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# Complex Systems, Bio-Inspiration and Morphogenetic Engineering: New Avenues Toward Self-Organized Architecture

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Engineering is caught in a contradiction: on the one hand, it strives for strong design and full mastery of its artifacts; on the other hand, it would like these same devices to be autonomous, self-repairing and adaptive—in one word, "intelligent". Still today, our most sophisticated contraptions (computer and robotic systems) must be spoon-fed at every stage of their existence: entirely architectured, built, and programmed, then continually monitored, repaired, and upgraded. Meanwhile, the insatiable user demand for functional innovation and robustness has created an escalation in system size and complexity at all levels (hardware, software and networks). In this context, the tradition of rigid design and control in every detail from a top-down perspective is becoming wholly unsustainable.

A bright light toward a solution is shining from *complex systems* (CS), large sets of elements interacting locally to produce an emergent behavior in a bottom-up fashion. Whether physical, biological, or social, CS can provide a powerful source of inspiration to future and emerging technologies. Understanding these systems by modeling and simulation could help create a new generation of artificial systems with the desired "self-x" properties still largely absent from classical engineering. For example, several disciplines originating from "bio-inspiration", "artificial life" or "natural computing" have already derived principles of distributed computation from the observation of natural elements, whether neurons (Artificial Neural Networks), genes (Genetic Algorithms), ants (Ant Colony Optimization), or lymphocytes (Artificial Immune Systems).

This course will focus on another possible avenue of complexity engineering: biological development, or morphogenesis. Multicellular organisms are striking examples of naturally evolved systems that exhibit both self-organization *and* a strong architecture. Can we export their precise self-formation capabilities to technological systems? A new research field called "Morphogenetic Engineering" proposes to explore the artificial design and implementation of complex, heterogeneous morphologies capable of developing without central planning or external lead. Particular emphasis is set on the programmability and controllability of self-organization, properties that are often underappreciated in complex systems science—while, conversely, the benefits of multi-agent self-organization are often underappreciated in engineering methodologies. Potential applications range from swarm robotics and cyber-physical systems, to techno-social networks and synthetic biology. In all cases, the challenge is not to design the system directly but rather "meta-design" the proper set of rules followed by each agent on how to behave locally and interact with the other agents and the environment.

<u>Class</u>: 09/03, 14:00-16:30