A minimal approach to modular assembly

Gregory Studer and Inman Harvey

University of Sussex
gms21@sussex.ac.uk

In this work, we propose a new research direction into minimal assembling agents. Our goal is to use very simple, inflexible assembling units to form complex and flexible assemblies (or meta-modules), guided by global environmental signals. Instead of the focus in modular robotics and self-assembly on creating maximally flexible and programmable assembling units (Yim et al., 2007, IEEE Rob. Aut. Mag., p.43), we suggest a different, complementary approach in which assembled structures maintain or enhance the range of assembly behaviors atomic agents are capable of. Replacing the idea of complex autonomous modules which are able to build arbitrary structures, like cells building organisms, we are beginning to simulate robotic platforms which themselves have rather limited assembly behavior but stochastically form structures or meta-modules with more complex interactions, like proteins built from interactions of a few amino acids. This is inspired by stochatic assembly results in the real world at any scale (Krishnan et al., 2007, Proc. ASME IMECE, ASME.org), (Winfree et al., 1998, Nature, 394, p.539), with an emphasis on understanding how function develops in these semi-controllable environments.

As a proof-of-concept and to gain intuition into how such units might look, we use a microbial genetic algorithm (MGA) to evolve the logic placed on simulated assembling agents. The agents are modeled as very simple units containing male (M) and female (F) assembly ports, as well as an input sensor, each of which may be in one of two states: enabled or not-enabled. Logic (in the form of Petri Nets) is generated by the MGA and identical copies placed on each agent, which are then allowed to assemble into chains in a well-mixed stochastic environment. Limited communication can occur between assembled agents' M and F ports. Instead of a traditional fitness function, however, where we might evaluate a logic as highly fit if it performs a particular assembly task, our fitness function rewards logics that maintain assembly behavior as the units assemble. In particular, we reward logic that maintains pairing behavior in response to a "start" signal. First, we enable the input sensor on all the agents, which may then form assembled structures including pairs which add to the fitness. If there are pairs, we then send a second "start" signal, and pairs may form of the pair structures themselves, and so on until no more pairing occurs. Higher level pairing was rewarded more than lower level pairing.

By limiting the complexity of the generated logics, and comparing the maximum fitness given these limits, there appears to be a lower complexity bound for our particular assembling units to maintain their assembly behavior as they grow orders of magnitude in size. This demonstrates that our initial proposal of designing simple assembling units which build functional assemblies themselves is feasible, at least in some cases. The successful controllers generated are interesting in that they function similarly alone or when linked together in groups of any number of agents: the *behavior* scales. In future work, we hope to expand this result and demonstrate assembly controller designs which generate more complex assembly (and other) behavior as they grow. Our eventual goal is to discover designs for very simple, inflexible units which create programmable and controllable meta-modules in response to global environmental signals.