On the Nature of Cognitive Representations and on the Cognitive Role of Manipulations. A Case Study: Surgery

Alberto Gatti (gatti3@unisi.it)
Department of Philosophy and Social Sciences, University of Siena
Via Roma 47, 53100 Siena, Italy

Abstract

The main point of discussion of the present article is the nature of representations, their formal structure and their origin and the cognitive role that manipulations of the environment can have. After having briefly reviewed the perspective expressed by the physical symbol system hypothesis, I take into account surgery as a case study that points out how many manipulative actions performed upon the environment have a cognitive relevance and the importance that the interaction with the environment can have in generating the representations used in cognitive processes and in giving them a formal structure. In the last part of the article I propose a model, that I call *Double Representation Approach*, which tries to give an explanation of the nature itself of representations, of the way they work in the cognitive processes and of certain important human cognitive behaviors.

Physical Symbol System Hypothesis

When first attempts were made to understand human cognition, one of the concepts that emerged as central was that of representation. A classical paradigm in which the notion of representation grew up was the hypothesis that an agent capable of intelligent action must be a physical symbol system (Newell, 1980; Newell & Simon, 1976).

A physical symbol system is a sort of device that contains symbols and symbol structures in memory and can perform processes upon these symbol structures. In more detail, according to the physical symbol system hypothesis, a physical symbol system and, thus, cognition performs three functional processes that occur sequentially and that are controlled by a central information processor. The three functional processes are the following: 1) a symbolic representation of the environment is constructed by means of a perceptual process performed by a perception subsystem; 2) the symbolic representation that has been constructed is delivered to the central processor, which processes it in order to extract information and to be able to select a symbolic expression that stands for an action; 3) an action subsystem decodes the symbolic description of the action and converts it into a concrete action in the environment.

It is important to understand what the terms "symbol" and "physical" mean. According to the classical definition given by Newell (1980), a symbol is an entity that stands for another entity. This kind of relation is called *designation* and its definition, with Newell's words, is:

> *Designation*: An entity X designates an entity Y relative to a process P, if, when P takes X as input, its behavior depends on Y. (Newell, 1980, p. 156).

Thus, a symbol is a syntactic element of a code and can be connected to other symbols to form symbol structures.

The term "physical" refers to the need for a physical implementation of a symbolic system in order for it to actually function and to actually operates upon and affect or be affected by the environment.

Following these definitions, we can distinguish three levels of organization in which a cognitive system can be divided: the semantic level, the symbol level and the physical level (Pylyshyn, 1989). At the semantic level, we have the content of knowledge and the goals that a system entertains. At the symbol level, the semantic content of the previous level is encoded by symbolic expressions. Finally, the physical level is constituted by the physical realization of the entire symbol system; in the case of humans, this level is represented by the biological level.

The postulation of a cognitive mechanism that works by means of symbols and symbol structures strictly implies the assumption that cognition takes place by means of internal representations and Newell (1980) considers "representation" as "simply another term to refer to a structure that designates" (Newell, 1980, p. 176):

> X *represents* Y if X designates aspects of Y, i.e., if there exist symbol processes that can take X as input and behave as if they had access to some aspects of Y. (Newell, 1980, p. 176).

Thus, according to the classical symbolic perspective, the central notion is that of representation. Now what we have to pay attention to and to focus on are two characteristics that Fodor and Pylyshyn (1988) indicate as the ones that identify classical symbolic models. Such characteristics are the *combinatorial syntax and semantics of mental representations* and the *structure sensitivity of processes*.

Let us begin with the first concept. Classical symbolic theories distinguish between structurally atomic and structurally molecular representations; structurally molecular representations are constituted by other representations that can be either atomic or molecular and the semantic content of a molecular representation is a function of the semantic contents of its syntactic constituents. According to this perspective, a *Language of Thought* (Fodor, 1975) is postulated, with syntactic components and structural relations between these components.

The second point is the structure sensitivity of processes. What this assumption means is that the principles by which mental representations are manipulated rely only on the structural properties of symbolic representations. More precisely, the formal, syntactic structure of a representation specifies the role of the representation within an inference and can cause the inferential process without reference to the semantic content. Hence, the mental operations upon symbolic representations are activated only by the form of the representations.

So far, I have tried to delineate the main features of the classical physical symbol system hypothesis. In the following section, by means of a case study applied to the field of surgery, I want to question some aspects that emerge from the physical symbol system hypothesis.

A Case Study: Surgery

The arguments and claims that will be presented in the following two subsections emerge from a case study on surgery that I am conducting in the field in order to analyze the cognitive processes that go on in the work of surgeon. In particular, this study is devoted to analyze which kinds of representations are used in surgery, what the role of physical manipulations is, whether they have a cognitive relevance and how the distribution is of the cognitive processes involved in surgery.

In the following two subsections I want to point out two important cognitive elements: 1) the physical gestures involved in the processes of perception of data from the environment and 2) the formal structure and the origin of the representations used in cognitive processes. I will use surgery as a reference case and I will try to point out some relevant differences with respect to the classical physical symbol system hypothesis. In the first subsection I will take into account the case of a generic objective examination of the abdomen. In the second subsection, I will consider a specific surgical operation: inguinal hernia.

Objective Examination

The first step in the process that brings to a surgical operation is the examination that the surgeon conducts on the patient who feels specific symptoms. After a brief discussion to reconstruct the history of the patient, the surgeon begins what is called objective examination. Objective examination is a process of gathering of diagnostic data from the patient's body which is guided by the four evaluation principles of medical semeiology: inspection, auscultation, palpation, percussion (DeGowin & DeGowin, 1976; Swartz, 2002). In this subsection I take into account the case of a generic abdominal examination. This kind of examination is constituted by a series of evaluation acts that the surgeon accomplishes on the patient's abdomen by means either of external instruments or of parts of the body of the surgeon herself. In addition, this examination involves the cooperation of the patient, who is sometimes asked to make specific actions in interaction with the examination acts of the surgeon.

A generic abdominal examination can be schematized as in the following table 1.

Table 1: Abdominal objective examination.

	Evaluation action	Means	End
1	Inspection of the abdomen as a whole	Eyes	To evaluate how the aspect and the shape of the abdomen are
2	Inspection of the abdomen after having asked the patient to profoundly breathe	Eyes	To evaluate whether the abdomen moves
3	Auscultation of the abdominal wall before stimulating it with palpation	Stethoscope	To evaluate if there exists an intestinal peristalsis and how it is
4	Superficial palpation of the abdomen	Hands	To evaluate if there are signs of resistance to the abdominal wall that are linked to pathological situations
5	Deep palpation of the abdomen	Hands	To catch the aspects that the various parts of the abdomen can exhibit and that are linked to the contained bowels: -Consistence -Tension -Existence of masses
6	Auscultation of the abdominal wall after the stimulation by means of palpation	Stethoscope	-To evaluate whether, after having touched and moved the abdominal wall, an increase or decrease of the intestinal peristalsis has occurred -To evaluate if there is liquid out of the intestinal loops

The most important element that we can observe in the objective examination and that emerges from the scheme above is the following one: the surgeon uses specific perceptive actions in order to catch and gather specific diagnostic data from the body of the patient. The data that the surgeon gathers are diagnostic signs that suggest a particular diagnosis or several different diagnoses and that help the surgeon in her abductive inference toward a final diagnostic hypothesis (Magnani, 2001). As diagnostic clues, the signs collected by the surgeon can be viewed, from a cognitive point of view, as representations that carry information.

The main feature of these representations is that they are constituted by structured sensations that the surgeon receives in response to her own structured perceptive actions. Therefore, two important aspects emerge: 1) the representations which are the diagnostic signs collected by the surgeon are sensations that the surgeon receives from the environment (the patient's body); 2) such representations are elicited and constructed by perceptive actions by means of which the surgeon interacts with the patient's body. These two points are important because they open the possibility to think of representations and cognitive processes in a new way which is different from the classical symbolic perspective.

According to the physical symbol system perspective, the representations that are used in cognitive processes are symbolic configurations that are inside the head of the cognitive agent. These representations are completely internal and are constituted by the symbols of a single language with a specific syntax. The case of medical examination seen above seems to lead to a more embodied perspective. It seems plausible to state that the representations on which the surgeon relies during an objective examination have, as formal structure, the one constituted by the sensations themselves that the surgeon receives. This formal structure can vary across a great range and, hence, is not the single one of the symbols of a single symbolic language.

Embodiment is also present at the level of cognitive processes. The physical symbol system perspective does not seem to give importance to the perceptive process as a moment in which not only data are simply perceived from the environment, but the environment is inspected and manipulated in specific ways in order to elicit more information. The perceptive actions that the surgeon performs during an objective examination have a strong epistemic value (Kirsh & Maglio, 1994), because they are devoted to examine the patient's body in specific ways so as to obtain specific information. These structured actions structure the sensations that the surgeon receives, that is, they structure her own representations.

A Surgical Operation: Inguinal Hernia

In this subsection I take into account a particular surgical operation as a case to point out some relevant aspects about the formal structure and the origin of the representations used by a cognitive agent. The surgical operation that I consider is the one of inguinal hernia in a male patient (Rutkow & Robbins, 1995; Shwartz, Spencer, Galloway, Tom Shires, Daly & Fisher, 1998; Trabucco & Trabucco, 1998). Inguinal hernia occurs when anatomical elements that are naturally contained in the abdomen enter the inguinal canal. Table 2 shows a schematic description of the main steps of an inguinal hernia operation in a male patient.

Table 2: Main steps of an inguinal hernia surgical operation

1	Incision of the cutis at the level of the inguinal canal
2	Incision of the fascia of the external oblique muscle to have access to the inguinal canal
3	Isolation of the spermatic cord
4	Isolation of the hernial sac
5	Rearrangement of the hernial sac into the abdomen
6	Hernioplasty at the level of the posterior wall of the inguinal canal
7	Suture of the fascia of the external oblique muscle previously cut
8	Suture of the cutis

One of the most relevant aspects of the inguinal hernia operation is that this operation requires a precise knowledge of the anatomy in order to recognize and carefully isolate the various anatomical structures that are found in the inguinal canal in an anatomical situation which has been altered by the hernia itself.

The main cognitive process which is involved in this surgical operation is, thus, the process of recognition. I define recognition as a matching process in which the real situation with which an agent has actually to do matches the salient features of an already defined internal representation that the agent entertains and that represents that identical situation or an analogous situation. Thus, in the case of surgery, a mechanism of recognition of an anatomical structure occurs when the anatomical configuration that the surgeon is confronting matches the internal representation that the surgeon entertains for that anatomical area.

Now, the first contact that a surgeon has with the external aspect of the anatomical structures of the human body is in the study of the illustrative anatomical tables on the anatomy books. This is the first moment in which the surgeon takes an anatomical representation that comes from outside and tries to memorize it, i. e., to bring it inside. I call this process internalization of an external representation. But every surgeon states that there is a difference between the book anatomy and the actual anatomical structures encountered in a real body, especially in those cases in which the anatomy has been altered by the pathological event, as it is in the case of the inguinal hernia. For this reason every surgeon states that recognizing the anatomical structures is a fact of experience.

Experience is a concept that deserves to be analyzed from a cognitive point of view. I have said above that the surgeon internalizes the anatomical representations that she studies on the anatomy books and that there is often a mismatching between these representations and the anatomical structures encountered in a real situation. Therefore, in order for the surgeon to be able to recognize anatomical structures in an actual situation, the book representations of the anatomy that the surgeon entertained must change in order to be in accordance with the anatomical structures actually encountered. Through the direct contact with the real anatomical elements, a process of change and adaptation of the previously internalized representations occurs. This is another process of internalization, but more complex and slower than the previous one and slightly different from it.

This new process of internalization of external representations occurs by means of the repeated observation of many cases similar to each other and it is similar to a process of abstraction, in which, however, the final abstract representation is constituted by elements that have their deep origin in the experienced external elements. I use for this process the name of experience and I define experience as the process of internalization of external representations and of progressive change and adjustment, through the contact with the environment, of the internalized representations during which such representations acquire a configuration that conveys precise information in an unambiguous way and that can fit several different particular situations.

Also in the case of experienced surgeons there can be situations in which it is difficult to recognize the anatomical structures. This happens when there is such a situation in the operating field that a gap is created between internalized representations of the surgeon and actual configuration. It is in these circumstances that we can see again the cognitive role that manipulations can play. When anatomical data are confused and, therefore, the mechanism of recognition is made difficult, surgeons often make use of manipulations in order to find known anatomical reference elements. These manipulations are devoted to fill the gap between actual situation and internalized representations and, thus, they have an important cognitive relevance. The surgeon, for example, in front of a situation in which she cannot see an anatomical structure that she can usually see, almost always uses her hands to touch in certain areas in order to find anatomical reference elements that she expects on the basis of one of her internalized representations.

In this example is evident the cognitive role played by the manipulation, which examines the internal parts of a human body to construct an embodied representation which be in accordance with the internalized representation of the surgeon herself. At the same time, if the internalized representation of the surgeon is visual, in this example the surgeon is bringing into coordination two different representations of the same information, a visual representation and a tactile representation and this can be taken as an evidence that demonstrates that human cognitive agents are able to handle and, in fact, handle different representational codes and not a single one.

The case of surgery seems to push toward cognitive hypotheses that give the environment and the manipulations that humans perform upon it a predominant role as to the process of generation of the representations used in cognitive processes and as to their formal structures.

Double Representation Approach

In the previous section I have presented a case study and I have advanced some hypotheses about the origin and the formal structure of representations. In the present section I propose a model that tries to explain in a more detailed and more schematic way the nature and origin of representations and some critical cognitive behaviors that we can observe in human beings.

The classical view within cognitive science drew a distinction between what was called functional architecture and what was called anatomical architecture (Pylyshyn, 1989). The anatomical architecture can be considered as the implementational basis on which the functional architecture is realized. The functional architecture, instead, has to do with the algorithms that the mind uses when it carries out cognitive processes. The classical view concentrated its attention especially on the functional architecture and, in some cases, even argued that the physical level can be considered as a matter of implementational details. The functional architecture was described as the place of symbolic processes in which internal symbolic representations was processed. The symbols had an arbitrary relationship with their referents and formed symbolic structures which had a combinatorial syntax and semantics.

I want to revise the distinction anatomical architecture versus functional architecture and take into account the relationships that can take place between anatomical and functional architecture. To do so, I propose an approach that I call *Double Representation Approach*. Such approach locates two different representations as the components of any cognitive process that takes place in the interaction between human agent and environment. The idea is as follows:

1) **First-Level Representation**: this is the *pattern of neural activation* that arises as the result of the interaction between body and environment. This is the representation at the anatomical level and this is not the representation that human agents directly use in their cognitive processes.
2) **Second-Level Representation**: this is the thing for which the pattern of activation stands and this thing is the *sensation* that emerges from the encounter between our receptors and the structures of the environment and that is shaped by the structure itself of the environment. This is the representation at the functional level and this is the representation used by human agents in their cognitive processes.

The First-Level Representation is called representation because it is a pattern that has an analogical relationship with the structure of the environment and, thus, can be considered as an analogical representation of the environment. The Second-Level Representation could be considered as the “face” that we think the world has; in a certain sense it could be considered as the world itself. This assertion comes from the consideration that the world is always given to us through our sensorial perception, which can be considered, at last, as the only possible representation in which we can receive the physical world and the representation which is closest to the physical world. This means that the Second-Level Representation, even though it cannot be defined exactly as the world itself, has a strict relationship with the world. Now, I call representation the Second-Level Representation because the structured configurations of the environment are used in cognitive processes because of their carrying specific information, their representing such information. Therefore, the representations are the form of cognitively relevant information, they embody this information.

Now I want to explain in more detail what consequences the Double Representation Approach has on the way we can account for the way human agents reason. The First-Level Representation has a twofold influence on the way humans reason, the first one is direct, the second one is indirect and is mediated by the Second-Level Representation. We propose the following scheme:

1) The First-Level Representation, as a pattern of neural activation, can be assumed to influence the basic mechanism that underlies any cognitive process, regardless of the specific kind of representation used and of the specific algorithm followed. This basic mechanism can be assumed to be the one constituted by the construction of a pattern of elements and the fixation of this pattern.
2) Thanks to the analogical relationship between the patterns of neural activation (First-Level Representations) and the structures of the environment, the Second-Level Representations which we entertain reflect the structures of the environment. Therefore, human agents use representations that have several different formal structures each of which influences in a different way the reasoning process.

The Double Representation Approach can provide an account not only of the representations that originate in a direct contact between agent and environment, but also of those representations that human agents generate internally in the absence of the environment in order to solve a problem, represent a goal and so forth. The representations that originate in the contact between agent and environment take, at the first level, the form of patterns of neural activation and patterns of neural activation, after adequate training, tend to become stabilized structures and to fix. At this stage the patterns of neural activation no longer need a direct stimulus from the environment for their construction and fixation. In a certain sense they can be viewed as fixed internal records of external structures that can exist also in the absence of such external structures. These patterns of neural activation that constitute the First-Level Representations always keep record of the experience that generated them and, thus, always carry the Second-Level Representation associated to them, even if in a different form, the form of memory and not the form of a vivid sensorial experience. Now, the human agent, via neural mechanisms, can retrieve these Second-Level Representations and use them as internal representations or use parts of them to construct new internal representations very different from the ones stored in memory.

In the case of human beings, whose neural growth, according to the studies in neural constructivism (Clark, 2003; Quartz & Sejnowski, 1997), seems to be strongly environment-dependent, if we assume a strong relationship between neural mechanisms and cognitive processes, we are brought to the conclusion that the representations used in cognitive processes have a deep origin in the experience lived in the environment.

At least three conclusions can be drawn from the discussion above. First, as I have already said, the analogical relationship between First-Level Representations and environment causes the representations that human agents use in cognitive processes, that is, the Second-Level Representations, to be able to have various formal structures, we could say various types of syntax and not a single one. The Double Representation Approach tries to provide an explanation of the mechanisms that would occur in those cases in which it seems evident that humans are handling various types of representations.

Second, the Double Representation Approach seems to explain why human agents accomplish both computations of a "connectionist" type, such as pattern completion or image recognition and computations that use a combinatorial syntax and semantics, such as the ones exhibited in language usage. The First-Level Representation is generated as a pattern of neural activation and, if we assume, as I do, a more direct relation between neural basis and mechanism of reasoning, the mechanisms of connectionist creation of the neural pattern that constitutes the First-Level Representation could sometimes influence in a direct manner the mechanisms of reasoning carried out by means of the Second-Level Representation. This would explain the computations of a connectionist type. But, on the other hand, the First-Level Representation, in virtue of its connectionist character itself, has an analogical relationship with the environment and gives rise to structured sensations, that is, Second-Level Representations, that reflect the structures of the environment. Therefore, the cognitive agent can exploit all the syntactic structures that it finds in the environment and, most important, can follow the computations suggested by these structures. Now, among the syntactic structures that an agent can encounter there are the combinatorial ones and this would explain the combinatorial computations we experience.

Third, the fact that the Second-Level Representation is directly connected to the First-Level Representation and, thus, emerges from the interaction between body and environment points out the importance of the manipulative actions at the cognitive level. We can say that, in many cases, it is the actions of manipulation of the environment that create a specific representation that embodies specific information. In this sense, the Double Representation Approach could give an explanation to all those actions that human beings seem to perform not for achieving a physical goal, but for gathering specific information.

Conclusion

In this article I have first reviewed the classical physical symbol system hypotesis and I have concentrated on the fact that, according to this classical perspective, the representations that humans use in their cognitive processes would be internal symbolic structures of a single language with a specific syntax.

Subsequently, I have taken into account surgery as a case study to point out that the manipulations that humans use to perceive the environment may have a specific cognitive value and that the interaction with the environment plays a direct role in generating the formal structure of the representations used by human cognitive agents in their cognitive processes. The hypothesis that seems to emerge is that human agents use not a single representational code, but representations that can have multiple formal structures.

Finally, I have tried to construct a model that was able to explain in a more detailed way such hypothesis about the use of representations of multiple formal structures and that was able to provide an embryonic hypothesis about the way human cognition works.

References

Clark, A. (2003). *Natural-born cyborgs. Minds, technologies, and the future of human intelligence*. New York: Oxford University Press.

DeGowin, E. L., & DeGowin, R. L. (1976). *Bedside diagnostic examination*. Indianapolis, IN: Macmillan Publishing Co., Inc.

Fodor, J. A. (1975). *The language of thought*. Cambridge, MA: Harvard University Press.

Fodor, J. A., & Pylyshyn, Z. W. (1988). Connectionism and cognitive architecture: A critical analysis. *Cognition*, *28*, 3-71.

Kirsh, D., & Maglio, P. (1994). On distinguishing epistemic from pragmatic action. *Cognitive Science*, *18*, 513-549.

Magnani, L. (2001). *Abduction, reason and science. Processes of discovery and explanation*. New York: Kluwer Academic/ Plenum Publishers.

Newell, A. (1980). Physical symbol systems. *Cognitive Science*, *4*, 135-183.

Newell, A., & Simon, H. A. (1976). Computer science as empirical inquiry: Symbols and search. *Communications of the ACM*, *19*, 113-126.

Pylyshyn, Z. W. (1989). Computing in cognitive science. In M. Posner (Ed.), *Foundations of cognitive science*. Cambridge, MA: MIT Press.

Quartz, S., & Sejnowski, T. (1997). The neural basis of cognitive development: A constructivist manifesto. *Behavioral ad Brain Sciences*, *20*, 537-596.

Rutkow, I. M., & Robbins, A. W. (1995). Groin hernia. In J. L. Cameron (Ed.), *Current surgical therapy*. St. Louis: Mosby Co.

Shwartz, S. I., Spencer, F. C., Galloway, A. C., Tom Shires, G., Daly, J. M., & Fisher, J. E. (1998). *Principles of surgery*. New York: McGraw-Hill.

Swartz, M. H. (2002). *Textbook of physical diagnosis: history and examination*. Philadelphia, PA: W. B. Saunders Co.

Trabucco, E. E., & Trabucco, A. F. (1998). Flat plug and mesh hernioplasty in the "inguinal box". Description of a technique. *Hernia*, *2*, 133-138.