Submitted to GSO 2014

Morphogenetic Engineering in Swarm Robotics and Synthetic Biology

René Doursat

BioEmergences Lab (UPS3674), CNRS, Gif s/Yvette, France
Complex Systems Institute, Paris, France
http://doursat.free.fr

Engineers are torn between an attitude of strong design and dreams of autonomous devices: they want full mastery of their artifacts, while wishing these were much more adaptive or "intelligent". Today, while we must still spoon-feed (program, repair, upgrade) our most sophisticated computer and robotic systems, insatiable demand for novelty has created an escalation in system size and complexity. In this context, the tradition of rigid top-down planning and implementation in every detail has become unsustainable.

Natural complex systems, large sets of elements interacting locally and producing non-trivial collective behaviors, offer a powerful alternative and source of innovative ideas. Going beyond metaheuristic disciplines based on "neurons", "genes", or "ants", I want to highlight a new avenue of bio-inspired engineering that simulates the *growth of fine-grained multicellular organisms*. I will present a brief overview of morphogenetic engineering (ME) [1], a field that explore the decentralized self-organization of complex morphologies and behaviors, then illustrate it with two potential applications, one in swarm robotics and one in synthetic biology.

(a) Embryomorphic engineering, an instance of ME, takes its inspiration from biological development to create robotic, software or network architectures by decentralized self-assembly of elementary agents. It combines three key principles of multicellular embryogenesis: chemical gradient diffusion (providing positional information to the agents), gene regulatory networks (triggering their differentiation into types, thus patterning), and cell division or aggregation (creating structural constraints, thus reshaping). In MapDevo3D [2], an embryomorphic model of developmental animats in a 3D virtual physics world, bodies are composed of several hundreds of cells, giving them a quasi continuous texture close to the tenets of "soft robotics". Motion results from local muscle twitching without central nervous system. Animats are selected according to their ability to perform tasks.

(b) Most works in synthetic biology (a rising discipline promoting the standardized manufacturing of biological components without natural equivalents) are currently focused on the individual bacterium as a chemical reactor. The SynBioTIC project [3] addresses a more complex challenge, *shape engineering*, which concerns the "redesign" of natural morphogenesis. Using realistic agent-based simulations of bacterial mats, we experiment with fundamental mechanisms able to generate collective behaviors typical of a cell assembly, such as homeostasis, self-repair, and development. We propose a hybrid methodology, "staged evolutionary engineering of development" (SEED), in which human mediation is used as a tool for exploration via an interactive evolutionary algorithm, and as a means of refining evolutionary goals between stages.

Altogether, ME stresses the *programmability* of self-organization, underappreciated in complexity science, and, conversely, the benefits of self-organization, underappreciated in engineering. The challenge is not to build a system directly but find the rules that its components must follow to build it for us.

References

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