Interactivist approach to representation in epigenetic agents

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Abstract

Interactivism is a vast and rather ambitious philosophical and theoretical system originally developed by Mark Bickhard, which covers plethora of aspects related to mind and person. Within interactivism, an agent is regarded as *an action system*: an autonomous, self-organizing, self-maintaining entity, which can exercise actions and sense their effects in the environment it inhabits. In this paper, we will argue that it is especially suited for treatment of the problem of representation in epigenetic agents. More precisely, we will elaborate on *process-based ontology* for representations, and will sketch a way of discussing about architectures for epigenetic agents in a general manner.

1. Introduction

The assumption of this paper is that *representation* is the crucial issue to be addressed whenever one engages in diverse endeavors: from attempting either to explain observed behaviors of human infants of certain age, finding plausible explanations of different cognitive (dis)abilities, to the projects which aim to construct artificial beings that mimic cognitive development. Where do representations come from? How do they acquire their meaning? Are they all innate? How can we account for the productivity and systematicity in human representational system? Those are some of the issues that were and still are in the focus of cognitive science and the related fields.

Despite the continuing discussions about the nature of representations, intentionality (intrinsic or not), the representational content, nature vs. nurture, origins of language, to mention but a few topics (for a fresh overview see Manzotti, 2001), in the last decade or so, some - more or less - widely accepted points have emerged (or at least that is the vibe the authors are sensing, but still, see e.g. Fodor, 1999). We give few of them below:

-representations cannot be treated in isolation, i.e. *in abstracto*, and detached from the architecture of the whole agent;

-they should be grounded in agent's sensory motor apparatus;

-embodiment plays a special role in understanding representations;

-we should account for their emergence – either they are learned in the development of the agent or inherited i.e. have emerged in the evolution;

The classical sense-think-act model, with its modular approach (with modules for *perception* – where external stimuli are somehow transformed into internal representation, then the *reasoning* module – where cognition happens and which sends its output to the *actuator* module) definitely lost its popularity (Cisek, 1999).

Still, although accepting these views, because of the inertia of dominant views in some scientific fields, many do not go through the consequences implied by them.

The paper is organized as follows: In the introduction we list the interactivist objections to the classical representations; in the second section we describe the interactive representations; the third section opens with a sketch for a generic interactivist architecture followed by an illustrative example of how some parts of it can be implemented; the paper closes with a discussion which relates this work to related research.

2. Representation: the interactivist way

2.1 Interactivist objections to classical representations

In Bickhard's (Bickhard, 2003) own words "[I]nteractivism is a complex philosophical and theoretical system... [and] involves a commitment to a strict naturalism. By naturalism is meant (roughly) a regulative assumption that reality is integrated; that there are no isolatable and independent grounds of reality, such as would be the case if the world were made of Cartesian substances."

Interactivism adopts *process metaphysics*, i.e. the fundamental nature of the world is organizations of processes. This stance is grounded in the history of sciences where as some field matures and progresses, *substance based models* are replaced with process models: phlogiston with combustion, caloric with thermal heat, élan vital with self-maintaining and self-reproducing organizations of processes and the like. The *exceptions* of this process so far, are the sciences of mind (Bickhard, 1998b)

Bickhard vehemently and persuasively argues against classical representations (Bickhard, 1993; Bickhard and Terveen, 1995) picturing them as ill-conceived, immature *substance based* models. Among other things, these *encodings* (classical representations in the parlance of

interactivism) cannot account for learning, for the normativity of representations, and they cannot generate new emergent representations. Below are several objections raised by Bickhard on various occasions.

Encodigism is circular. By postulating the existence of symbols as the basic representational unit, which represents objects (actions, events…) from the real world, it presupposes phenomena, which it is supposed to explain. Namely, it cannot give any account for learning new representations.

Encodigism is incoherent. Encodings are able to carry representational content given that such content *is already* provided. X_n can *stand-in* for X_{n-1}, i.e. X_{n-1} provides the representational content for X_n. So, all human generated representations (maps, diagrams, drawings convey a content by virtue of pre-established conventions. They stand-in for those conventions.This stand-in relation, can be iterated many times but there must be some bottom level X_0 so that we are forced to admit that there must be representations that don't just stand-in for other representations and that these representations are encodings, too. Bickhard calls this *the terminal incoherence*.

Encodigism leaves open the question of interpreter for the symbols. Maps, statues, pictures, being external representations are useful for their human interpreters. It is not clear, once they are made internal for some system where and who is supposed to be the interpreter.

From *within the cognitive system*, and not having a direct (whatever that could mean) contact with the world how could the system ever know if some representation is not correct? Bottom line, if given some external feedback about the correctness of a given representation it can change it for (a combination of) another symbols of a pre-given set.

Instead of dealing with systematicity, productivity, and other characteristics of representational systems in linguistically capable agents, we should first deal with these problems.

2.2 Interactive Representations

Interactivist representations emerge out of agent-environment interaction. They are not an outcome of any sort of processing of inputs.

"Passive systems that only receive inputs *cannot* be representational in the interactive sense. No "processing" of inputs can yield interactive representationality, including any connectionist processing of inputs: representation is an emergent property of situated *interacting* systems, not passive systems." (Bickhard, 1998)

In some of our previous work, we have put forward similar claims (Stojanov et al, 1995) which comes as no surprise, because according to Bickhard (2003) interactivism shares much with Piaget's genetic epistemology, and this is exactly our departing point for several works (e.g. Stojanov et al, 1995, 1997). In our later research we explicitly embraced interactivist ideas (Stojanov, 1997; Stojanov, 1999a, 1999b).

As we hinted above, in this paper we wanted to pause a bit, step back, and try to see the bigger picture and discuss and put forward some general issues regarding autonomous systems and representations.

Before proceeding further with the nature of interactivist representations, we will elaborate on the generic notion of an agent.

2.3 Agents as Action Systems

The generic agent within the interactivist framework is seen as *an action-system*. Action-system is a system that is *autonomous*, *stable*, and which could *perform actions* in the environment it inhabits and *sense the effects* of those actions (Figure 1)
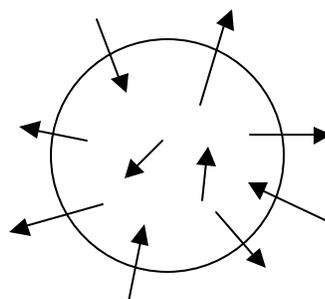
Figure 1. Artistic vision of an action system; the circle represents the tentative boundary of the agent; arrows represent actions; note that even arrows coming into the system are treated as differentiating/detecting/perceptual actions of the action system, and not actions of the environment on the system;

Subsystems of the action-system are engaged in interactions with the portions of the environment (Figure 2). The very structure (embodiment) of the agent imposes the primordial structure on the sensory influx.
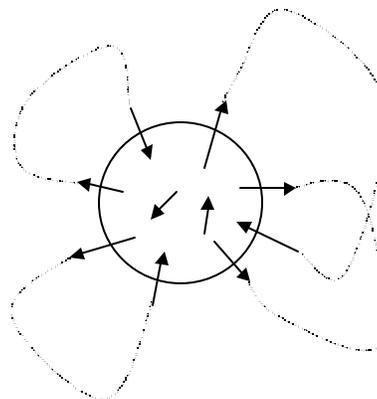
Figure 2. Subsystems of the action-system are engaged in interactions with the portions of environment

For example, in a (more or less standard, and without additional equipment) human agent, it is impossible that the agent can see what is in front of them *and* what is behind them - at the same moment. Or, you cannot touch your lips with the thumb and the top of your head with the index finger of the same hand, simultaneously.

The action-system *creates* its inputs by performing various actions. The sensory-motor influx thus generated, serves as a basis for interactive representations. So, we can write that:

$$S=f(A, E)$$

where the sensory input (S) is affected by the actions (A) that the agents performs, and by the environment (E) which imposes certain constraints. Note that the notion of *action* incorporates the constraints imposed by the very embodiment of the agent (mentioned in the previous paragraph) and that to a specific agent the environment is manifested via particular relation f(). Note also that some subsystems work *within* the action system, i.e. not resulting in some externally observable behavior, but still capable of inducing changes in S. Stating this in other words, the environment unfolds its structure to the agent (the action-system) by putting specific constraints on how processes initiated by the agent proceed through time.

We can illustrate the dynamics of such a system by displaying the trajectories of some chosen set of parameters (p_1... p_n) in time (Figure 3). One can think of these parameters as a subset of elements of S and A, i.e. they are strictly a view from within.
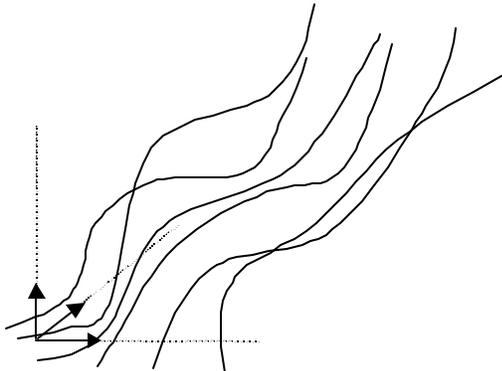
Figure 3. Trajectories in the parameter space of an action system; one of the dimensions is time and others depend on the nature of the parameters

At a given moment, the snapshot of the values of the parameters, as well as the indications for their possible continuations is called *situation image*. An instant of time is represented by the plan in Figure 4.
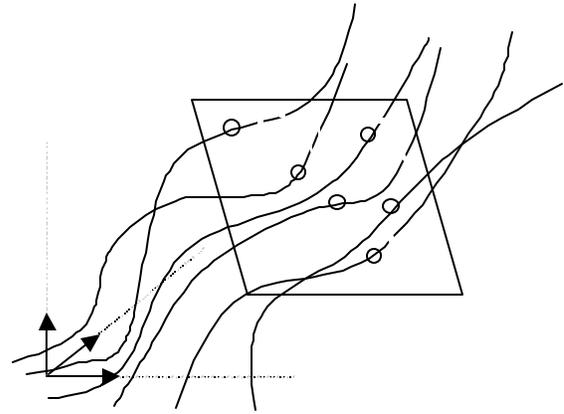
Figure 4. A snapshot of the values of parameters and the possible continuations at a given moment is called *situation image. An instant of time is represented by the plane.*

Quick et al (1999; 1999a) describe very appealing and rather similar concepts to those that we are presenting here. They construe an embodied system as a system with "perturbation channels" through which it can affect the state of the environment, and the environment can affect its states. We are quite sympathetic with this view of the embodiment, and the agent-environment structural coupling, together with the notion of an action-system, is almost interchangeable with their notion of embodied systems.

So far in our discussion, we remained on a fairly general, and one may say - definitional level. In the next section we resume our elaboration on interactive representation.

2.4 Why do agents act?

The answer to the question 'Why do agents act?' is far from straightforward. An external (human) observer could describe the behavior of the agent at different levels, depending on what would be taken as an element of behavior, as a basic action.

Although in this context we tend to construe the verb *to act* as something that the agent is doing intentionally, we would like to cover all the processes taking place *in* and *in-between* the action-system and its environment.

Future potential trajectories

Present situation image

Actual past trajectories
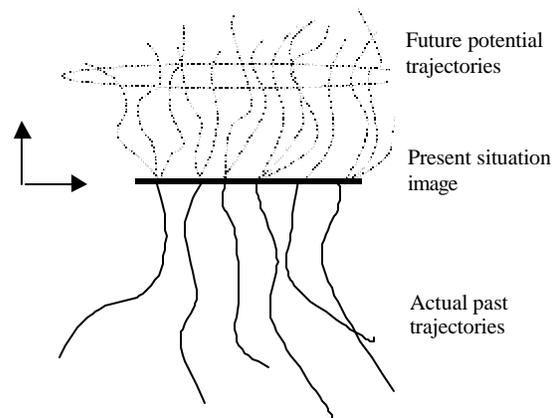
Figure 5. A view from above

First, we take the *autopoietic* (Maturana and Varela, 1980) view that agents (or action-systems) act to preserve their autonomy and to maintain the conditions for their further existence. Bickhard often puts forward the canonical example of a candle flame. The flame maintains above threshold combustion temperature, vaporizing wax into fuel, and in standard conditions induces convection (which brings in fresh oxygen and disposes the waste products). He calls these systems *self-maintenant*. Furthermore, a system that could maintain its condition of being self-maintenant is called *recursively* self-maintenant system. Candle flame certainly is not recursively self-maintenant, because there is not much that the candle flame could do when it runs out of wax. But, a bacterium (Campbell, 1990) may be able to swim as long as the sugar gradient raises, and tumble if it senses that it is swimming down the gradient. In the above-mentioned sense, this bacterium is a primitive recursive self-maintenant system capable of switching between interactions that differentiate *good* and *bad* direction of swimming. We see that in order to be recursively self-maintenant, an action-system has to be able to *discriminate* various aspects of environment and evaluate them within its *inner value system*. Back to the Figures 3 and 4: the situation image in a given moment should include also indicators for potentialities for interactions, which would guide the trajectories towards preferred (in the sense of the inner value system) subspaces. For example, a representation of some physically manipulable (for some agent) would include indicators for the invariant patterns of interaction with that object, based on past experiences. As depicted metaphorically in Figure 5, the situation image would include also indicators for the potential paths that may be taken. These indicators would include contextual information regarding agent's goals, experience, and the level of its ontological development.

Wrapping up this section of the paper about interactive representations we want to quote Bickhard (1980) again:

> "There is no direct or total knowledge of the world, only fallible and partial knowledge of its interactive characteristics. Thus, the world image is constructed from the specific to the general, out of the basic elements of knowledge in the *procedures innate to the system*, while the situation image is differentiated within the world image from the general to the specific by the outcomes of various interactions. The world image is a *hierarchicalized network* of general interaction possibilities and dependencies, while the situation image is a scheme structure of current possibilities." (emphases added)

3 Generic interactivist architecture

Based on our earlier works (Stojanov, 1997, 1999a; Kulakov, 1998) in (Kulakov and Stojanov, 2001) we have put forward the essential elements for a developmental architecture, which was based on: structures, inner values, hierarchies, and stages. Here, we want to argue that this architecture can be seen as a special case of a more general interactivist architecture, presented by Stojanov in a talk and tutorial (Stojanov and Trajkovski, 2001) during the First Interactivist Summer Institute at Lehigh University, August 2001. (www.lehigh.edu/~interact).
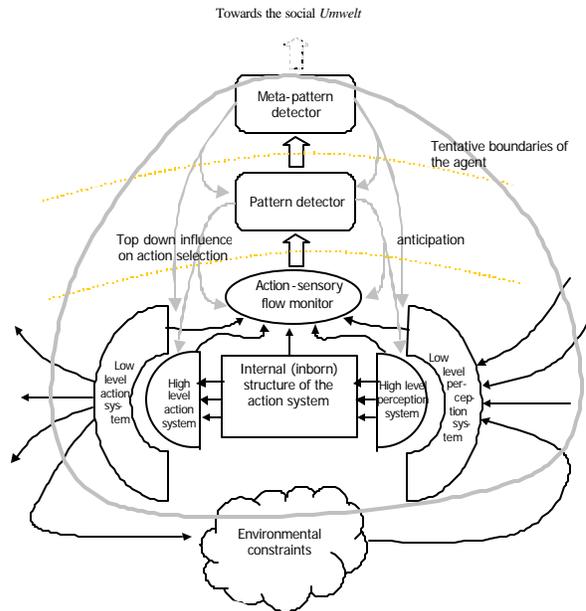
Figure 6. Generic interactivist architecture

Figure 6 is far from being a blueprint to build an interactivist robot but it illustrates the main concepts. Here is the idea: in the core of the system there is its the innate structure which determines the actions that can be initiated by the system; once the agent comes into existence it starts acting in the environment according to these structures; the environment being as it is, puts constraints on the way actions are being performed; a subsystem called *action-sensory flow monitor* transmits its output to a *pattern detector* subsystem which is triggered by certain patterns in the flow (see Figure 3) and can have top-down influence on action selection, as well as can generate anticipations about the incoming sensors; all this is necessary so that the recursively self-maintenant action system can generate keep the trajectories in the "good" subspaces (cf. bacteria example). Naturally, a particular implementation would require minimally specification of the details of the inner value system, and definition of the pattern recognition accordingly. As the agent grows, structural changes introduce meta-pattern detectors, and with this mechanism more complex value systems appear which provides a basis for more complex behavior. The *tentative boundary of the agent* stresses the fuzziness of the transition between "physical" and "social" environment, as well as the process metaphysics of the whole approach.

The next step would be to find interpretations of the concepts mentioned in the previous paragraph, in terms of

goals, motivations, emotions, cognitive development, adaptation, social and physical situatedness, and so on.

In order to illustrate some points expressed above, in the next subsection we present the results of an experiment that we performed with our existing agent Petitagé (see e.g. Stojanov, 2001. for a detailed description of this agent).

3.1 An illustrative experiment

Originally, Petitagé architecture was developed to illustrate the sensory-motor, and the beginnings of the pre-operational stage according to Piaget (1954). By building a model of its environment it successfully solves the navigation problem in a 2D maze-like environments.

Central element to this architecture was the notion of an "inborn" schema. An "inborn" schema is a particular sequence of elementary actions that the agent is capable of performing. Petitagé can perform 4 elementary actions ("f"-go forward, "b"-go backwards, "l"-go left, "r"-go right) so one possible "inborn" schema is ffrffffrfflbfff.
Two experiments were conducted with the agent Petitagé in two different environments, starting with the same "inborn" schema. The "inborn" schema in a way reflects the particularities of the embodiment of the agent.

For the sake of this experiment, we neglected the navigational system of the agent, and after choosing a particular "inborn" scheme we let it cruise in two different environments. The first environment (Figure 7) is more "corridor"-like, while the second one (Figure 8) is more "open". The step of the agent is one agent's length. The starting "inborn" schema was frfrflfrflfrfrffrlfrffrflflffl-ffrlrlf. The agent tries to execute this "inborn" schema, but due to the environmental constraints, only certain action sequences are enabled.
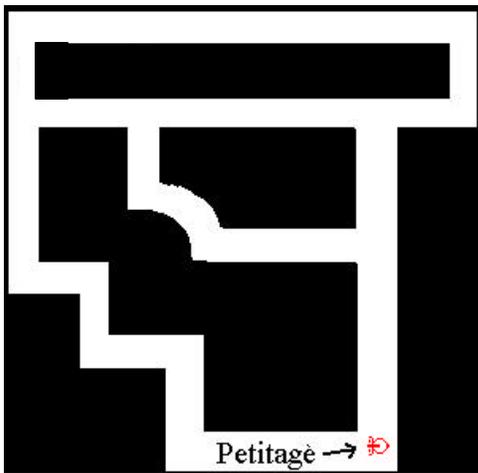
Figure 7. Corridor-like environment

If the agent is in front of a "wall", and the next action to be executed is "f", then this action is skipped, until the next possible action is encountered from the "inborn" schema. In that way, in the first environment, the created schemas look like: lffffffffffffflfff, ffffffffffffrffffrf, ffffffffffffffffffrf, frfflffffffffffffffrf, etc. while in the second environment the created schemas look like frrflfrlfrffffrlfrffrflflflfflrlf, rfrflfrrfrffrlfrrffffffrrlf,

frfrflfrflfffffffffllffrlrlf, frfrlfrlfrflfrlflfflfffrlrlf, frrffrflfrfrffrflfrffrffffffffrrlf, etc.
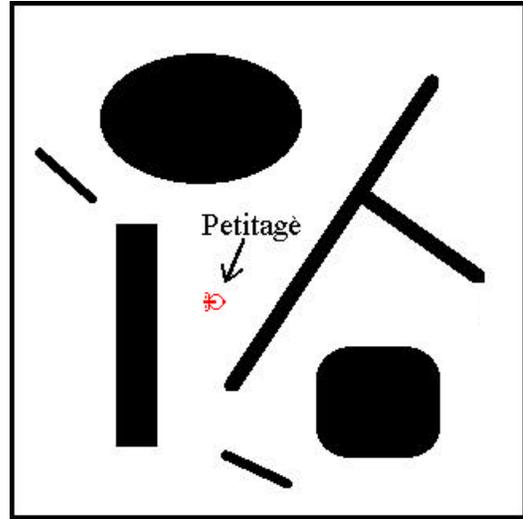
Figure 8. Open environment

It should be noted that a subsequence, as understood here, may contain actions that are not contiguous in the original schema (e.g. ab is a subsequence of accb).

It is apparent that in the corridor-like environment, the schemas contain long subsequences of "f"-s, while in the open environment the schemas contain equal or greater number of "r"-s and "l"-s than "f"-s.

Also, the average length of the schemas in the corridor-like environment (19.6 actions, stdev = 2.18) is smaller that the average length of the schemas in the open-environment (26.9 actions, stdev = 3.46), because of the greater constraints that the corridor-like environment enforces to the agents' actions.

What we need now is the pattern detector mentioned in the previous subsection, in order to enable the agent to differentiate between these two environments (and act according to its inner value system). Below we present two possible examples of how such a pattern detector can be implemented.

In order to have a quantitative measure of the differences between the schemas in the two environments, a dissimilarity function was created that compares two sequences and after normalization returns the result in the interval [0,1], where 0 means most similar, while 1 means most different. The function that measures dissimilarity between two schemas counts all possible subsequences from the shorter schema, that appear in the longer schema.

The number of all possible appearances is:

$$n = \sum_{i=1}^{n_2} (n_2 - i + 1)\left(n_1 - \frac{n_2 - i}{2}\right), \text{ where } n_1 \text{ and } n_2$$

are the lengths of the longer and shorter schemas respectively, which yields

$$n = n_2(n_2 + 1)\frac{3n_1 - n_2 + 1}{6}.$$

Then the dissimilarity function $\delta = 1 - \dfrac{c}{n}$, where c is the number of appearances of the subsequences of the shorter schema in the longer one.

Since this function returns values in the upper part of the interval [0,1], it has been decided to use much smaller number $n = n_2\left(n1 - \dfrac{n_2 - 1}{2}\right)$, which is the number of all possible appearances of the whole shorter schema in the longer schema, while truncating values of the function δ which are smaller than zero.

This function is then used to produce the dissimilarity matrix, between all schemas that emerged in both environments, which is further used in multidimensional scaling statistical method for grouping similar objects in increasing number of dimensions. The method gives the Kruskal's best stress value for 2 dimensions (stress: 0.38396). As can be seen on the following plot, the schemas from different environments tend to group themselves according the environment where they where created.
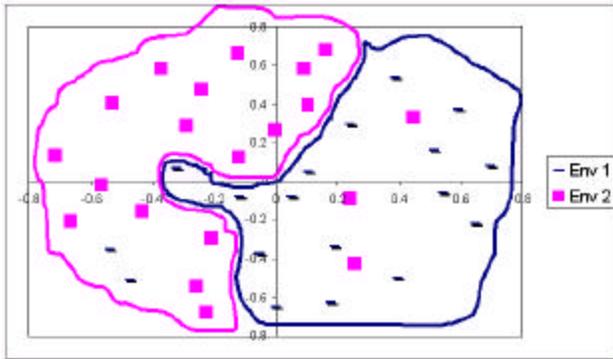
Figure 9. Distribution of schemas on 2 dimensions after performing multidimensional scaling

The boundaries are drawn afterwards with freehand, only to emphasize the groupings. In that way, different subschemas describe different environments, i.e. objects.

The second method that was implemented was cluster analysis. The motivation to use cluster analysis was the expectation that enabled subseqences would group into structures that would reflect the structure of the encironment. Indeed, as it can be seen in Figures 10 and 11 different patterns of clustering emerge among the schemas from the corridor-like environment, and among the schemas from the open environment.

The actual architecture would embody a rich set of pattern detectors that would constantly monitor the sensory motor flux and update the current situation image with indexes of the future potential trajectories. As depicted in Figure 6, detected patterns can exercise top-down influence in the process of action selection, as well as provide an anticipatory context for interpretation of the incoming stimuli.

One can now easily imagine extensions of these pattern detectors in various directions. If we add some particular inner value system, the number of schemas that will be emerge for describing a certain environment or

object, may depend on factors such as motivation and emotion.
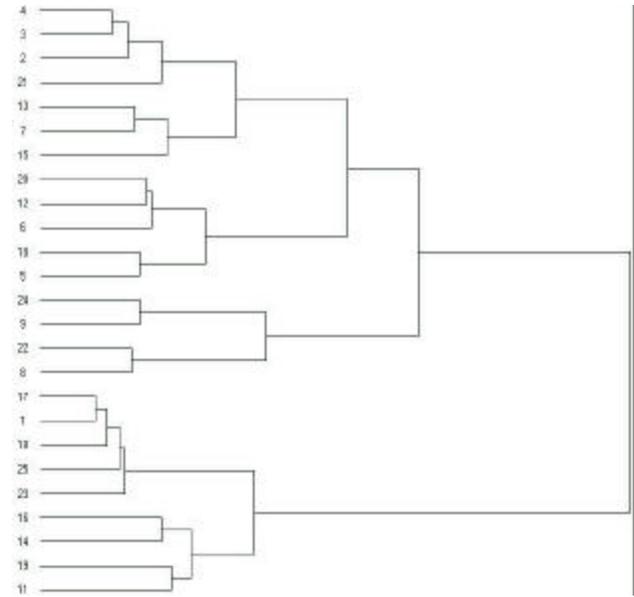
Figure 10. Cluster analysis of schemas in the "corridor" environment
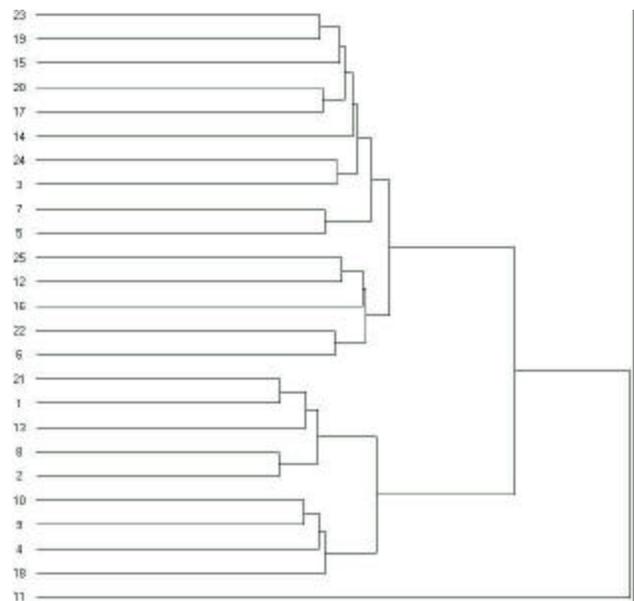
Figure 11. Cluster analysis of schemas in the "open" environment

For those cases where the motivation for learning and successfully manipulating with that particular environment is high, many schemas will be learned with many subtle differences among them. While for those cases, when there seems to be no need to learn in details the issue at hand, only some rough, long and clumsy schemas will be learned, without paying attention to details.

4. Discussion

In this paper we have indicated some first steps as how the problem of representation in epigenetic systems might be tackled within interactivist framework.

In the first section, we listed some of the interactivist objections to the encodingist approach to representation.

In the second section, we tried to describe the interactive representations, and to introduce some of the vocabulary of this complex system.

Third section was devoted to the introduction to generic interactivist agent architecture. It also included one illustrative experiment where we showed how some parts of the interactivist architecture could be implemented.

Although, to our knowledge, it does not exist an implementation of fully interactivist architecture, having the interactivist vocabulary, we can find elements of it in several works. Mataric's Toto robot (1995) builds its environment model autonomously, out of the sensory motor flux. Tani's Yamabico robot (1996) adopts similar strategy, and uses recurrent neural networks, instead of Toto's finite automata. We can also mention Drescher (1991) and Stein (1994). However, although departing from the classical encodingism, they are still commited to the substance-based ontology in approaching the representation problem.

A researcher, who would like to apply interactivist approach, would certainly benefit from the works of French (1995) and Zlatev (2001) in constructing various parts of the agent.

Also, we can easily give an interactivist interpretation of the research in social robotics (e.g. Dautenhahn, 1998; Breazeal, 2000; Kozima and Yano, 2001; Metta et al , 2001)

Particularly exciting are the findings of Rizzolatti and his collaborators (Rizzolatti et al, 1988; 1996) regarding mirror and canonical neurons. The empirical findings further blur the boundaries between the agent and its environment (quite in the spirit of interactivism) and give ideas regarding the extension of the generic archutecture

Finally, as a related work, we would like to mention the research of O'Regan and Noe (2001) in visual perception, and their accounts for representation as a *process* of checking the external world to confirm anticipations of the visual (or other sensory system). Again, the data from their experiments put useful constraints, which can lead to further refinement of the interactive representations.

Acknowledgements

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