A CONTRIBUTION TO SPECIFICATION TOWARD TRULY AUTONOMOUS ROBOTS

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ABSTRACT

A great deal of current research work in robotics and autonomous systems is still focused on getting an agent to learn to do some task such as recognizing an object or going to a specific place. The learning process may be supervised, unsupervised or a process of occasional reinforcement, but the whole aim in such work is to get the robot to achieve the task that was predefined by the researcher. The next logical step along the road towards truly autonomous robots that can dive in unpredictable environments is to investigate how one might design robots that are capable of `growing up' through experience. A living artifact grows up when its capabilities, abilities/knowledge, shift to a further level of complexity, i.e. the complexity rank of its internal capabilities performs a step forward. Robotics researchers increasingly agree that ideas from nature and self-organization can strongly benefit the design of autonomous robots. In this paper we studied the modalities through which pre-school children (from 4 to 5) tackle with a growing up process: the abstraction. Children of these ages are not supposed to be able to perform the abstraction process, but they have a sufficient knowledge of the natural language that allow the description of the processes they are using when they try to reach the meaning of an abstract sentence. This experiment resulted in some very interesting suggestions on what can be useful for the architecture of an adaptive and evolving robot. The importance of multi-sensor perception, motivation and emotional drives are underlined and, above all, the growing up insights shows similarities to emergent self-organized behaviors.

Index Terms— growing up, emergence, adaptive systems, living artifacts, epigenetic robotics

1 INTRODUCTION

Biological organisms have evolved to perform and survive in a world characterized by rapid changes, high uncertainty, indefinite richness, and limited availability of information. Industrial robots, in contrast, operate in highly controlled environments with no or very little uncertainty. Robots having to perform in the real world should be able to cope with uncertain situations and react quickly to changes in the environment. Although many challenges remain, concepts from biologically inspired (bio-inspired) robotics can enable researchers to engineer machines for the real world that possess at least some of the desirable properties of biological organisms, such as adaptivity, robustness, versatility, and agility. These processes are strictly connected to the growing up process. Natural systems provide an exceptional source of inspiration. Given the vastness of the information available, the question arises as to what insights from biology could and should be exploited for designing robots. Simply copying a biological system is either not feasible (even a single neuron is too complicated to be synthesized artificially in every detail) or is of little interest (animals have to satisfy multiple constraints that do not apply to robots, such as keeping their metabolism running and getting rid of parasites), or the technological solution is superior to the one available in nature (for example, the biological equivalent of the wheel has yet to be discovered). Rather, the goal of this paper is to work out some principles of biological systems that can be in some way used as inspiration in robot designing. Living systems, starting from a pre-structured set of functions, develop competence to better adapt to the environment all life long, from childhood to maturity. This phenomenon is called growing up. In individual development, 'growing up' would include the processing of perception, the knowledge organization, the emotions, the value system, the motivations and drives , the experiences and the social interactions. Some psychological theories call the growing up phenomenon ‘insight’, others refer to it as ‘complexity growing’ and others speak about ‘creativity’. These are different points of view of the same process consisting of a step toward the enlargement of the internal knowledge map. From the knowledge level, i.e. processing and analysis of input data coming from sensors, growing up introduces a new level of comprehension of the objects in relationship to other known objects. The new representation of the world can be more abstract and it strikes roots in the experience connected to a preceding familiar object. A living artifact grows up when its capabilities, abilities/knowledge, shift to a further level of complexity, i.e. the complexity rank of its internal capabilities performs a step forward. Steels in [22] claimed that the new level can “slave” the level or the levels below, or it is possible to see a kind of co-evolution towards greater complexity.

The next logical step along the road towards truly autonomous robots that can dive in unpredictable environments is to investigate how one might design robots that are capable of `growing up' through experience. A developmental intelligence for growing up robots must be able to generate automatically representations for unknown knowledge and skills. Like humans and animals, the robots must learn in real time while performing "on the fly"[8].

By a robot growing up we mean a robot that starts with only some basic skills such as an ability to move about and an ability to sense and react to the world (such as trying to avoid obstacles), and in the course of time it develops new skills that were not entirely engineered into it at the start [20]. Robotic models of development can play an important role in specifying the minimal preferences, faculties, and processes needed for this skill to emerge.

Growing up is an emergent mechanism. This means that it cannot be reduced to its parts. In other words, it exists at one level of structure but cannot be fully explained in terms of structure at a lower level. A better understanding of the growing up mechanism is fundamental for the knowledge of what really is intelligent behavior.

In the language research field, abstraction is an example of growing up. From the cognitive point of view, abstraction is a mapping between views of the world, and the modifications of the structure and of the language are side-effects, necessary to describe what happens at the level of the perceived world. In Machine Learning, abstraction has been used to explain learning of different levels of concepts [11,4,6]. Underlying any source of experience there is the world , where concrete objects (the “real things”) reside. However, the world is not really known, because we only have a mediated access to it, through our perception. Then, what is important, for an observer, is not the world in se, but the perception that the living being has of it. At this level the percepts “exist” only for the observer and only during their being perceived. Their reality consists in the “physical” stimuli produced on the observer. In order to let these stimuli become available over time, they must be, first of all, memorized into an organized structure .

Abstractions are not only grounded in perceptual experience, and retaining something of the “perceptual character” of the experiences of which they were derived, but they are also product or reasoning or creative though.

The abstraction is not something that one experienced at a particular time in the concrete world, but it captures the essence of many concrete experiences. Abstraction is the result of a complex cognitive activity that leads to a growing up in knowledge, in mapping of the environment, in progression to language acquisition and production.

It is quite easy to imagine what is the Growing up process that occurs in abstraction, but it is quite difficult to understand how this process starts and goes ahead. What kinds of procedures do people activate to turn up the abstraction? What mechanisms are trigged off?

In this paper we propose a perspective on the analysis of the process of abstraction, originating from psychology.

We tried to find out which mechanisms are adopted by living beings while cognitively growing-up through an experiment on children.

2 THE EXPERIMENT

We studied the modalities through which pre-school children turn up the meaning of a metaphor hidden in common idiomatic sentences in their native language. This process requires an abstraction. We chose preschool children (from 4 to 5) since at their level of cognitive development, they are not supposed to be able to process an abstraction[17]. Nevertheless they are able to communicate and to describe what they are thinking.

2.1 Experimental Set Up

The experiment has been carried out in an infant school in the Genoese Municipality. Children had participated to a “Sea Laboratory” where they became accustomed with some sea animal names and with some of their characteristicsand behaviours.

Forty-two Italian sea world idiomatic sentences have been proposed to eight working groups, of nine to ten children each. A teacher asked the working groups for help to understand the meaning of each sentence. Children where free to express themselves as the wanted: they were allowed to answer through gesture (deixis), through drawing and verbally. They where also asked to try new interpretations of the sentence until someone was reaching the abstract meaning. The teacher was asking only ‘neutral’ questions like ‘*what can it mean?’*, ‘*what else?’* and so on. The experiment was audio-video registered. Collective behavior have been considered to compensate the individual differences. Answers have been analyzed and classified as function of the activated processes.

When an unknown new sentence is proposed, an attention filter selecting only some key words, is activated. This filter is a function of motivation, emotional states, value systems, affects, previous and actual experiences, knowledge system etc. The first strategy is to verify if the sequence of words can co-exist with the internal script called to mind from the sentence.

If an input sentence can be led back to the reference script, then it is accepted. The child adapts the new information to its previous knowledge maps, avoiding the cognitive effort of abstraction.

If the children realized that in the proposed sentences there were some contradictions in comparison with the script of their knowledge, then they tried to apply different strategies to reach an acceptable internal configuration. The emotion (affective) filter plays a very big role in driving the choice of the investigative/creative procedure.

Children reach the abstraction through the combination/integration of different sub processes.

3 RESULTS

The child disclosure were driven by motivations and emotions. If within the scripts there are no acceptable solutions, the children carry out many different strategies.

The children try to solve the current problem by using the knowledge structures stored in their working memories. If the problem cannot be solved, the information processing mechanism backtrack and another set of procedure are tried. If the problem cannot be solved with any possible set of procedure, the children start another set of association of words. This procedure is repeated until a solution is found.

When children hear a sentence whose meaning is not clear to them, they choose a known "semantic pole" and then try to build up linguistic constructs, conceptual reasons and contexts in order to adapt the proposed sentence in such a way that it becomes, from their point of view, full of meaning and understandable. We collected 3898 answers that have been classified within the classes described below.

Children leant to contextualize their concrete definition within a fantastic world. The context in which a new bit of information can be understood seems to be necessary to the coherence of one's script. A phrase or an event without a context could be interpreted in different and contrasting ways. The presence of a context reduces the probabilities of misinterpretation and leads to greater understanding of the information.

Very close to the contextualization are the following strategies:

- Scenario building (21%). Often children try to give a fantastic, but plausible scenario to the novel metaphor proposed by the idiomatic sentence. The most common mechanism used by children is that of making similarities with known cartoons or comic characters. Well-known situations are proposed in a way that is associated to the ones implicit in the idiomatic expressions.They proposed many alternative solutions

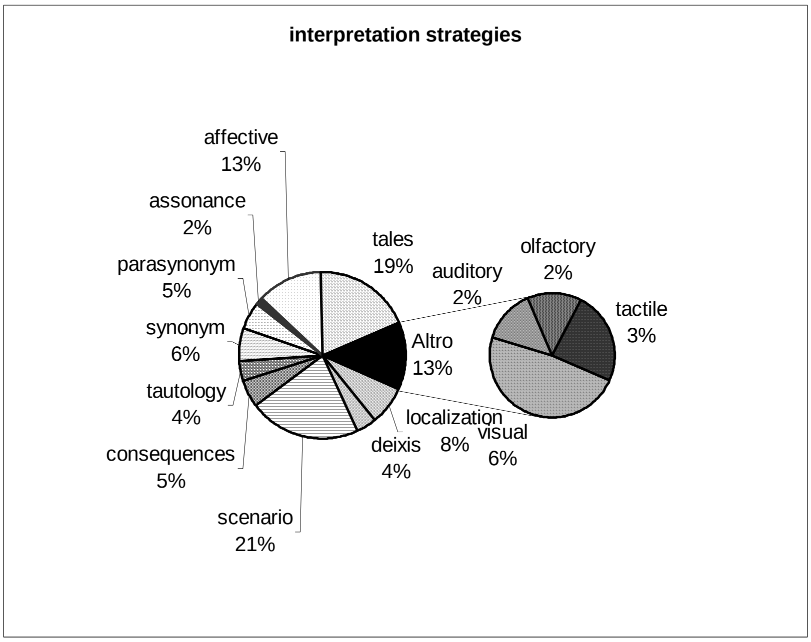

FIGURE 1. Children interpretation strategies percentage distribution.

justified by fantastic stories or validated by reminiscences connected in some way with the sentence.

- Tales creation (19%) They built stories and contests as explicative processes where they can easily insert the chosen keywords.
- Localization (8%). Children, in the attempt to find the meaning of some unknown information, also need to define their conceptual borders. They tended to give localization to every new input, especially to every new idiomatic sentence.

Another set of classes are the sensorial similarities. Memory accesses seem to work on a sensorial base. Sensorial similarities are used in the 15% of answers : we got respectively visual (6%)-auditor (2%), olfactory (2%), tactile (3%) references. Children keep as close as possible to their perceptions. The most used sensors are visual and auditory. It seems that children have the habit to store in their mind every single information under images. This modality is widely confirmed in the drawings. In their pictures children primarily recorded their first impression of the novel input of the idiomatic sentence and drew it by transferring it into a reality plan.

If there is a weak correspondence between the reality level and interpretation of the idiomatic sentence, children explore other understanding strategies. Most of these strategies are strictly linked to their perceptual environment, but all the strategies are characterised by strong emotional motivation.

- Affective bonds (13%): Children mediates their behaviours and their answers with their affective bonds : they used direct reference to their families or to their parents. The emotional world seems to be driving each level and it seems to be involved in each information processing step. The similarities with a strong emotional connotation are stated through sentences such as " *to embrace each other*", "*to keep close*" or with references to people belonging to the closest relationship: "*my mother*", "*my father*", "*my brother*", "*my grandfather*", etc. Although in AI world emotion was considered for a long time as a negative factor hindering the rational decision-making process, the important role of emotions in human cognitive activities is progressively being documented by psychologists, neurologists and AI scientists. Whether they are called emotional control or merely an analogue version of reinforcement learning with criticism (evaluative control), these instruments should be increasingly used by control engineers, robotic designers and decision support system developers to yield adaptive systems.

Other important classes of found strategies are:

- Deixis (8%) and Psychomotor response. Ignoring a verbal answer children tried to express their filling through gestures or movements.The deixis suggests the importance of the imitation in the learning process, but also suggests that we use all our body self-perception to express an unknown concept.

logical connections:

- Consequence connections (5%): children try to connect words through cause-effect relationships: i.e. "muto come un pesce" (*dumb as a fish*):- "*it is because you don't speak anymore"* (the child-mermaid has been drawn without her mouth) "*that you lose your voice"*, *"because you have no tongue"*. This is the first spontaneous way of behaving and of transforming the knowledge into a new, inferred concept or meaning.
- Tautology (4%). Sometimes this exercise falls within the realm of tautology: i.e. "sano come un pesce" ("healthy as a fish" – *"as fit as a fiddle"*) is explained as "It is healthy because it is healthy",

similarities on knowledge information storage:

- Synonyms (6%) Children tried to give "grammatical" definitions to the novel metaphorical inputs, concentrating on the sense of the sentence and not on the referent.
- Parasynonims (5%). There is also a noticeably frequent assimilation with objects coming from their experiential environment. The process utilised by a child to explain the sentence "volere il pesce senza lisca" ("*to want a boneless fish*" – "*to wish for the impossible*") is an example. In his interpretation the little boy wasn't worried about giving a meaning to the whole phrase; instead, he said that the fishbone (that, in Italian, is a synonym for "spina" and "spina" in Italian is a polysemic noun that could mean fishbone, plug, etc.), is the fish's engine, its source of energy. He continued saying that if you have a fish without its spina *(fishbone)* it could die, unless you put new batteries inside the body right away. He conceptually associated the word "lisca" *(fishbone)* to the word "spina" *(fishbone* but also *plug)*: like a "spina" *(plug)*, through electricity, makes it possible for a machine to move, the "lisca" *(fishbone)* lets the fish move. He forced the meaning of the sentence into his cognitive domain: in his formal and perceptive world he successfully combined lexemes that he was familiar with and that he could easily associate to the objects of his experience with others, such as "lisca" in this case, that looked or sounded similar.
- Assonances (2%): They searched coherence in their scripts choosing words with similar sound. Words with similar sounds were associated to the same meaning.. Also in this case the employed mental process consists of getting hold of something familiar to make some sense out of the sentence.

The exploratory behavior seems to "shape" the information flow in various sensory channels. The exploitation of the data for learning, and the derivation of the conditions under which a growing up artifact can learn new categorization behavior, while maintaining the stability of existing ones can get some inspiration from the results of this experiment. Human infants exhibit a wide range of exploration strategies.

This experiment underlined the importance of some characteristics that seem to be very important fro the architecture of an adaptable growing up robot. The child processes resumed in figure 2 underline the importance of multi-sensorial perception sensors, but also the need of contextualization procedures to build a map of the world. Concepts seem to be stored and accessed through similarities that are not much functional or logical but more based on sensorial vicinity.

Naturally the drive to reach the solution is very important and we observed the usage of the whole knowledge set available. The behavior of children was driven by their motivation systems that should have some kind of equivalent system or mechanism in a self adapting robot, to push the search of a new solution if the internal script is not coherent. Last but not least the deixis underlined the importance the embodiment in growing up artificial systems. Through its own action, living beings are able to generate stable sensory patterns in different sensory channels, which can be exploited to form cross-modal associations. In humans these associations seem to be a basic prerequisite for concept formation [10,23], which is of fundamental importance for what might be called high-level cognition.

Children are working on partial subset of information as function of an attention filter that was drives by their internal sense status, their value system, their previous experience, their actual knowledge system, their actual sensor states, their emotions and their motivations.

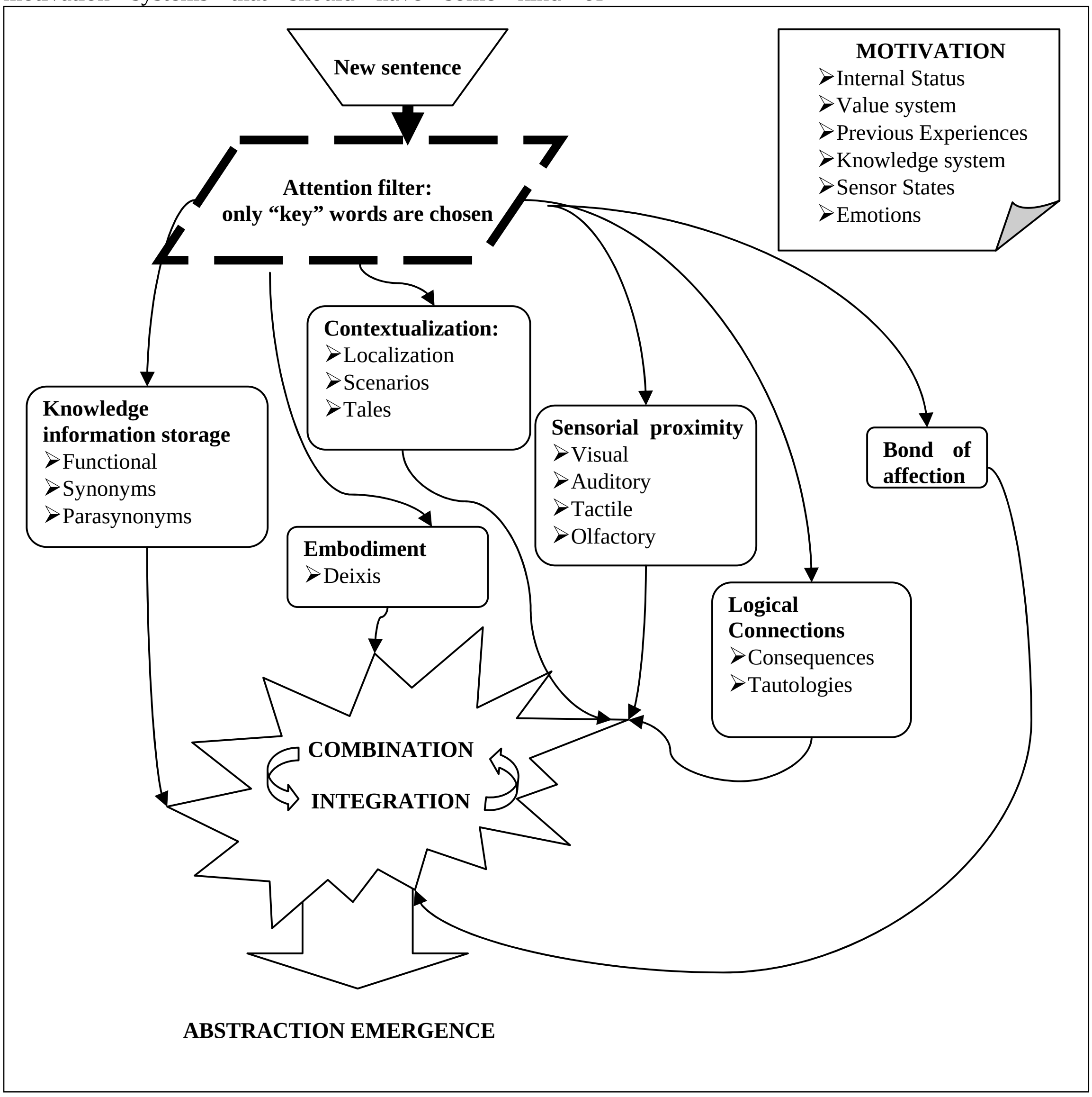

Figure 2 The Abstraction Process in children

There is no need to produce a complete world view by designing a complex ontology, only the most important decision criteria should be provided. One of the most profound "emergent properties" of the human brain, and to a lesser extent the brains of autonomous agents, is the ability to construct, explicitly or unconsciously, models of itself and its environment. The brain in fact seems to "fold back" this process upon itself, by abstracting and observing its general rules and by making rules with a higher-level description. Regularities are discovered at this level, inferring meta-level rules, and this continues level after level.

4. CONCLUSION

In this paper some of the most important characteristics of growing up behavior are underlined. As the complexity of living being is much higher then the complexity of actual artifacts, only few experiments can be done, nevertheless the increase of this perspective is very important. Our experiment led to some considerations regarding a growing up architecture. It suggests that an efficient developmental architecture should have a hierarchy of basic boxes that can process different aspects of knowledge in parallel. To let the 'growing up' phase emerge, the system should be able to process a combination of different paths within an internal representation. . This study generates suggestion about the evolutionary conditions that let the emergence of growing up in children and provides guidelines for designing artificial evolutionary systems displaying spontaneous adaptation abilities. The importance of multi-sensor perception, different types of memory storage and accesses, motivation and emotional drives are underlined and, above all, the growing up insights shows similarities to emergent self-organized behaviors.

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