The dynamics of appropriation

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Abstract. In the framework of the embodied approach, this paper tries to emphasize that, aside from its closed loop organization, a body is a *growing* object. A body can indeed recruit external elements to make them part of its own structure. The general question we address is the following : to what extent does the process of recruitment relate, in a direct or indirect fashion, to the cognitive activity? We show in this paper that the structure of the interaction between an agent and its environment is comparable to a recruitment process, taking place both at the level of the nervous activity, and at the level of the group of individuals. During an interaction process, the coordination between the agent's body and its surrounding is interpreted as an intermittent expansion of the agent's body. For that reason, we say that the agent *appropriates* the surrounding elements. The choice of a relevant partner among various partners illustrates the ability to anticipate, through the co-construction of action, some desirable forthcoming interaction. The agent indeed takes part in the realization of its own predictions. The paper finishes with some remarks about the learning processes, seen as the crosswalk between nervous-environment processes and body growth processes.

1 Introduction

The "embodied" approach is a well-known alternative to classical cognitive models. Under that approach, an agent identifies with its body, and the cognitive activity identifies with the continuous trade-off between the dynamics of self-construction and the body/environment structural couplings [1]. Under the embodied approach, a cognitive process is not something located inside the agent. It relies on the continuous interleaving of physiological and environmental autonomous flows, with the body's skin acting as a barrier or a frontier preserving the body's operational closure [1].

We will try in this paper to explore some of the embodied approach conceptual extents, according to the questions of learning and anticipation, and their implementation in artificial devices.

2 Model setting

The aim of this paper is not to give definite or elaborate models, but to accompany some of the proposed ideas with a light mathematization. We thus introduce this paper with a global model of interaction, with the use of some of the concepts of classical control theory (input, output, functional diagrams) and dynamical systems formalism. A control system is thus a *model* of interactions between a model of controller (or agent) and a model of the environment. The agent perceives the environment through sensors and acts on the environment through actuators. The environment evolves under the actions of the agent, and those actions are updated according to the sensory flow.

In this presentation, the agent's and environment evolutions are co-dependent, i.e. belong to the same process, whose evolution both originates from the two sides. It results, formally speaking, by a simple splitting in two parts of a single autonomous dynamical system composed of an environment and an agent for which we suppose we have a precise state description (see also [2]). An *interaction system* can classically be described by the set of equations:

$$\begin{cases} u_{\text{out}}(t) = k_{\text{out}}(x_{\text{in}}(t)) \\ \frac{dx_{\text{in}}}{dt} = f_{\text{in}}(x_{\text{in}}(t), u_{\text{in}}(t)) \\ u_{\text{in}}(t) = k_{\text{in}}(x_{\text{out}}(t)) \\ \frac{dx_{\text{out}}}{dt} = f_{\text{out}}(x_{\text{out}}(t), u_{\text{out}}(t)) \end{cases} \tag{1}$$

Where X_{in} is the internal state space, U_{in} is the internal input state, $f_{\text{in}} : X_{\text{in}} \times U_{\text{in}} \to X_{\text{in}}$ is the internal transition function, $x_{\text{in}} \in X_{\text{in}}$ is the internal state, $u_{\text{in}} \in U_{\text{in}}$ is the internal command, X_{out} is the external state space, U_{out} is the external input state, $f_{\text{out}} : X_{\text{out}} \times U_{\text{out}} \to X_{\text{out}}$ is the external transition function, $x_{\text{out}} \in X_{\text{out}}$ is the external state, $u_{\text{out}} \in U_{\text{out}}$ is the external command,

- The mapping $k_{\text{out}} : X_{\text{in}} \to U_{\text{out}}$ represents the transformation of the agent's state space to the commands space, i.e. the various forces which activate the agent's body. The outer process is thus dependent on the internal state, through its "actions" $u_{\text{out}}(t)$.
- Conversely, the mapping $k_{\text{in}} : X_{\text{out}} \to U_{\text{in}}$ represents the transformation from the external space to the agent body-centered space, basically corresponding to the signal sent to the agent by its various sensors. The inner process is dependent on the external state, through its "perceptions" $u_{\text{in}}(t)$.

The functional scheme of this system is represented in figure 1.

In the most general case, every subsystem (agent and environment) owns one or several hidden processes, whose dynamical evolution actively take part in the production of new perceptions and new actions. Given some perceptual configuration, the agent's reaction is not strictly predictable. Conversely, the environment does not always react the same. The global evolution is not exclusively under the control of the agent, or under the control of the environment. The global evolution is as much driven by the hidden processes than by the commands.

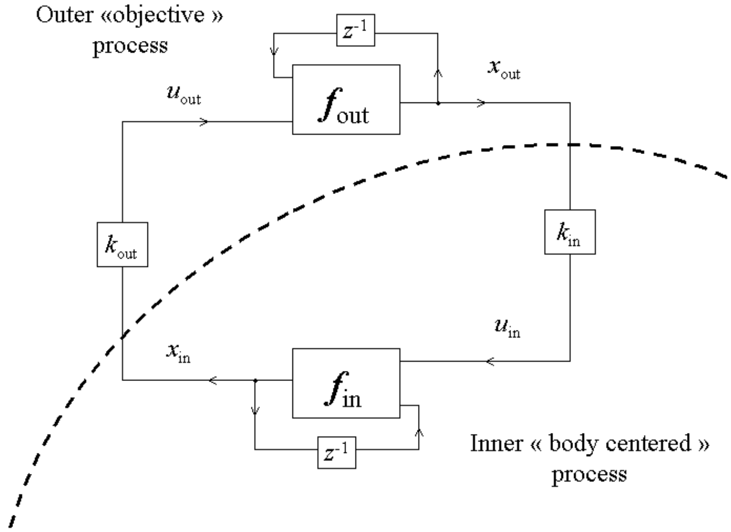

Fig. 1. Functional diagram of an interaction system.

3 The processes of recruitment

This section is about growth processes and the ability of dynamical models to relate to such processes.

3.1 Recruitment and growth

Animals or plants life relies on the permanent process of body self-construction and growth. A distinction can be made between the body macroscopic structure and the process of recruitment and extension which continuously modifies the body. A body "survives" as long as it can access to a minimum amount of nutriments and energy. The assimilation of external elements is thus a fundamental process by which a given body *recruits* external element as new body compounds. The necessity of a permanent renewal of internal components makes the body very dependent on its environment. Our proposal in this paper is to identify *the process of recruitment and growth* as the fundamental level from which every further cognitive refinement develops.

Under this schematic view, the bodies can face different situations which may facilitate or prevent the fundamental growth process. Any nutritive assimilation facilitates this internal growth process. Any aggression or nutriment lack is in conflict with the current internal growth process. Reciprocally (in a recurrent fashion), the internal growth process is selective and opportunist. The body develops in a way which facilitates compatible assimilations, and prevents destructive intrusions. For instance, a plant basically grows where the energy and nutriments sources are the more abundant (roots extension, foils development,...). Different mechanism prevent and repair intrusions and aggressions.

In terms of modeling, the most popular models of plant growth relate to a fractal process of replication of branch growth patterns [3]. Those models however only care about the structures, and do not take into account the properties of the substrate. Here, we use as a reference the models of aggregation processes, which have been given for instance in Turing reaction-diffusion equations [4]. In an aggregation process, the various particles belonging to the substrate obey to two antagonist tendencies, i.e. a strong local attraction tendency and a weak distant repulsion tendency, which results in the constitution of macroscopic aggregates. In that model, the current aggregates can recruit new individuals in the constitutions of its own "body".

3.2 Nervous dynamics

Contrarily to plants, animals own a nervous system, so that they can produce movements. Plants thus passively consume the energy of light and soil nutriments, while animals actively seek for sources of food and energy. The nervous system allows high speed processes which operate in parallel with the original self-construction growth process. The nervous process is accompanied by muscles contractions and body movements. The nervous activity (neurotransmitters release and ionic electric transmission) is persistent during the whole life of the body (i.e. more or less quiescent). This persistent activity needs external stimulation (i.e. perception-induced neurotransmitters release) in order to maintain its activity, like bodies need nutriments.

This analogy helps to to analyze the nervous dynamics in the terms of a recruitment/aggregation process. New stimulations thus "feed" the nervous dynamics, and a lack of stimulations diminishes the nervous activity. Conversely, the nervous activity propagates through the nervous system, like fire, and recruits new stimuli as components for its "combustion". The activity grows better where the stimulations are, and thus extends toward the current stimulations. The property of aggregation also relates to the property *synchronization*, which has been extensively observed within local assemblies [5] or between different assemblies [6]. The dominant hypothesis is that such synchronization expresses the involvement of a structure in a process taking place at the global level. This involvement manifests in a measurable cooperation between the local and the global level, so that a certain dynamical pattern "recruits" participants to its own activity (and conversely some neurons "choose" to take part in the global process, modifying their dynamics and being modified by the global dynamics).

This property of synchronization has been extensively established as a rather common phenomenon taking place in various models of artificial neural networks [7–11], from binary models [7] to elaborate stochastic and sparsely connected integrate and fire models [9]. More generally, the model given in eq.(1) is well suited for the representation of such dual nervous/body interactions. The internal variables may correspond to the nervous dynamics, while the external variables may correspond to the agents body and also partly to the environment. The internal process of recruitment may be obtained with topologically organized neural maps [12, 13], where incoming stimuli can operate as seeds for new aggregates of neural activity. The two subsystems may mainly differ by the integration times, i.e. the internal integration time may be of one or several order faster than the external ones, mimicking the difference between internal and external "reaction times".

4 Interaction and appropriation

4.1 Partners and perceptibility

The way the nervous system reacts to external events is dependent on the structure of the animal's body. I call here "*partner*" an object which is affordant [14] with the body, i.e. which facilitates a structural coupling with the agent's body. It can touch its senses, or even make an attempt on its life (ravine, poisoned food, predator)[1].

The way bodies perceive their surrounding objects or partners is first determined by their respective physical properties, forms and spatial extension. Some surrounding objects are perceptible, others are not. In the natural world, perceptibility is basically rooted on the symmetry/disymmetry of the facing bodies in one or several physical dimensions, i.e. relative spatial extension, relative speed, relative illumination, and also in the symmetry/disymmetry of the individuals sensors. So, two facing bodies may easily ignore each other for basic physical reasons, possibly colliding by chance.

The main aspect however of perceptibility is that bodies are built in a way that favors the perception of the most relevant features in their environment. For evolutionary and/or adaptive reasons, attractive or aversive sources of food, attractive or aversive partners, are more salient in their perceptual field. This basically means that bodies are prepared to interact with *elective* partners. The bodies are predisposed to perceive the items they can interact with. So, in a schematic view, a body is surrounded by various partners, which are potentially eligible for interaction. The eligibility of a partner means that a given partner does not by itself necessarily trigger a pre-definite reaction. At a given moment, a process of decision takes place where a partner is elected, among others, for an interaction.

How do a particular body "take the decision" to select an elective partner? This relates to the question of action selection and decision processes. From a global point of view, one can not say that a certain decision is strictly taken "inside" the body. One should better say that the environment dynamics facilitates a certain series of interaction patterns, and reciprocally the body's internal dynamics facilitates a certain series of interaction patterns, and the decision relies on a mutual process of convergence toward a compromise:

[1] On the contrary, an infectious agent may not be considered as a partner, as it can not touch the agent's senses

– At the nervous scale, only the more *desirable* perceptual compounds are chosen by the nervous process. Reciprocally, the desirable items are defined by the process of selection which occurs in the current nervous activity.
– At the body scale, only the more desirable partners are chosen. Reciprocally, the desirable partners are the ones which find themselves chosen by the animal.

The election of a partner for interaction is comparable to a recruitment process. In a particular bodies/environment context, an interaction pattern is formed and various partners are recruited to participate to that process. Such recruitment process is a mix between individual choices and global entrainment.

Given a certain interaction system (1), can we measure whether the two subsystems cooperate or, on the contrary, disturb each other? This question relates to the question of the *coupling*, or matching, between the two sub-processes. Such matching may be measured by the way the two sub-processes display common features in their state space, like periodicity, synchronicity[2]... In the general case, one can not strictly define a causal path in the process giving rise to a certain interaction pattern. The two parts are equally involved in this process, i.e the two subsystems may end up on a compromise, so that they mutually resonate with the other, or, on the contrary, end up on a dissension, so that they tend to produce, for instance, a chaotic pattern of interaction (see also [16]). In the first case, the two processes are easily penetrated by the other's influence. In the second case, the two processes remain blind to the other's influence.

4.2 The appropriation process

At a given moment, some of the elective partners are "elected" to take part in the ongoing interaction process. That moment is accompanied by a specific nervous pattern. A perceived partner fundamentally appears in the form of various sensory compounds (i.e. neurotransmitters). At the local scale of the nervous activity, some of those latent sensory compounds are integrated in the current nervous dynamics ("chosen" as relevant nervous compounds), and take part in the current nervous dynamics. The nervous activity thus recruits some new sensory compounds among several sensory appeals. The elected partners (their sensory compounds) are "used" and manipulated by the nervous dynamics, i.e. they are integrated in the internal/external process of action construction. They thus "belong" to the nervous dynamics.

In parallel, the body participates to an interaction pattern. Under this interaction pattern, the various partners are found to act coherently according to the body's current dynamics. In other terms, the body and its surroundings are synchronized. In accordance with the internal dynamics, it appears that the

[2] The measure of the coupling between the two dynamics may empirically rely on a comparison between the embedding dimension of the global trajectory D, and the embedding dimensions of every local trajectory D_{in} and D_{out}. This point will not be developed in this paper. See also [15].

various partners *virtually belong to the animal's body*. In that sense, the animal *appropriates* its partners. For that reason, the interaction moments can also be called "appropriation moments", where the agent's body virtually extends to one or several partners taking part in the interaction. This virtual body and the neurons internal dynamics operate at the same speed. There is thus a correspondence to be found between the neuronal aggregation dynamics and the "aggregation" that comes with the current interaction.

5 Anticipation and learning

5.1 An uncertain body in an uncertain environment

A world item, as a partner, can locally represent a future moment (a prey for instance represents a future meal). This is true only in a particular context (a fed up predator does not consider a potential prey as a future meal). The current partner can thus be seen as an anticipatory clues of the following events, in the particular context of the current interaction. The agent's anticipations are closely linked to the agent's decision. The election of a particular partner corresponds to the election of a particular forthcoming pattern of interaction. The agent thus actively takes part in the realization of its own predictions, and there is no separation between anticipation and action decision.

The way the agents *choose* partners is often simple and non controversial. In many situations, there is no serious trouble in doing what the senses suggest to be done, so that almost automated responses can be triggered. The set of familiar partnerships may be seen as what the agent feels as "belonging" to its own world : usual places, usual faces, usual habits. The usual partners trigger usual responses and usual interactions.

On the contrary, unknown territories, unknown environments, unpredictable reactions are the major part of everyday life. The persistent environment uncertainty requires persistent attention! Reciprocally, internal processes often present some uncertain aspects : the strong complexity of internal processes can lead to unstable and/or chaotic internal patterns.

The global uncertainty of the agent/environment coupling are the reasons why a significant part of structural couplings do not issue as they were anticipated! This is often referred as "cognitive dissonance", i.e. a lack of congruency between the agent actions and the environment reactions. The process of election, i.e. the process by which elective partners are chosen, is driven by an internal nervous process which is known to be highly unpredictable, presumably chaotic [17]. The precise moment of action decision is thus growing on a moving ground in an uncertain surrounding.

5.2 Reward dynamics

Reward and learning dynamics are precisely at the crosswalk between the body growth dynamics and the nervous dynamics. We give here some tracks toward a modeling of the learning process according to the primitive process of growth and nutriment assimilation. From a global point of view, the body growth is favored when the movements that accompany the nervous activity orientate the body toward sources of nutriments, and avoid major dangers. The reciprocal is not obvious. In which fashion does the slow process of assimilation orientate the nervous activity toward the facilitation of body persistence? Due to the difference of speed between growth and nervous dynamics, the direct dependency between nutriments and growth is not operant. The nutriments are not assimilated at the same place and at the same speed than where the nervous activity is.

The point I want to suggest here is that the plant tendency to grow better where the nutriments are is mimicked and extended by animals *in the behavioral domain*. Some behaviors tend to be consolidated for they give a better access to power sources. Some parts of the internal construction (neural circuits mainly) are consolidated and grow, for they participate to a body-environment coupling which gives access to a rewarded moment. Other circuits degenerate for they don't bring such access. The important point is that a new domain of growth is defined, which is not related to the body mass, but on the body's abilities and skills. These new abilities correspond to *an extension of the agent appropriation capabilities*, i.e. knowledge extension. The knowledge of the environment increases with the number/variety of eligible objects and partners. The more the agent can identify various partners, the more it can take a part in the construction of future events, and the more it can avoid to face cognitive dissonances.

The learning process must rely on a local storage of neurotransmitters, which are released and then recruited by the current nervous pattern. Those neurotransmitter (dopamine for instance) may be seen as the substitutes of real nutriments, following the path of the current nervous activity, and possibly stimulating local weight reinforcement mechanisms. That moment of neurotransmitters release is often described as a "reward". It is a signature that something positive has been identified by the body. In neural networks modeling terms, if we decompose internal input u_{in} in various components, i.e. $u_{\text{in}} = (u_{\text{signal}}, u_{\text{weights}}, u_{\text{other}})$, the weights vector $u_{\text{weights}} = \{W_{ij}\}_{i,j\in\{1..N\}^2}$ directly relates to the interconnection pattern of the neural network[3]. The weight evolution rule, even directly depending on the internal activity, may thus be attached to the slow external process.

The question is now to define the nature of the operational core from which new partners may emerge through the global and local body-environment processes. A preliminary implementation of that principle using the properties of an internal chaotic dynamics as a generative process for action production and environment appropriation can be found in [18].

[3] where for instance the neural activation dynamics may be updated according to

$$x_i(t+1) = f(\sum_{i=1}^{N} W_{ij}(t)x_j(t) + u_{\text{signal},i}(t))$$

References

1. Varela, F.: Principles of Biological Autonomy. North Holland, Amsterdam (1979)
2. Beer, R.D.: Dynamical approaches to cognitive science. Trends in Cognitive Science **4** (2002) 91–99
3. Lindenmayer, A.: Mathematical models for cellular interaction in development i+ii. Journal of Theoretical Biology **18** (1964) 280–315
4. Turing, A.: The chemical basis of morphogenesis. Philos. Trans. R. Soc. London (1952) 37–72
5. Singer, W.: Time as coding space in neocortical processing : a hypothesis. In Buzsáki, G., ed.: Temporal Coding in the Brain, Berlin Heidelberg, Springer-Verlag (1994) 51–79
6. Rodriguez, E., George, N., Lachaux, J.P., Martinerie, J., Renault, B., Varela, F.: Perception's shadow: long-distance synchronization of human brain activity. Nature **397(6718)** (1999) 430–433
7. Amari, S.: A method of statistical neurodynamics. Kybernetik **14** (1974) 201–215
8. Gerstner, W., Ritz, R., Van Hemmen, L.: A biologically motivated and analytically soluble model of collective oscillations in the cortex. i - theory of weak locking. Biol. Cybern. **68** (1993) 363–374
9. Brunel, N., Hakim, V.: Fast global oscillations in networks of integrate-and-fire neurons with low firing rates. Neural Computation **11** (1999) 1621–1676
10. Hansel, D., Sompolinsky, H.: Chaos and synchrony in a model of a hypercolumn in visual cortex. J. Comp. Neurosc. **3** (1996) 7–34
11. Daucé, E., Moynot, O., Pinaud, O., Samuelides, M.: Mean-field theory and synchronization in random recurrent neural networks. Neural Processing Letters **14** (2001) 115–126
12. Amari, S.: Dynamics of pattern formation in lateral-inhibition type neural fields. Biological Cybernetics **27** (1977) 77–87
13. Daucé, E.: Short term memory in recurrent networks of spiking neurons. Natural Computing **2** (2004) 135–157
14. Gibson, J.J.: The ecological approach to visual perception. Houghton-Mifflin, Boston (1979)
15. Penn, A.: Steps towards a quantitative analysis of individuality and its maintenance: A case study with multi-agent systems. In Polani, D., Kim, J., Martinez, T., eds.: Fifth German Workshop on Artificial Life: Abstracting and Synthesizing the Principles of Living Systems, IOS Press (2002) 125–134
16. Tani, J.: Symbols and dynamics in embodied cognition: Revisiting a robot experiment. In Butz, M., Sigaud, O., Gérard, P., eds.: Anticipatory Behavior in Adaptive Learning Systems, Springer (2003) 167–178
17. Skarda, C., Freeman, W.: How brains make chaos in order to make sense of the world. Behav. Brain Sci. **10** (1987) 161–195
18. Daucé, E.: Hebbian reinforcement learning in a modular dynamic network. In: SAB 04. (2004)