new approach is to make possible environments where computing resources of many types are smoothly integrated into on-going computations, even if each resource is only sporadically available. An example of such an environment is that of a future smart transportation system, where each car has its own goals (such as reaching its destination given a number of constraints: some compulsory intermediate route points, a maximum duration of the trip, a maximum energy consumption, and others), and it interacts with its environment to reach its goal. The interaction may involve local communication with other cars to gather and distribute information about the traffic situation (such as traffic jams, accidents, alternative routes) and with the transportation infrastructure itself on aspects such as road repairs, speed limits and weather predictions. Collective decentralized decisions may be taken ad-hoc in this environment, such as collective actions to avoid imminent collisions or increased traffic jams, involving changes of the constraints, which in turn will affect the goals of each car and the decision they make further. The system has no central server to overlook the computation, but rather it is self-organizing and attempts to self-optimize on the basis of brief ad-hoc interactions between the actors and on decentralized decision making.

The robustness in decentralized systems, with self-organizing, emerging architecture, cannot be achieved through top-down structural designs that include, as in “classical computing”, well specified control and through pre-programmed responses to various (fixed) failure scenarios, typically based on fixed network architecture. Instead, the focus is on dynamic activation of computing resources, dynamic decision making, and self-adaptation, all emerging from processors of weak (non-universal) computing power and of sporadic availability. Biology serves here as an ideal source of inspiration. Biological robustness is typically implemented through mechanisms such as multiple feedback loops, alternative pathways and function redundancy, taking advantage of an environment where many different types of particle are constantly present. Cellular robustness manifests through self-repair mechanisms, the ability to mount efficient responses to changes in the environment, tolerance for broad parameter spaces, multiple response pathways, etc. We work on taking these lessons from computational systems biology, and applying them to the design of novel paradigms of computing based on large numbers of processors, each having limited power and with sporadic availability. Indeed, emerging computing platforms, such as Internet-based computing, or cloud computing offer a perspective where high computing power can be made available on demand. We aim to expand beyond the typical distributed computing paradigm where the network architecture and the communication mechanisms are fixed, and each processor is capable of universal computations, towards a paradigm where processors of limited power are able to engage in ad-hoc communications and cooperation with any available partner, and where the computing power engaged in a specific task can be increased or decreased dynamically depending on the evolution of the computation. The inspiration again comes from biology, where enzymes, catalysts, transcription factors, etc can be made available on-demand in large quantities, and then released for other tasks once they are not anymore needed.

This research is carried out in collaboration with Diego Liberati (CNR, Italy), Alessandro Villa (University of Lausanne, Switzerland), Tatiana Guy (Institute of Information Theory and Automation, Academy of Sciences of the Czech Republic), and Jüri Vain (Tallinn University of Technology). Other parts of the project focus on bio-inspired cooperation and interaction for decentralized decision making, brain-inspired evolvable networks for decision making, and on applications to robot swarm systems. The multi-disciplinary character of the project makes the enterprise possible through the combined, multi-disciplinary expertise of the consortium members, spanning from computer science to biomedicine, information systems, and neuroscience.

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