Algorithmic Programmable Matter: From Local Markov Chains to "Dumb" Robots

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Abstract

Many programmable matter systems have been developed, including modular and swarm robotics, synthetic biology, DNA tiling, and smart materials. We describe programmable matter as an abstract collection of simple computational elements (particles) with limited memory that each execute distributed, local algorithms to self-organize and solve system-wide problems, such as movement, reconfiguration, and coordination. Self-organizing particle systems (SOPS) have many interesting potential applications like coating objects for monitoring and repair purposes, and forming nano-scale devices for surgery and molecular-scale electronic structures.

We describe some of our work on the algorithmic foundations of programmable matter, investigating how macro-scale system behaviors can naturally emerge from local micro-behaviors by individual particles: We utilize tools from statistical physics and Markov chain analysis to translate Markov chains defined at a system level into distributed, local algorithms for SOPS that drive the desired emergent collective behavior for the problems of compression, separation, and foraging, among others. We further establish the notion of algorithmic matter, where we leverage standard binary computation, as well as physical characteristics of the robots and interactions with the environment in order to implement our micro-level algorithms in actual testbeds composed of robots that are not capable of any standard computation. We conclude by addressing full concurrency and asynchrony in SOPS.

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