Action Switching in a Dynamical Agent

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Living systems are embedded within a complex environment, which is full of many different kinds of obstacles for the organism to overcome. In order to navigate such an environment, organisms use flexible behavioral strategies that allow them to switch between multiple possible actions in a fluid and effective manner. They use fixed patterns of coordinated action in bounded contexts, but remain responsive by shifting to different actions when relevant new information about their context becomes available. To study behavior from a dynamical systems perspective, many researchers have focused on how coordination patterns unfold between components of the organism's nervous system, body, and environment throughout a particular task. But, studying an individual action pattern is not sufficient; we must also study the dynamical strategies used to fluidly transition between such coordinated actions.

To explore the dynamics of action switching within a simplified and controlled context, a series of continuous-time recurrent neural networks (CTRNNs) were evolved using genetic algorithms. These simulated nervous systems were embedded within a simulated body and situated in a simulated 2-dimensional environment. The environment consisted of two resources, each of which provides a different essential nutrient for the agent's survival. Throughout the evolutionary runs, if the agent failed to obtain a resource by the time its internal nutrient supply was fully exhausted (and its value fell to zero), then the agent died and the simulation ended. By optimizing for longevity, the CTRNNs were forced to spend enough time on top of each nutrient source to sufficiently fill the corresponding supply, and to move between resources efficiently so that neither nutrient is depleted. This involves multiple types of actions: movement towards each resource requires the engagement of a different set of chemosensors that detect concentrations of chemical that diffuse from the resources. Additionally, different patterns of effector activation are required for tracking the resources than are required for consuming them.

This basic scenario was approached from multiple methodological angles in order to cover a more comprehensive basis of possible action switching strategies. Multiple variations of the agent were evolved under different constraints, which led to different dynamical strategies. In one set of experiments, some agents were provided with sensory input from their nutrient levels throughout their simulated evolution, and some were evolved without any nutrient level input. Agents that were provided with nutrient inputs evolved to use this relevant sensory information to directly control their behavioral state and guide their action switches. Agents without nutrient sensors evolved a strategy for approximating appropriate behavior by using a dynamical timing mechanism. By comparing these two types of agents with behavioral and dynamical analysis, this project uncovers two very different strategies for action switching: those guided by sensory sources of information and those guided by dynamically self-generated sources.

In other experiments, some agents were evolved with two spatially-extended chemosensors designated to each of the two resources, and some were evolved with only one chemosensor per resource. Additionally, agents were evolved with varying amounts of interneurons. These different constraints led to the development of different chemotaxis strategies for finding and approaching the resources, different strategies for the consumatory behavior, and different strategies for action switching. We look for the mechanisms behind these actions by manipulating parameters throughout the simulation, and studying how each action's resulting dynamics unfold. Once these actions are understood, we identify the variables that drive the shifts between them and how they are able to do so reliably in the appropriate context. Through examining such simulated dynamical behaviors, we can begin to identify general patterns and build a framework for understanding action switching in terms of dynamical systems and information.