Paving the Way Toward Minimal Affectivity-in-Collectivity (AiC) Models: A 4E Cognition Proposal

Georgina Montserrat Reséndiz-Benhumea[1*], Jesús M. Siqueiros[2], Carlos Gershenson[1,3,4], Gabriel Ramos-Fernández[1,3,5] and Katya Rodríguez-Vázquez[1]

[1]Instituto de Investigaciones en Matemáticas Aplicadas y en Sistemas, Universidad Nacional Autónoma de México, 04510 Mexico City, Mexico
[2]Instituto de Investigaciones en Matemáticas Aplicadas y en Sistemas - Unidad Mérida, Universidad Nacional Autónoma de México, 97302 Mérida, Mexico
[3]Centro de Ciencias de la Complejidad, Universidad Nacional Autónoma de México, 04510 Mexico City, Mexico
[4]Lakeside Labs GmbH, Lakeside Park B04, 9020 Klagenfurt am Wörthersee, Austria
[5]UPIITA, Instituto Politécnico Nacional, 07340 Mexico City, Mexico
gmontserb@comunidad.unam.mx

Introduction and Contribution

In classical cognitive science, affectivity and agent-environment interaction have been commonly understood as mere products of neural activity within the brain. Thus, traditionally, cognition has been assumed as an individualistic, private, intellectual, and affect-free process occurring inside the head, even during social encounters.

In sharp contrast, according to the more recent embodied, embedded, enactive, and extended (also known as “4E”) approach to the mind, affectivity and agent-environment interaction are constitutive to cognition. In this view, “cognition is not an event happening inside the system; it is the relational process of sense-making that takes place between the system and its environment” (Thompson and Stapleton, 2009).

Following the latter perspective, on the one hand, recent contributions to the field of affective science drawing on enactive theory have challenged the mainstream accounts on affective phenomena (mainly focused on the study of emotions and moods, i.e., temporary phenomena). On this view, agents are *precarious* autonomous systems that actively need to regulate their interaction with their environment, in order to maintain their own identity, otherwise, they tend to dissipate or disappear (Di Paolo, 2009). At its core, *affectivity* implies that agents are sensitive to the *precariousness* of their different dimensions of embodiment (further detailed in the next section), which contributes to the conservation of their own existence. Thus, affectivity is a broader and deeper phenomenon that constitutes cognition, and is defined as “a *lack of indifference*, and rather a *sensibility* or *interest* for one’s existence” (Colombetti, 2014). Broadly, this perspective supports the claim that sense-making (conceived as the mark of cognition) is also affective, which entails that “even the simplest living systems have a capacity to be sensitive to what matters to them” (Colombetti, 2014).

On the other hand, recent studies in the field of social cognition using agent-based modeling as a computational proof of concept, also known as *embodied dyadic interaction models* (e.g., Froese et al., 2013a; Candadai et al., 2019; Reséndiz-Benhumea and Froese, 2020; Reséndiz-Benhumea et al., 2020, 2021), have demonstrated that *social interaction*, which would be defined as a relational property of a whole integrated brain-body-environment-body-brain system (Froese et al., 2013b; Froese, 2018), increases the complexity of neural and behavioral dynamics of a pair of embodied agents to higher levels than those possible in isolated conditions. During mutual interaction, agents become integrated into a larger, coupled system of higher dimensionality (Froese and Fuchs, 2012), exhibiting “new properties and processes at the collective level” (Froese and Krueger, 2020). Our modeling work will focus on the study of this particular subset of the phenomena characterized by the notion of the socially extended mind (Krueger, 2011, 2013), namely, *genuine intersubjectivity* (Froese, 2018; Froese and Krueger, 2020). Briefly, genuine intersubjectivity refers to “the subset that has to do with the socially extended *lived experience*[1] that is associated with the co-regulated real-time interaction taking place between two or more persons” (Froese and Krueger, 2020). As Varela (2000) anticipated, the current enactive approach to genuine intersubjectivity, corresponds to what he called the cognitive science of *inter-being* (Froese, 2018).

Based on those recent findings and theoretical developments, we propose then to take a first step toward bridging both research fields, by investigating the *affective dimension* of *genuine intersubjectivity* (Froese, 2018), under an agent-based modeling framework, through the introduction of what we call *minimal Affectivity-in-Collectivity (AiC) models*. In the following, we succintly present the description and methods of our first-proposed minimal AiC model. Results will be presented in future work.

We expect our research to contribute to the current debate

[1]An in-principle limitation of minimal agent-based models is the lack of this experiential dimension (Froese, 2018).

in affective and social robotics in two main ways: 1. In stark opposition to cognitivist perspectives, we pretend to make affectivity our point of departure, and not something that adds "coloration" to cognitive processes (Varela and Depraz, 2005). 2. By contributing fresh findings to current research on the fields of artificial intelligence, social and cognitive robotics, and human-robot interaction, that have already addressed the understanding of emotions and its artificial simulation within a 4E perspective (e.g., Ziemke and Lowe, 2009; Damiano and Cañamero, 2010; Dumouchel and Damiano, 2017; Cañamero, 2021).

Our long-term goal consists of applying these simulated models on the study of the role of affectivity in social phenomena, such as that exhibited by eusocial insect colonies, human and non-human primate groups, to gain novel insights of biological systems and explore new possibilities in artificial and hybrid systems.

Modeling the Affective Dimension of Genuine Intersubjectivity: Minimal Affectivity-in-Collectivity (AiC) Models

Overall, our proposal consists of creating simulated "thought experiments" (Di Paolo et al., 2000), following the synthetic approach to studying adaptive behavior as current embodied dyadic interaction models (e.g., Candadai et al., 2019; Reséndiz-Benhumea et al., 2021). This will allow us to investigate, as simplified as possible, the affective dimension of genuine intersubjectivity by simulating vertical and horizontal circular causalities (Fuchs, 2018), in which the crucial role of precariousness will be emphasized for the emergence of affective phenomena, starting off using pairs of simulated agents as the minimal social group toward more complex societies (Kappeler and Pozzi, 2019).

To start with, we will take as a basis of our modeling work the interdependent dimensions of embodiment, as shown in Fig. 1A, taken from Arandia and Di Paolo (2021): *organic* (i.e., metabolic), *sensorimotor* (i.e., habitual), and *intersubjective* (i.e., mutual specification and participatory sense-making). Current embodied dyadic interaction models, explore in a minimal way, sensorimotor and intersubjective dimensions, however, they lack a minimal form of an organic dimension. This organic dimension is essential for our research given that its precariousness is the foundation of agency.

Hence, in our first-proposed minimal AiC model, we will follow similar methods as Reséndiz-Benhumea et al. (2021), yet we will introduce in our small-brained (2-neuron) agents (where, the neuron layer will be modeled as a continuous-time recurrent neural network (CTRNN)), a minimal form of an organic dimension, by transitioning from acoustically coupled agents to light-powered agents with an internal battery, two light sensors, two motors, and a light emitter, inspired in Di Paolo (2010), as shown in Fig. 1B.

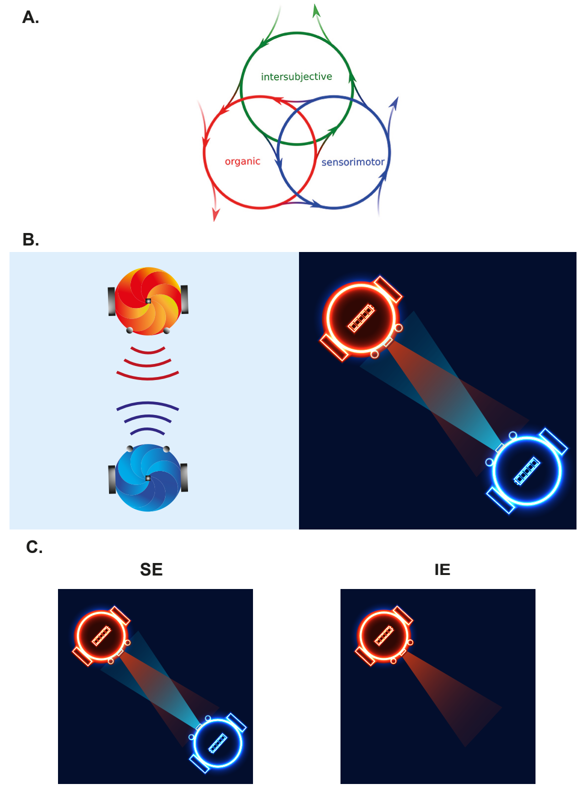

Figure 1: First-proposed minimal Affectivity-in-Collectivity (AiC) model: **(A)** Dimensions of embodiment: organic, sensorimotor, and intersubjective (figure taken from Arandia and Di Paolo (2021)). **(B)** Types of agents: in the left, acoustically coupled agents used in embodied dyadic interaction models; in the right, light-powered agents with an internal battery, two light sensors, two motors, and a light emitter, inspired in Di Paolo (2010). **(C)** Evolutionary experiments: in the left, Social Evolution (SE); in the right, Individual Evolution (IE).

Our next step will be to evolve either pairs of agents (Social Evolution, SE) or solitary agents (Individual Evolution, IE), as shown in Fig. 1C, for: (1) maximizing their neural complexity, operationalized as Shannon entropy, and (2) maintaining their battery-energy levels within their space of viability, by being re-charged from a light source different from their own, otherwise, the corresponding agent "dies" (i.e., the agent loses its identity, it is unable of regulating its relationships with its environment). Then, the best pairs or solitary agents will be tested under different scenarios: social, isolated, and with fixed, random-blinking or ghost light sources. Finally, we will compare their performance, in terms of neural complexity, to those previously obtained with acoustically coupled agents (see Reséndiz-Benhumea et al. (2021)) and analyze their behavioral strategies to maintain themselves "alive" (i.e., by regulating their interactions with their environment), in precarious conditions, while maximizing their neural complexity.

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