A dynamical multi-scaled approach to sensorimotor behavior

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Abstract. We outline a view of perceptual-motor behavior, and in continuation therewith, cognition, grounded in theories of self-organized pattern formation and dynamical systems theory. Rather than making the notion of state the centerpiece of the approach, we emphasize the emergence of low-dimensional attractive manifolds onto which a structured phase flow is inscribed for a limited duration during which a functional process evolves [3]. Dynamical systems theory states that every deterministic, time-continuous and autonomous system can be unambiguously described through its flow in phase space. Phase flows are (temporally) invariant structures, and are here interpreted as objects that capture the functional organization of a purposeful, goal-directed system embedded in and coupled to its surroundings [6]. The notion of control, in this sense, is associated with structured flowsthus distributed over the organism-surroundings system, rather than the formation of the trajectory itself, which merely is a consequence of system organization and initial conditions. In being temporally invariant objects, structured flows may be said to entail a systems potential, ongoing as well as future trajectories. In that sense, the notion of structured flows echoes representational accounts like the generalized motor program concept [5]. In contrast to traditional representational accounts, under the present view the locus of representation is distributed over the system-surroundings.

By their very nature, structured flows are associated with functional processes of a limited complexity and are insufficient to account for sequences of functionally distinct behaviors. Sequences of distinct behaviors can be conceived of as recurring, typically fast transitions between functional modes, which can be formalized by a competition dynamics operating on a slower time scale than the ones adhering to the modes [4]. Formally, a competition parameter is associated with each functional mode. During the time a competition parameter dominates, the process entailed in its corresponding functional mode evolves. During (short-lived) transitions, the operational flow transforms from one functional mode into another. The coming to domination of a given mode, i.e., action selection (decision making) implies the coming into being of a functional organization, i.e., planning. That is, rather than being serial events, action selection aspects, if not interpretations, of a single underlying process.

We coin the ensemble of functional modes available to an organism its behavioral repertoire, and metaphorically depict it as a (high-dimensional) potential landscape. In the absence of task activity, the brains resting state reveals spontaneous coherent intermittent network activity [1]. These resting state networks show a strong degree of overlap with networks observed under various task conditions, are intermittently visited driven by noise [2], and as an ensemble are latently present (i.e., being close to a bifurcation point, they are ghost attractors) during resting state. As such, little task-relevant information is necessary to push the network into the appropriate task-relevant state. In an analogue fashion, but without equating brain states with functional modes, switches between distinct behaviors may be metaphorically viewed as the intermittent occupation of distinct attractive sub-spaces (i.e., functional modes) in a dynamical repertoire (landscape). The likelihood of hopping between attractive subspaces is not homogenous but depends on the distance separating them. For an active organism, the probability of visiting a given attractive mode rather than any other is to a considerable degree context dependent, even though stochastic effects are in all likelihood ever present. Consequently, the layout and structure of the (metaphorical) landscape is situational, given by the organisms repertoire and sculpted by context. By altering context, behavior, next to whatever other contextual changes, thus also re-sculpts the landscapethe dynamic landscape and behavior are bi-directionally coupled even though evolving at different time scales. Any behavior thus influences the likelihood of (near) future behaviors. Consequently, representations, should the notion be evoked, are not like entities freely available at ones disposal but are constrained by a continuously changing situational dynamic landscape.

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