SEAMS 2017 –
12th International Symposium on Software Engineering for Adaptive and Self-Managing Systems

Reconciling architecture with self-organization via Morphogenetic Engineering

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Engineering is torn between an attitude of strong design and dreams of autonomous devices. It wants full mastery of its artifacts, but also wishes these artifacts were much more adaptive or "intelligent". Meanwhile, exploding growth and complexity in hardware, software and networks forces us to rethink the traditional ways in which computing systems are programmed, as rigid top-down planning and implementation in every detail are becoming unsustainable. These two challenges have created an opportunity to usher in a new generation of technologies based on an entirely novel kind of unconventional, "organic" architectures. Toward this goal, we need to boldly transition from classical top-down design to bottom-up "meta-design", i.e. mechanisms that *enable* these architectures to self-assemble, self-regulate and evolve—not directly specify them.

Looking around us, we observe that decentralized collective phenomena are pervasive in nature (physical and biological). Commonly referred to as "complex systems", these large sets of elements interacting locally and behaving collectively seem to be more efficient and, paradoxically, simpler than our centralized devices. This is why they constitute a powerful source of inspiration and can help create a new generation of artificial systems with the desired self-* properties absent from classical engineering. Historically, along these lines, the observation of neurons and genes has given rise to machine learning and evolutionary algorithms. Yet, these domains have also shifted their focus toward classical optimization and search problems, away from emergent computation.

Morphogenetic Engineering, a recent field of investigation, explores other avenues of bio-inspired software design stressing the importance and benefits of a genuine *self-organization in architectured systems*—as exemplified by the growth of multicellular organisms or the nests of social insects. It studies how sophisticated functional architectures can reproducibly emerge from a large number of heterogeneous agents via dynamical, developmental, and evolutionary processes, without central or external control. Potential applications range from swarm robotics to techno-social networks and synthetic biology. What they all have in common is a myriad of agents that can be programmed to dynamically build structures on the sole basis of peer-to-peer communication. In sum, instead of making a puzzle yourself, shape its pieces in such a way that they will self-assemble for you—and even come up with new solutions.