The Cognitive Body: from Dynamic Modulation to Anticipation

Alberto Montebelli and Tom Ziemke

University of Skövde
SE-541 28 Skövde, Sweden
{alberto.montebelli, tom.ziemke}@his.se

1 The cognitive body

What is the role of the body of an organism? The obvious, common sense answer, would highlight its role in dictating the physical relation between an agent and its environment. Of course the fundamental function that the body of any organism plays, conveniently situating its available set of sensors and actuators in a spatio-temporal frame of reference, cannot be missed or ignored. However, this common sense interpretation is broadened in embodied and situated approaches to the study of cognition, both at a theoretical and experimental level [1,2,3,4] . The body shapes the cognitive potential of the agent by specifying the conditions for possible interactions with its environment, whilst constraining their range. A self-organized agent typically depends on and exploits such constraints [5].

Nowadays, a more systemic view of the mind pervades at least a few major theoretical frameworks in the study of cognitive processes. Several authors are currently committed to the underpinning of a theoretical background, in which the specific embodiment of an organism has non-trivial cognitive consequences. The body massively pre-/post-processes the information flow to and from the nervous system, and the common phylo-/onto-genesis of body and nervous system provides a deep, distributed integration of bodily and nervous functions [6]. Perception and action are not causally sequential activities, but can be seen as an interwoven process, one supporting the other [7,5].

Nevertheless, we have reasons to think that this might not be the whole story. We find that the hidden, bio-regulatory dynamics developing under the surface of the body are typically largely neglected in the study of cognitive phenomena. As some authors put it, the interaction between bio-regulatory events that take place inside of the body of an agent and what is traditionally interpreted as its control system, might be a non negligible component of its ongoing cognitive processes [8]. In this short article we comment on our ongoing experimental testing of a such proposal [9,10], focusing on the role that the intrinsic non-neural bodily dynamics might play in supporting and boosting cognition. Furthermore, we also formulate the programmatic foundations for an experimental extension of our work by advocating a new cognitive architecture for the study of anticipatory behaviors in which non-neural bodily dynamics play a fundamental role.

2 The dynamic role of the cognitive body: a minimalist case study

In a recent study [9,10], we have shown how even very simple non-neural bodily states might play a crucial role in the modulation of the behavior generated by an artificial neural network (ANN) implementing the controller of our simulated robotic agent. We used standard evolutionary algorithms to set the weights and biases for a reactive ANN (with no hidden layers), driving the motoneurons of the robot. The system self-organized in order to find a recharger for its energy level, sensed by the ANN, thus overcoming its temporal linear energy decay. The choice of a simple scenario aimed to facilitate our analysis.

As part of the analysis of the successfully evolved system[1], we manipulated the energy level as the control parameter of the whole system. By systematically clamping[2] it to a discrete set of values ranging from zero to 'full', we classified a number of possible behaviors. We found two general classes of qualitative behaviors dependent on the current energy level: exploratory behaviors at the lowest levels of energy (e.g. the agent engaged in loops between potential energy sources and also in broad external loops) and local behaviors at higher levels of energy (i.e. the agent was closely looping in the neighborhood of a single source).

Back to the evolutionary task, we then examine the implications of the behaviors observed in clamped conditions. As the energy level is left free to follow its dynamics, it stands for an effective self-organized dynamic action selection mechanism. Different classes of behavior are locally available to the agent as a function of its current energy level. High energy levels imply that a source of energy was recently visited; apparently, it must be still in the proximity of the agent, consistent with the selection of local behaviors. Low energy levels imply that the recent search for an energy source was unsuccessful. This correlates with broader exploratory behaviors. Therefore, the solution of this minimalist cognitive task relies on the self-organized dynamics of the whole system. In the traditional cognitivist approach however, a similar mechanism would be modeled in terms of explicit representations and memory.

So far, we have described our model using the intuitive metaphor of an energy level mechanism. Nevertheless, the fundamental aspect to consider in our system is the coupling of dynamic systems characterized by time scales that are dissimilar by several orders of magnitude (in particular we refer to the dynamics of the sensory-motor and the energy level systems). During its evolution, the system is adapted to exploit the information of the energy level, whose slow dynamic structures the sensory-motor flow in dynamically related events. This gives the evolved system the capacity to integrate information over time even though it relies on a purely reactive sensory-motor mapping. Generalizing, we formulate

---

[1] By 'system' we mean the global system constituted by environment, agent, its ANN and non-neural dynamic mechanism of the energy level.

[2] 'Clamping' refers to the injection of a steady energy level in the ANN during the whole replication. The agent moves freely in its environment for a time sufficient to exhaust all behavioral transients, yet permit observations of satisfactory duration.

the *hypothesis* that the access to a collection of attuned dynamic sub-systems characterized by intrinsic dynamics at different time scales and the exploitation of such differences, might constitute a widespread cognitive mechanism. This mechanism, widely operating at the different levels of organization of biological cognition, might provide the cognitive system with the capacity to accumulate information on events which are relevant to its survival, with no need for explicit representations, memory or consciousness.

3 The bodily path of anticipation

Operative definitions of anticipatory behavior stress the effect that an estimation of the future state of the system has on its current behavior. We suggest that settling on a dynamic attractor constitutes an implicit form of anticipation in at least two important senses. First, once engaged with an attractor, the system enters a stable and fully determined regime. Once settled on an attractor that currently satisfies specific functional requirements, the whole dynamic of the system is attuned to a specific flow of events. An example of this attunement and its anticipatory role is Pavlov's dog, that salivates when food is made potentially available, thus effectively preparing its body for the digestive process. Second, often during a metastable regime (e.g. see [11]), the closer the system is to a bifurcation the more its trajectory in the phase space tends to develop in the proximity of the attractor that will take over after the transition; therefore its future attractor is slowly formed from its own 'ghost' in the actual current trajectory (for a clear example: [11, chapter 4]). In other words, the body, together with its non-neural internal mechanisms, represents a fundamental component of the dynamical richness of an agent-environment attunement. Such richness, when autonomously viable, is intrinsically endowed with anticipatory power.

With the present work we intend to present a hypothesis about the possible role of an explicit model ('emulator') predicting the dynamics of the agent-environment sensory-motor interaction in a cognitive architecture. For example, let us consider a cognitive agent engaged with some activity that might result in noxious or undesirable consequences. Preliminarily, we have to state a few assumptions: first, the current behavioral attractor for the agent-environment interaction (i.e. the current sensory-motor flow, similar to [9,12]) is described by a few global variables that compress the specific relevant information for the current activity out of the enormous number of degrees of freedom of the system. Second, a sensory-motor emulator (similar to [13]) is also embedded within the current global dynamic, whose evolution is dynamically correlated with the actual behavior. Finally, following its faster time scale, the dynamics of the emulator (onto-/phylogenetically adapted) can anticipate, in the sense illustrated above, the sensory-motor consequences of the engagement with a noxious activity.

If we assume the possibility of a direct interaction from anticipatory to behavioral dynamics, we immediately recognize a critical problem: which kind of dynamic would emerge after the current action is inhibited or redirected? Obviously, the dynamics emerging in the emulator should elicit a viable alternative behavioral attractor. Generalizing our example to include other situations critical for the agent's viability, our *hypothesis* is that, rather than a direct influence on the current behavior, the effect of the prediction is actually mediated by the body. The outcome of the emulator affects the actual bodily dynamics, and altered bodily quantities transiently act as control parameters for the global system. Hence, the problem of the determination of the next behavioral attractor is offloaded on the bio-regulatory dynamics of the body. Destabilized by the input from the sensory-motor emulator, the body reacts *as-if* actually engaged in such sensory-motor experience, pulling back the system towards safe regions. This mechanism exploits the knowledge achieved by the body during a long and complex process of onto-/phylogenetic adaptation, functional to the viability of the agent. An equivalent knowledge, in case of a (theoretically possible) path directly coupling anticipatory and sensory-motor dynamics, should be somehow achieved by the neurocontroller. Clearly, our hypothesis requires a detailed experimental investigation, currently being developed in our research activity.

References

1. Varela, F.J., Thompson, E.T., Rosch, E.: The Embodied Mind: Cognitive Science and Human Experience. MIT Press (1992)
2. Clark, A.: Being There: Putting Brain, Body, and World Together Again. MIT Press, Cambridge, MA (1997)
3. Ziemke, T., Zlatev, J., Frank, R.M., eds.: Body, Language and Mind: Embodiment. Volume 1. Mouton de Gruyter, Berlin/New York (2007)
4. Thelen, E., Smith, L.B.: A Dynamic Systems Approach to the Development of Cognition and Action. MIT Press (1996)
5. Nolfi, S.: Power and limits of reactive agents. Neurocomputing **42**(1-4) (2002) 119–145
6. Chiel, H., Beer, R.D.: The brain has a body: Adaptive behavior emerges from interactions of nervous system, body and environment. Trends in Neurosciences **20**(12) (1997) 553–557
7. Suzuki, M., Floreano, D.: Enactive robot vision. Adaptive Behavior **16** (2008) 122–128
8. Parisi, D.: Internal robotics. Connection Science **16**(4) (2004) 325–338
9. Montebelli, A., Herrera, C., Ziemke, T.: On cognition as dynamical coupling: An analysis of behavioral attractor dynamics. Adaptive Behavior **16**(2-3) (2008) 182–195
10. Montebelli, A., Herrera, C., Ziemke, T.: An analysis of behavioral attractor dynamics. In Almeida e Costa, F., ed.: Advances in Artificial Life: Proceedings of the 9th European Conference on Artificial Life, Berlin, Springer (2007) 213–222
11. Kelso, J.A.S.: Dynamic Patterns: The Self-organization of Brain and Behavior. MIT Press, Cambridge, MA (1995)
12. Ito, M., Noda, K., Hoshino, Y., Tani, J.: Dynamic and interactive generation of object handling behaviors by a small humanoid robot using a dynamic neural network model. Neural Networks **19**(3) (2006) 323–337
13. Tani, J., Nolfi, S.: Learning to perceive the world as articulated: an approach for hierarchical learning in sensory-motor systems. Neural Networks **12**(7-8) (1999) 1131–1141