Gardening Cyber-Physical Systems

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Today's artefacts, from small devices to buildings and cities, are, or are becoming, cyber-physical socio-technical systems, with tightly interwoven material and computational parts. Currently, we have to laboriously build such systems, component by component, and the results are often difficult to maintain, adapt, and reconfigure. Even "soft"ware is brittle and non-trivial to adapt and change.

If we look to nature, however, large complex organisms *grow*, adapt to their environment, and repair themselves when damaged. Current research in "growing" software tends to concentrate either on developing structures or shapes with no obvious computational purpose, or on generating pure programs from (grammar) rules. With Gro-CyPhy, both sides grow together in an integrated fashion: the shapes provide the structure and perform the functions; the programs embedded in the structure control the functions, making the system adaptive and responsive.

Gro-CyPhy provides a framework for creating "programmed organisms", both software-intensive embodied systems and cyber-physical systems, grown in a "garden", where they are autonomous and yet reactive and controllable at a high level. Such programmed organisms help blur the artificial distinction between the abstract software programs and the substrate in which the software actuates (execution hardware plus supporting physical structures).

The Gro-CyPhy architecture comprises: (i) a *Seed Factory*, a process for designing specific computational seeds, to be implanted in physical devices (nanobots, protocells) or in virtual systems, to meet cyber-physical system requirements; (ii) a *Growth Engine*, providing the computational processes that, from given seeds, grow software virtual components, and hardware components in simulation; (iii) a *Computational Garden*, where multiple seeds can be planted and grown in concert, responding to their environment, and where a human gardener can plant, graft, prune, and train them as they grow, further shaping them into complex cyber-physical systems with the desired functions and qualities.

The vision is to apply Gro-CyPhy to a significant application, such as a self-constructing skyscraper, comprising several mutually interdependent physical and virtual subsystems, such as the shell of exterior and interior walls, electrical power and data networks, plumbing and rain-water harvesting, heating and air-conditioning systems, and building management control systems.