Contextual selection mechanism

« 11 » There is a very interesting point stressed by the target article: it clearly stresses how external resources can shape behavior differentiation in agent society. This is indicated through the *Predictive Utilisation* measure that the authors introduce. This may really be considered to apply or adapt to other implementations of learning agents. Still, even if the influence of the environment may be more easily observable with predefined behaviors, experimental results show the emergence of subsystem formation in the simulation.

« 12 » Nevertheless, following the previous questions, we could wonder whether the selection of loops may rather occur according to the ephemeral context? Enabling or disabling some loops may somehow be considered in a more dynamic way, depending on a specific on-the-fly experienced context. This would possibly remain consistent with the double contingency problem. If we imagine a scenario where the number of food sources varied over time, it might lead to dynamic subsystem formation under dynamic constraints.

Parallel co-constructed loops

« 13 » Besides, we could speculate whether specifying such a closed sensory-motor loop for each behavior may be in full agreement with radical constructivism. The closed loop remains a sequential concept originating from traditional causal thought. But if we follow the requirements promoted by enactivism (Varela, Thompson & Rosch 1991), for instance, I am not sure whether we can deduce that the closed-loop is the best possible implementation for modeling cognitive mechanisms.

« 14 » The traditional vision of the closed-loop in first-order cybernetics and control theory is architectured around the notion of feedback and anchored in a *sensing-thinking-acting* loop. There would then be, as the authors seem to agree and promote in their model, a new paradigm arguing that humans control their input/sensation rather than their output/behavior in a homeostatic fashion (Riegler 2007). But this leads to a model that is not flawless either.

« 15 » One can rather imagine multiple sensory and motor loops evolving in parallel on their own while interacting continuously. This parallelization may eventually approach a complex system vision of the construction of cognition. Within this framework, sensory and motor loops would become entities in themselves, reciprocally disrupting and adjusting each other. As evidence of this, in the sensory-motor contingencies theory, O'Regan, Myin & Noë (2005) insist on an intrinsic quality of the feeling of presence, which they call "grabbiness" (or alerting capacity). This is that sensory systems possess sudden change detectors and are able to interrupt the ongoing cognitive activities and cause an automatic orienting response. How could this mechanism be achieved if there were no dedicated sensory loop(s)?

Are loops sufficient?

« 16 » More radically, we could even wonder whether the notion of a loop is actually consistent with the cognitive phenomena? This is the credo of dynamic systems theory. For instance Tim van Gelder (1997) argues in favor of abandoning loops, by comparing the Turing machine and the Watt governor. He argues that we should preferably get inspiration from the latter for understanding and/or modeling cognition. He points out that the Turing machine a-contextually manipulates symbols, obeying rules given by the programmer, while the Watt governor only obeys physical laws applied to built-in constraints. In other words, he stresses that the Turing machine relies on mathematics while the Watt governor relies on mechanics and physics. In this context, the notion of the loop is considered to be a hidden way of monitoring the need to do something. But sensing and acting do not consist of waiting for something to do. Rather, cognition must be considered as constituted of continuous processes that are fundamentally proactive, compared to the passive waiting character of looping.

« 17 » The aspects covered in my commentary represent only a fragment of a deeper ongoing debate. This is probably where the frontiers are situated of what *in silico* simulation can offer to help build constructivist foundations of socio-cognitive understanding. So far, computational methods may lead us to understand complexity growth by using simulation. In the meantime, however, we must ask ourselves how these purely deterministic sequential methods can really help us simulate what we, as adaptive animals, are.

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The Relevance of "Differentiation" and "Binary Code" for Simulating Luhmann

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> **Upshot** • I acknowledge the value of Porr & Di Prodi's piece for simulating Luhmann's key process of subsystem formation and exploring how the concepts of "differentiation" and "binary code" relate to their model.

« 1 » Bernd Porr & Paolo Di Prodi's target article does a great job of showing how the process of "subsystem formation," central to Niklas Luhmann's sociology, can be simulated. To assess the value of Porr & Di Prodi's work, we must first make explicit our interests. For this commentary, I take a sociological point of view. What interests me the most is how this simulation sheds some light on the intricate levels underlying the process of subsystem formation and how they relate to key concepts taken from Luhmann's work.

« 2 » The first level corresponds to neuronal systems with interrelated signals processed by agents. This model is based on the guidelines of radical constructivism, and although it could be said that Luhmann differs from RC in several aspects, Porr & Di Prodi's model seems to me in line with Luhmann's cognitive and systemic postulates. Systems' self-referent operations driving the learning process are stimulated by irritations (internal states) (Luhmann 2006: 627).

« 3 » The second level is perhaps even more important from a sociological perspective. It corresponds to a social system that is drawn upon the interaction of agents' behavior. To talk about communicative systems, at least in the way I understand Luhmann's model, it is not enough that agents are able to broadcast signals (§62). Contingency is the link between the two levels. Contingency arises when an agent faces another agent whose behavior cannot be predicted but only expected. Alterity (otherness) is the heart of a sociological perspective. Luhmann depicted double contingency as two black boxes that deal with one another under the constraints of their own capacity to observe and influence (Luhmann 1991: 118f). The authors suggest that double contingency raised by this interaction could motivate an agent to select a particular aspect of its environment as a complexity reduction strategy (§61). The agents then could specialize into a role or particular behavior (§57) by triggering a modification in their neuronal structures. The agents are not individually preprogrammed to adopt one particular role. They are just programmed to adapt their behaviors under the conditions of their environment (§64), which is only possible because they have been first programmed to observe the environment through distinctions (e.g., food sources). The emergent order (social system) is conditioned by the complexity of the individual systems, without depending on their capacity to coordinate or control it (Luhmann 1991: 119).

« 4 » Does this process illustrate the emergence of social subsystems in accordance with Luhmann's theory? To answer this question, I think two concepts should be analyzed: "differentiation" and "binary code." The authors clearly take this direction in their conclusion. And I agree with their remarks, as pointed out in what follows.

« 5 » According to Luhmann (2006), the process of system differentiation can be triggered spontaneously as a result of evolution and can induce structural transformations. Differentiation takes place when a system/environment distinction is drawn within an existing system; the latter is seen as global in the eyes of the just-differentiated system (Luhmann 1991: 42). The authors illustrate the simplest and most trivial form of this differentiation, namely, one that carries no reference to the society as a whole and produces no subsequent formations within the system.

« 6 » A binary code can be established when the system is able to distinguish-and-select without losing the reference that created the distinction in the first place. Then there is always the possibility to turn to a (preexisting) negative value. This type of selection differs from basal operations that can only refer to identical elements and are blind to what is different (Esposito 1996). The distinction driven by binary code does not correspond to difference between system and environment but it refers to internal, accessible and contingent states of the system that duplicate the reality. A communication can accept or deny a certain value (e.g., a paper suggesting that an entire theory is false) but it cannot deny the importance of this distinction (Luhmann 1996: 222). In my opinion, this is the most substantial part of Luhmann's sociological work: it enables the treatment of a multi-contextural significant construction of reality within modern society.

« 7 » Porr & Di Prodi's model for simulation looks to be far from the conditions for generating a binary code. The systems they describe rely more on actions than on communications, and have no place for understanding. Without communication and language, is not that clear how acceptance/denial could play a part in this model (Luhmann 2006: 170). However, having a binary code is not a *sine qua non* condition for illustrating how social subsystems emerge. It is important to keep this in mind to avoid raising false expectations while evaluating the authors' contribution and its relevance to sociology. They are not simulating the emergence of functional systems, but showing that double contingency can lead to subsystem differentiation at the basal operations level.

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Authors' Response

What to Do Next: Applying Flexible Learning Algorithms to Develop Constructivist Communication

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> Upshot • We acknowledge that our model can be implemented with different reinforcement learning algorithms. Subsystem formation has been successfully demonstrated on the basal level, and in order to show full subsystem formation in the communication system at least both intentional utterances and acceptance/rejection need to be implemented. The comments about intrinsic vs extrinsic rewards made clear that this distinction is not helpful in the context of the constructivist paradigm but rather needs to be replaced by a critical reflection on whether one has truly created autopoietic agents or just an engineering system.

« 1 » **Olivier Georgeon**'s commentary shows that there is a deep mistrust between two communities: on the one hand the reinforcement community, which has emerged from both engineering (e.g., optimal control) and economics, and on the other hand the community that has emerged from behaviour-based robotics, now branding itself as "enactive cognition." As **Patrick Pilarski** (§6) rightfully emphasized, the trouble comes from introducing the notion of reward. While in reinforcement learning the reward plays a central role, in enactive cognition it is very fashionable to claim that rewards are not part of the equation (**Georgeon** §9). However, rewards are then introduced through the back door in the form of "enjoyment," "dislike" or "intrinsic satisfaction." Even "sensor loops" (**Fabien Hervouet** §15), which learn to detect novelty, essentially reward themselves to be able to predict sensor