A systematic approach to meta-cognitive modeling

Contents x process oriented teaching and assessment

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0. INTRODUCTION

Human communication is a continuous process involving roughly one quarter of all biological activity of the individuals, and it is indeed a very complex process. Its analysis can be done along different lines of study. In order to proceed systematically, some scientific discipline is used as a guide.

After shortly reviewing the concepts of the General Systems Theory, one will use its methodology to analyze human communication. The metacognitive aspects of modeling will be stressed, and then emotivity and rationality will be pointed out as dimensions of thought. Verbal and non-verbal behaviors will be seen as more or less unbiased or biased reactions to the environment.

Along several school semesters, an experiment was undertaken in some classes of an undergraduate course in informatics, in witch the following teaching criteria have been used: a) the courses were started with a basic introduction to the General System Theory; b) there was a training in meta-cognitive thinking; and c) along the course the focus was on the meta-cognitive awareness of the mental activity in the learning process. The contents of the disciplines were worked out as sample material for that activity.

Formal assessment was done under the same focus, rather than on the contents, with stress on the meta-cognitive judgement for correctness. As a consequence, not only the topics of the disciplines were worked out, but also a better attitude and better studying habits were developed by the students, and higher grades have been obtained.

Although there has been often a strong initial resistance to such an approach from many of the students, the method has been recognized as effective for the totality of the non-quitting students in the experimental classes.

The next step in this approach is to statistically control the experiment, in order to derive the formal conclusions it can produce.

1. GENERAL SYSTEMS THEORY

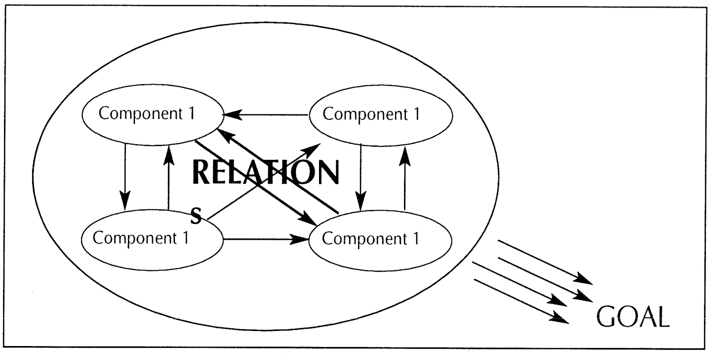
In a multidisciplinarily connected context like psycholinguistics, the approach is to be an interdisciplinary one, as that of the General Systems Theory.

It is not possible to introduce here the General Systems Theory as a whole. Only three of its aspects are briefly introduced: cutting, building a state space and modeling.

1.1. Cutting

There is a fundamental cut on each system: its components, the relations between them, and its goal. This is the defining cut of a *general system.* One same object can be viewed as many different systems, depending on the components, relations and goals shown up after different cutting criteria.

Fig.1 Layout of a general system



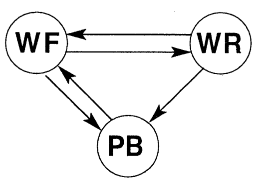
As an example, a living organism can be seen as an organized collectively of cells, or as a set of interacting organs, or as a set of vital functions, or as a set of interacting (sub)systems, or as a set of interconnected tissues, or as a set of chemical reactions, etc. Each of these approaches will show some aspects of the organism and hide many other aspects.

It is impossible to have an universal cut capable of showing all the relevant aspects of a complex system. It is the choice of some cutting criteria that defines the kind of system to be analyzed.

1.2. Building a state space

In order to analyze the behavior of a system, it is necessary to show how it changes along time, and so, it is needed to recognize its different states along time.

Fig. 2 Mathematical structure of an office



	WF	WR	PB
WF	0	0.5	0.5
WR	0.1	0	0.9
PB	1	0	0

WF = secretary Writing, phone Free
WR = secretary Writing, phone Ringing
PB = secretary Phoning, phone Busy

As an example, a little office has a writing desk, a telephone and a secretary. The desk does not change, so its unique situation is irrelevant. The telephone may be free(F), ringing(R) or busy(B). The secretary can be writing(W) or phoning(P), all other possible situations being transparent to the present observation. The Cartesian product of the sets of situations for the components is {W,P}x{F,R,B} = {WF,WR,WB,PF,PR,PB}. Not all of these combined situations are states of the system. PF and PR are physically impossible, and WB is not necessary if what the secretary writes while speaking at the telephone is part of her task of phoning. So, {WF,WR,PB} is the set of states.

Mathematical models of that system are depicted in Fig. 2. One is the state graph, and the other is an (arbitrary) transition probability matrix.

Through mathematical matrix manipulation many properties of the system's behavior along time can then be inferred.

1.3. Modeling

Mathematical models are seldom as easy as shown, but they are not always needed. There are many kinds of models. Some are concrete, some are abstract; some are iconic, some are verbal or otherwise symbolic.

Fig.3 Some kinds of models

CONCRETE	**ABSTRACT**
Prototypes	Tables
Maquettes	Maps
Statues	Equations
Pictures	Graphics
STATIC	**DYNAMIC**
ICONIC	**FORMAL**
Movies	Formulae
Figures	Texts
DETERMINISTIC	**STOCHASTIC**

There is basically one criterion for the choice of a model: its goal. What kind of knowledge about the system is available, what kind of analysis is to be made, what results are looked for by this analysis? Are there static ore dynamic aspects to represent? Is the main appearance more important, or is the internal structure to be shown? Are the formal aspects to be analyzed, or is its behavior to be demonstrated?

The awareness of the goal is the first step to the meta-cognitive aspects to be analyzed in what follows.

2. HUMAN COMMUNICATION

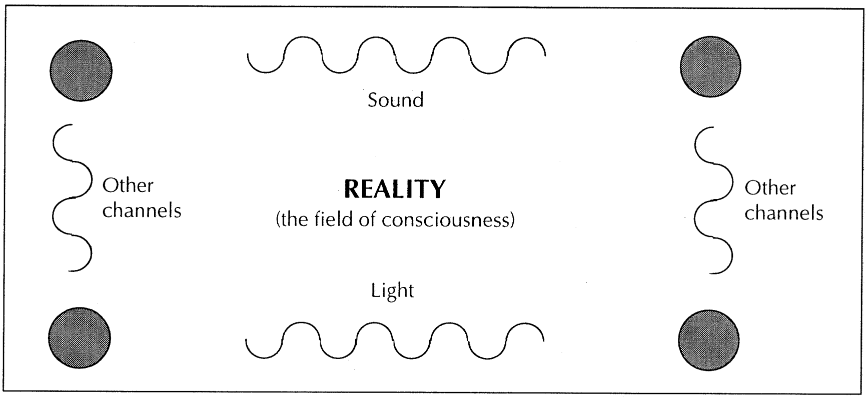
Human communication is indeed very complex. In order to analyze the process of human communication as a whole, it is important to explicitly state the cutting criteria and the expected limitations of the analysis. Using creativity in selecting the cutting criteria for a system may result in new insights, new research fields or new theories.

Human communication will be used here more as a sample system on which one will demonstrate the art of meta-cognitive modeling than a research field in itself.

A top-down modeling strategy will focus first on the partners of the communication process and the link established between them by the exchange of auditive and visual signs. This is quite similar to to a physical system where two or more bodies exchange mechanical, gravitational or electrical information about themselves.

In physics one speaks of fields, potentials and forces in order to describe the physical behavior of the observed bodies. The concept of a field is a holistic one, in that the field extends through all space and can be sensed or detected at long distances of the body. Information interchanges between bodies or systems occur in such a field through some pattern of quanta of energy, usually seen as oscillatory in nature, and analyzed in terms of wave mechanics.

Fig. 4 Communication in a structure of fields



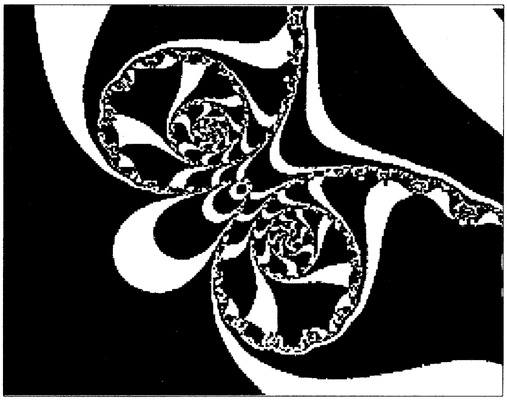
Under this analogy, the process of human communication can be seen as an instance of a more general system of communicating bodies, where the field is at once the air (as a system of molecules where sound waves propagate auditive signals), the electromagnetic field (as a structure on which light propagates visual information) and the semantic field of the universe of discourse. It is in some aspects the field of consciousness, called «nous» by Anaxagore, who made of it the *prime matter* of the Universe. It is a multidimensional space of a very dense and highly dynamic structure.

Exhaustive analysis of the semantic field is quite impossible, so it is necessary to chose some simplifying criteria, and this will result in some scientific discipline like morphology, syntax, semantics, pragmatics, psycholinguistics, semiotics, etc. The **elementary particles** of the **semantic matter** are determined by the set of cutting criteria on the semantic field or the areas of the field of concepts. And this is so simply because of the specific symmetry groups shown up by those cuts, from which all the properties of field of behaviors will follow.

3. META-COGNITIVE MODELING

When only the static structure of a system is analyzed, the most important characteristics of the system remain invisible to the analysis. Even the state graphs, as they describe the behavioral surface of the systems, result in a limited approach. The full range of the systemic analysis will be reached when the internal dynamics of the system are focused. Physics has been the paradigm of science, exactly because it constantly focus the internal dynamics of the systems. The recent studies of fractals brought new insight into the complexity of dynamic systems (Mandelbrot, 1977). Fig.5 shows the fractal map of a simple differencial equation, the form of which is not relevant here.

Fig. 5 Fractal aspects of a dynamic system



It is not said that the static components of the system are less important. Its states and possible transitions are also important, because it is in terms of these elements that its dynamics can be explained. These elements are the boundary conditions of the dynamical behavior. For instance, the behavior of a neural network cannot be put in terms of the possible states of the individual neurons, although without knowing how these states change in time would it be impossible to model the behavior of the brain.

Scientific disciplines formally state their cutting criteria: what segment of reality is focused on, what methodology is used, what results are looked for. It is important to state the cutting criteria in order to do science. Too frequently these criteria are chosen without the awareness of its motivation: there is some problem, there are some methodologies available, some techniques and instruments are known, and so one formulates a new science. The very process of doing this often remains hidden to the conscience. After some time, a generalist or a meta-scientist analyzes that discipline and detects some inconsistencies or lacks in the theory.

On the other hand, if the choice of the cutting criteria is done under full awareness of the process, including its steps and stages, its motivation and emotional appeal, then there will be no surprise in that the resulting science is a superb one, in the sense given to that term by Roger Penrose in "The emperor's new mind". This has been the case along History: Newton, Descartes, Einstein, Heisenberg and many others have reported their process of establishing a new science, and all of them were aware of being emotionally caught by the process.

Modeling reality is the aim of all science. The awareness of the modeling process will be rewarded by better results. The resulting model will then be a meta-cognitive model, containing the explicit statement of its cognitive and meta-cognitive structures.

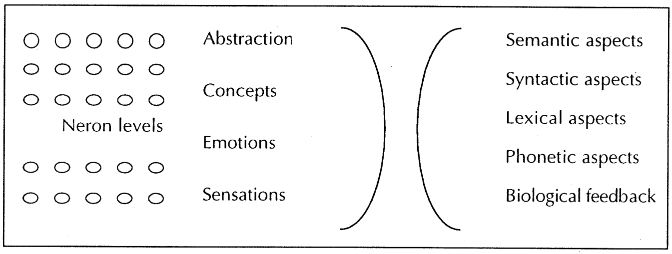
The theoretical motivation behind the experimental classroom dynamics was related to the Heisenbergs's quantum-mechanical incertainty principle (Julia, 1949; Sakurai, 1967; Wheller,1988; Marshall, 1989) and the resulting observer dependency of any measure done on natural systems. From this one must conclude that the traditional assessment (TART, 1975; Vianna, 1982) done outside the 'learning eigenstate' is inadequate for reliably and fairly judge student's progress in the use of programming skills.

As an example of meta-cognitive modeling, it was investigated how emotivity and rationality interact in speech production and comprehension. The investigative methodology of Edgar Morin in «La Méthode» is used as a paradigm.

4. EMOTIVITY AND RATIONALITY

As a result of computational simulations for neural behavior (Kohonen, 1990), networks of several levels showed the ability of generalization and abstraction. Distancing the output level from the input level has an effect of dissociation. This is to indicate that the development of abstraction, dissociation and generalization in humans have a common bias in the multilevel structure of the neural connections in the brain.

Fig. 6 Interaction of emotion and thought in speech processing



If thought is seen as a dissociated kind of emotion, then speech results as a biased form of emotional reaction to the environment, while screaming and crying are unbiased, more direct and primitive forms. It is not yet very clear how the level of abstraction is controlled, but there are hints indicating that the hormonal spectrum established by endocrine activity has to do with it.

Even in sciences where the experimental data and the theoretical consistency indicate a high degree of certainty, there are many open questions, as it is the case of physics. Researchers in any science, at the frontier of knowledge, must have the limits of the paradigm under attention, in order to correctly interpret their findings. It is not enough to fit them into the previous schemata. In the frames of physiology, neurology or psychology, will it be nefast to the scientific activity, to fit new data to old schemata. (it would be like putting new wine in old bottles: both will be lost.) The model must constantly be checked in its validity, and then be effectively adjusted.

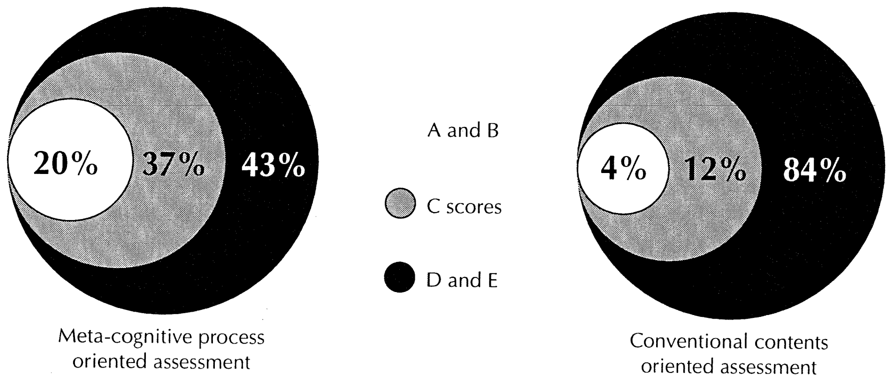
When attention shifts from the problem to the model, there is a change of level. From physics we know that a change of level results in (or from) an exchange of energy (witch is implicitly defined by this relation and by continuity considerations). Process management is then an energy management. The awareness of this process is in turn another level, the awareness of witch is another, and so forth, inducing the recursion. The meta-cognitive modeling process gets the liberty (the degree of freedom in mathematical sense) to move along this recursion line.

5. EXPERIMENTAL RESULTS

The experimental classroom dynamics used top-down computer programming, through guided exercises, constantly focusing on the mental processes active at each step: comparing a concrete situation with abstract data types; comparing the successive refining steps with each other; remembering basic algorithms for algebraic and arithmetic operations and then formalizing them by the use of generalization; inferring some common steps for the solution of new problems. Some results of this experimental classroom dynamics are now discussed.

Along the process of computer programming, the various levels of the formal specification were to be expressed in different ways, from free natural language at one end of the chain, to an artificial programming language at the other end. The main goal of the pilot experiment was to evaluate the impact of metalinguistic and metacognitive awareness on the efectiveness of

Fig. 7 Assessment results for undergraduate programming classes



the programming process. Most students initially have had great difficulty to split attention between the subject of their study and their own process of thinking about it. Meta-cognitive judgement must first be re-learned, remembering that children of four or five years are able to state «I don't know", witch is evidently a meta-cognitive judgement, and witch students are soon conditioned not to admit.

How does meta-cognitive awareness influence the modeling process? In short, this is also to be modeled. And so it turns out that meta-cognitive modeling is a recurrent process. And one must decide, in terms of the recursion depth, how strong the emphasis is on the problem, and how strong it is on the model. And it is still to be determined how these two emphases fit together in the short term memory to be managed together during the learning process. The most serious dilemma is to adjust the strength of attention to be paied to the subject, and to the meta-cognitive thinking.

Experimental data, however, indicate that there is a shortcoming to this dilemma: there is no need to have a conflict of emphases, but they can be melt together in a new emphasis, the attention to be paid to the process. Not particularly the process to be modeled, not particularly the process of modeling, but the cognitive process unifying them. The focus on a cognitive process is then a meta-cognitive focus, and the modeling process becomes a meta-cognitive one.

In the experimental classes, each exercise and each assessment was done under the same focus, established and maintained by a set of working conditions. The main goals of the class were repeatedly introduced, and the (meta-cognitive) goals of each exercise or question were explicitly stated at its very beginning. Also, the steps of the meta-cognitive reasoning were always present to the students. They had to state explicitly: a) what was given and what was asked for the question; b) what was to be answered and what was to be done in order to reach the answer; c) what kind of reasonning or mental processes were to be used; and d) what was the answer.

As the assessment was also meta-cognitive, the mental states of learning and of undertaking an examination were the same: the resulting scores had a chance to be eigen-values of the corresponding eigen-states: guessing or cheating maked little sense, and so the results were individual mesurings, not only statistically distributed scores.

6. CONCLUSIONS

At present time, when information and knowledge are the main goods on the market, it is more than ever important to develop a meta-cognitive attitude in all aspects of life. Some goods can be stored and even exchanged without strictly processing then. But information and knowledge are goods only in terms of their handling process. Getting mastery on the information and knowledge handling processes in ones own mind is the only way to participate in this new market in a wider way. Modeling reality is not only a task for scientists. It is the only way to deal with the world. More than this, each elementary particle in the Universe interacts with its environment following a model of it, given by the shape of its dynamic scattering cross section in the corresponding fields (WHEELER, 1988).

Being aware of the modeling process brings the mastery of the communication process, gives a new degree of freedom, and by this way, more behavioral flexibility and, thus, more decision power. This is in few other contexts more important than in teaching. Not only mastering the meta-cognitive aspects of the modeling process, but also giving the students the opportunity to earn the same profits. A meta-cognitive attitude is one of the most important traits of the profile of an outstanding professional of any area.

Although not formally stated and not rigorously controlled, the reported pilot experiments were able to show the importance of the process oriented learning, mainly in a context like informatics, where contents are rapidly obsolete. Teaching and assessment have to be done in the same eigenstates, for the resulting scores to have a suitable meaning. Meta-cognitive attention to the mental processes in both moments is a common state variable, and thus a measuring space for the learning activities.

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