CONTRIBUTED PAPERS IN THE ALPHABETIC ORDER OF FIRST AUTHORS:

Evolution of functionality as the emergence of logical structures

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During evolution, in order to survive, living systems gradually develop a useful approximation of their environment. During that process, organisms have to perceive environmental properties and either incorporate them into existing functional traits or create entirely novel functional combinations.
Here, we create an agent-based system where agents can evolve an internal frame of reference against which they can functionally distinguish environmental properties. Basic elements of the frame of reference are segregation (ability to distinguish environmental objects) and categorization (ability to develop a variety of functional responses to an observed environmental object). Both segregation and categorization parameters are not predefined. Instead, they are defined during the evolutionary process as a function of their contribution towards the agent's survival. Therefore, the evolutionary development of the frame of reference is not externally guided but is driven by the internal emergence of systemic functionality. As a result, an arbitrary property of the environment becomes either (i) a proper signal that triggers a set of adaptive actions; (ii) a functionally unimportant background signal that is ignored.
In the model, the frame of reference of each agent is implemented as a growing complex network with randomly added nodes. Nodes are elementary functions (move, observe, transform …) while links between them indicate pair ordering, with an assigned probability of execution. The behaviour of agents is governed by the network structure. At each time step, the network topology can change in two fundamental ways: (i) a randomly chosen node is either added or removed to/from a random location in the network and (ii) new random links can be added to a network or existing random links can be removed. With such rewiring, we simulate the evolution of embodied cognition. The behaviour of agents on each time step is determined by traversing through their internal networks. If a node has multiple links, the order of path execution in a certain time step is determined according to the probability of execution. Each agent can develop multiple internal networks. Agents compete for limited resources and their evolution is governed by natural selection. Over time, selection strongly favours the emergence of networks that build a proper frame of reference by first identifying environmental signals and then execute a set of adaptive actions.
As a next step, we analyze logical structures that appear and grow during the evolution by transforming growing random complex networks into graphs that represent formal logic. An arbitrary directed graph does not necessarily hold all the properties of formal logic. Therefore, we first determine necessary axioms (e.g. axiom of pairing, the composition of logical connectives, the emergence of transitive law). Then, we analyze temporal (composition of functions by ordered pairs) and spatial (representation by non-ordered pairs) logical properties. We finally discuss the parallel generation of functionality and logical structures with spatial and temporal aspects.