Mental Models and Referential Processing

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Abstract

This paper proposes that the representation of the referent of discourse might be characterized as the construction and updating of a non-linguistic mental model. Mental models of the referent allow the reader to set up some implicit parameters such as temporal, spatial, and behavioral scales, magnitude of quantifiers, etc. The set up of these parameters is critical to appropriately understand and integrate new pieces of information from the incoming text.

A second function of modelling is to compute the consequences of the events described by the text. There is psychological evidence demonstrating that comprehenders are very efficient in calculating on-line the consequences of described events or changes. However, it is difficult for a purely deductive processor (e.g., a declarative data base plus some rules) to compute appropriately the effects of change. This is the so called «frame problem». Such problem might be overcome by means of a mental model account. Mental models are sensitive to the implicit knowledge of world's regularities and, as a consequence, some courses of modeling are more likely than others. This implies a functional advantage: The number of potential models for a given linguistic message can be drastically reduced.

Traditionally the mental models framework has focused on the representation of spatial contents. However, I suggest that mental models involve also the representation of psycho-social and self traits. Comprehension, is a knowledge state that potentially involves an ecological, a psycho-social, and a self model. At a given moment certain level of modelling is more prominent (foreground) than the others (background).

Some computational principles are proposed in order to guide an eventual implementation of mental models. First, the building blocks that underlies models are primitives. Primitives are variable rather than discrete and fixed semantic values. Secondly, the building and updating of models demand cognitive resources, therefore mental models are sensitive to the structural limits of the system (e.g., working memory, attentional resources). Thirdly, the updating of mental models is cyclic rather than continuous, and it takes place at the end of the main text constituents (clauses, sentences and paragraphs). Fourthly, some models' parameters are structurally isomorphic (some spatial relationships, the temporal structure of events, etc.). Finally, the computation of primitives in the model is based in a multiple constraints principle.

According to the modular approach to cognition the only scientifically describable events of human mind are those related to the encapsulated «modules» (e.g., Fodor, 1983). On its side, the conceptual or «central processor» is, by definition, too flexible and indeterminate as to be properly analyzed by conventional scientific procedures. Therefore, if we study language comprehension we must focus on relatively specialized or modular components such as phonological and graphemic processing, lexical access, syntactic parsing and so forth.

It is likely that the functional architecture of language processing involves some modular or encapsulated mechanisms. However, at some stage of processing, language might have close interfaces with the conceptual system. Thus, comprehension of discourse requires that the listener or reader builds up a non-linguistic representation of the referent of discourse and this conceptual activity is almost simultaneous to the more linguistic levels of discourse processing. In the same vein, speakers encode their linguistic messages starting with a pre-verbal representation elaborated by the conceptual system or the «conceptualizer» (Levelt, 1989). The mechanisms responsible for the representation of reference are still unclear. However, the notion of «mental models» is a promising framework which have generate a remarkable amount of relevant research.

The critical insight of the mental models framework (also named «situation models», «possible worlds», «scenarios», etc.) is that the comprehender builds a representation of the referent of the text (the objects, events, objects and processes described or implicit in the text) rather than -or in addition to- a representation of the text itself (Sanford & Garrod, 1982; Johnson-Laird, 1980, 1983; van Dijk and Kintsch, 1983; Garnham, 1987; Glenberg et al., 1987). An illustration of this idea is the experiment of Glenberg, Meyer and Linden (1987). Subjects were given small text like this:

(1)   John was preparing for a marathon in August (Setting sentence)
(2a)   After doing a few warm-up exercises, he put on his sweatshirt and went jogging (Critical associated)
(2b)   After doing a few warm-up exercises, he took off his sweatshirt and went jogging (Critical dissociated)
(3)   He jogged halfway around the lake without too much difficulty (Filler)
(4)   Further along his route, however, John's muscles began to ache (Filler)

Target: SWEATSHIRT

Subjects read a given version of the text with instructions of comprehension, and immediately they received the target word. They were asked to decide as soon as possible whether or not the target had been included in the text. The critical manipulation was that in the second sentence there were two alternative versions. In the critical associate version (2a) the meaning of the target word was «attached» to the main character by means of the action described by the verb. In the critical dissociated version (2b) the target was dissociated as a consequence of the character's action.

As was expected the decision time for targets was shorter in the associated than in the dissociated version of the texts. The association between the target object and the main character determined that the critical concept were more accessible. This acces-

sibility relies on the situation model rather than on the surface features of the text. In fact, the words between the critical word («put on» or «take off») and the target were exactly the same under both versions of the texts.

A propositional account of text's representation cannot explain either the observed differences, as both the associated and the dissociated versions of the text have virtually the same propositional structure. Thus, the propositional structure for the critical associated sentence and for the critical dissociated one only differ in a single concept.

(5) ... he put on his sweatshirt...

(5') <JOHN, SWEATSHIRT, PUT ON>

(6) ... he took off his sweatshirt...

(6') <JOHN, SWEATSHIRT, TOOK OFF>

There is no apparent reason for becoming more closely associated the nodes <JOHN> and <SWEATSHIRT> in (5') than in (6'). Notice that a propositional system involves computations upon uninterpreted symbols. Namely, the content or meaning of the symbols might be irrelevant in terms of the resulting strength of connections among them. Therefore, both predicates (PUT ON and TOOK OFF) should take the same associative power in order to connect the corresponding concepts. The empirical results (better accessibility of the target SWEATSHIRT under the associated condition) suggest that the computation of text referent relies on fine-grained details of our world knowledge.

Approaching comprehension from a mental model framework has demonstrated to be useful. Mental models put the emphasis in a different theoretical perspective and, consequently, new hypothesis are available. Thus, the emphasis of the mental model approach is on:

- The representation of referents triggered by the text (including thematic inferences) rather than on the structural or formal features of the text.
- Post-lexical processing rather than on lexical processing.
- On-line or incremental changes in representations rather than the final (off-line) products of comprehension.
- Isomorphic dimensions of text representation rather than on linguistic or propositional codes.

Some function of mental models in comprehension

The notion of mental model has been used as an explanatory notion for several psycholinguistic phenomena such as text structure and co-reference, thematic inferences and expectations, anaphoric reference, narrative perspective, focus and background in comprehension, etc. I will focus on two less mentioned phenomena that in my opinion have to do with our modeling capabilities: the implicit scale set up and the modelling of change.

Scale set up

When the reader or listener processes a linguistic message she has to set up the appropriate scale for several dimensions such as time, spatial coordinates, speed, action

level, etc. These particular scales determine a dimensional field that allows the reader to appropriately interpret and integrate the incoming text. Dimensional scales frequently are not explicit in the linguistic message but should be figured out in a top-down manner from some semantic clues provided by the text.

For instance, spatial distance referred by the verb: TO APPROACH is different in (7) and (8). The size of the corresponding goals determines a different «approaching distance» in the reader's mental model.

(7) We were approaching Chicago

(8) We were approaching the door

(Morrow and Clark, 1988)

The temporal scale established from a given temporal adverbial depends on the semantic context provided by the sentence (van Jaarsveld & Schreuder, 1986). For instance, the present denoted by NOW involves different magnitudes in (9) and (10), and the time interval denoted by JUST differs in (11) and (12).

(9) The sky's color is changing now

(10) Europe is changing now

(11) John has just smoked a cigarette

(12) John has just got married

(van Jaarsveld & Schreuder, 1986)

A clear demonstration that parameters are set up is that any violation in the implicit scales is often perceived as an error, a joke or a bizarre expression. For instance (13) is a violation of both the temporal and the behavioral scales:

(13) Q: Well... now that you have finished your PhD what are you going to do?

A: I am going to have a coffee

The clues used by the comprehender to establish the scales of a dimensional field are varied (the sizes of objects, places or agents, the level of the character's goals and intentions, etc.). Hypothetically, dimension scales correlate among them, therefore, the reader might be able to compute the value of implicit parameters from the explicit cues provided by the text. For instance, given a very small moving agent (e.g. an spider) we can «infer» a dimensional field involving small scales for time, space, behavioral level, etc.

Notice that the elusive phenomena of «connotative meaning» might be partially explained as an implicit set up of mental model scales. Actually, connotative meaning cannot be properly understood as a lexical phenomenon. The meanings denoted by some words in different linguistic or communication contexts are not fixed entries «pre-stored» nor «accessed» from a lexicon. For instance, there are not pre-stored magnitudes for «few», «now», «approaching distance», etc. Instead, these magnitudes are computed from a dimensional field or mental model.

The modeling of change

Mental models are dynamic. In other words, the representations of one or several of its entities are transformed in the course of time. However, the question of change is rather complex, as a given transformation in a single entity can determine an effect on several parameters of the model. Let us see a short text that describes a situation model or scenario and some events:

(14) John is sitting in front of his office table
(15) At his right there is a cup of coffee on its plate
(16) In front of him there is an article on the table
(17) At his left there is a bookshelf
(18) John takes the cup and gives a small drink of coffee
(19) John took a new book from the bookshelf

Sentences (14) to (17) allow the reader to build a representation of a static model of a physical environment. Sentence (18) conveys information about a simple action. This action (an object manipulation) produces several changes in the parameters of the model. Not only the cup changes its location but, as a consequence of this change, the relative positions and states of a few things became different while others remain equal. Thus, the action modifies the relative position between: the article and the cup, the cup and the plate, etc. However, another spatial relations remain unchanged: the plate and the book, the book and John, etc.

The principle underlying the readjustment of positional parameters that follows the action seems straightforward in the above example. The moving object approaches a landmark (in this case John's lips) and, consequently, the moving object takes the positional parameters of the landmark. However, things are more complicated than that: Why does the coffee follows the cup in its displacement? and why the plate does not?. Initially the triad «coffee, cup, plate» belonged to the same spatial cluster in the model, however a given action causes that two entities became detached from the third one. Furthermore, a small modification in the action can produce a different pattern of consequences. For instance, if the action (18) substitutes: «John got the plate and gave a small drink of coffee» then the three entities remain together in their movement. In summary, the readjustment of positional parameters in a model involves some subtle knowledge about the behavior of supporters, containers, gravity, and so forth.

Even more complex is the pattern of change during and after the action (19) because the initial scene had been described from the character's perspective. Therefore, if the character moves many situational parameters should be readjusted to keep his perspective. Moreover, often the character's actions determine that some entities came out of focus while others enter the focus and became more accessible (Anderson, Garrod and Sanford, 1984; Glenberg et al., 1987).

A possible argument is to say that the reader just does not make all these implicit computations because it is not necessary. That is probably true in many cases of superficial reading in which the subject does not bother to elaborate a complete and coherent representation of the referent (Oakhill et al., 1989). However, there is some evidence that the reader is able to some extent to make parameters adjustment after a given change has been described by the text. For instance, Duffy (1986) found that subjects generated expectations about the consequences of a physical phenomenon described in short texts. This is an example of an item:

(20) John was eating his first meal ever in the dining car of a train
(21) The waiter brought him a large bowl of bean soup
(22) John tasted the hot soup carefully
(23a) Suddenly the train screeched to a stop (high expectation)

(23b) The train slowed down entering a station (low expectation)
(24a) The soup spilled all over John's clean shirt and pants (key event)
(24b) The waiter came to offer John some coffee (script related)

There were two critical experimental manipulations: the expectation value of the fourth sentence (high or low) and the content of the target sentence (either describing the inferred event or an script based action). The reading time of the target sentences was the dependent measure. The results showed that under the high expectation condition (23a) reading time was faster for the sentence describing the key event (24a) than the script related one (24b). Conversely, under the low expectation conditions (23b) there were no differences. This experiment suggest that the subject is able to make some rather sophisticated computations on the implicit parameters of the situation model. Furthermore, the outcome of these computations determines inferences or expectations more salient than the script-based default values.

How a given change (e.g., an action or an event) affects the whole model state?. What should be up-dated and what would remain equal?. These are non-trivial questions. Many of these changes are not explicit in the text because the text producer assumes that the reader will infer them by means of her implicit world knowledge. However, there are not simple rules that allow to predict what will change and what will remain equal. In order to appropriately address these questions we need a more elaborate notion of the underlying mechanisms and constraints of mental models.

The problem of modelling change is familiar to the Artificial Intelligence researchers who have labeled it the «frame problem» (Fodor, 1983, 1988; Janlert, 1988). The problem emerge in robots design. An efficient robot that performs goal-oriented actions in a complex environment has to be able to build a dynamic mental model. The robot's mental model must keep track of the state of the robot's goals as well as the consequences of any environment change produced either by any external agent or by the robot itself. The problem of doing that is both quantitative and qualitative. The quantitative problem is that an unlimited number of predicates should be checked continuously to see whether their truth values are appropriate after the change. This is hardly compatible with the time pressure under which a robot (or a human) has to make decisions. The qualitative problem is that there are not simple «logical» principles governing change and its consequences. Therefore, it is unsuitable to store in the robot's memory some simple deductive rules that enable it to adapt its representations to the changing world.

However, the frame problem is probably derived from the technical decision of using a declarative format of representation and trying to model change according to a deductive logic (Janlert, 1988). In my opinion, the use of some isomorphic parameters in the mental model (such as mimicking the temporal structure of events, representing structurally spatial relations and quantifiers, and some kinemati transformations) could reduce considerably the problem (see section 2.8).

Mental models are sensitive to world knowledge

Some authors, notably Pylyshyn (1986), have criticized the notions of cognitive science that are cognitively penetrable, namely that are influenced by our tacit world knowledge, intentions, wishes and so forth. The only scientifically acceptable mechanisms are those non-penetrable that operate isolated or encapsulated from the influence of the «central system». However, mental models are by definition cognitively penetrable. Therefore, there must be features of the models functioning partially derived from our implicit knowledge of the world. For instance, the set up of implicit dimensions, the representation of change (e.g., mental kinematic), the computation of the consequences of change, the changing of focus or perspective. In fact, a mental model is a simulation device that operates upon representations of world entities (tokens), and analogically represent their transformations, temporal structure, etc. This simulation in order to be efficient must be influenced by our knowledge of world regularities. The sensitivity of mental models to the knowledge of world regularities probably avoids computational overloads, inasmuch as some modelling courses are more permissible than others. We usually do not waste our time trying to model impossible or implausible world-states, such as «five-dimension cats».

Consider the well known phenomena of mental kinematic. Our mental representation of moving objects (e.g., rotation or scanning) usually mimics our implicit knowledge of the ecological environment. In other words, for a living organism mental kinematic is anisotropic. First, there is a vertical anisotropy. Although geometrically the three dimensions of space are isotropic, from an ecological point of view this is not true. Specifically, the vertical dimension is privileged because the bias introduced by gravity and/or the head-feet axis of human body (Franklin & Tversky, 1990). Furthermore, the vertical axis is asymmetric as objects fall from top to down, and in order to produce the opposite movement some source of power is required. This determines a lot of predictable events and relations in our mental model without need to mention them in the surface text.

Secondly, the environment is horizontally anisotropic. This anisotropy results from the design of our body, specifically its motor and perceptual functions. Depth dimension is more central because it is associated with the direction of march. In addition, the depth's frontal pole is more salient because it is related to the goals and to the perceptual field (Clark, Franklin & Tversky, 1990).

Furthermore, our ecological mental models are probably constrained by the implicit knowledge of the reversibility or non-reversibility of particular events (e.g. rotation is usually reversible, whereas breaking is non-reversible); and our psychosocial models might be constrained by social norms and implicit theories that make some modelling courses more permissible than others; finally, our self model is constrained both by the social determinants and the self-concept.

However, there must be something non-penetrable in our mental models. The segmentation of reality in some primitive components (Miller & Johnson-Laird, 1976; Johnson-Laird, 1983), and the laws governing kinematic transformations (Shepard, 1984, Shepard & Cooper, 1982) might be universal, innate functions, or built-in «a priories» that underlay mental models.

Mental model's contents

Mental models involve at least three levels of contents:

The ecological (or Gibsonian) model. A three-dimensional frame, unfolding in time, and containing physical entities spatially and dynamically related, and a particular observer's perspective. Actions and events are represented as «mental transformations» of objects or objects' parts (e.g., displacement, rotation, physical deformation, etc.). These transformations not only affect the target object, but they also determine a readjustment of several parameters of the ecological model, such as the relative position of the objects, the new distance, the coming in or out of focus, the updating of causal links (either their activation or deactivation), the computation of some predictable consequences of events, and so forth.

The psycho-social model. A frame involving characters (actors or agents) with individual features, goals and intentions, interpersonal links (emotional links, professional roles, social status, etc.), and person-to-objects links (ownership, instrument, transference). Notice that the psycho-social model, unlike the ecological model, does not correspond to physically «objective» features of the world. To be true, there are physical events and objects in our psycho-social models, but these events and objects are only cues for a higher order interpretation (e.g., in terms of between-personal links, status, intentions, etc). For instance, certain facial expressions and gestures are physical actions, but they are interpreted as signals that convey an interpersonal meaning, such as intentions, feelings, etc.

The self model. The receiver of a verbal message is herself a psycho-social character with a very articulate representation of the self and its states (e.g., goals, intentions, status, emotional and affective links, ownership, and so on). In many occasions, specially if the receiver is involved in a conversational setting, she has to monitor the self model as a function of the events and actions that are incorporated in the model generated by the conversation. The monitoring of the self model relies on the fact that the listener belongs herself to the ongoing psycho-social model. However, even if the listener attends some impersonal source of discourse (a fiction narrative or an expository text) the self model might be monitored and readjusted to some extent. Thus the reader can vicariously shift her mood (feeling intrigued, amazed, surprised, etc., see Brewer, 1985) as a function of her unfolding model of text's characters and situations.

There is another aspect in which the self model is actively engaged in the comprehension processes. The self operates as a metacognitive monitoring device. Thus the reader or the listener is usually aware of her understanding level, the plausibility, permissibility or truth of the world state referred by the text, etc. This metacognitive monitoring has functional consequences in terms of processing strategies. The subject can regulate her cognitive activity according to the comprehension state monitored by the self model. This regulation is based on several possible strategies as asking questions (in conversational settings), going back to parts of the text previously read, trying to elaborate more the current model according to her world knowledge, etc.

Knowledge is a three-way model. The ecological model, the psycho-social model, and the self-model converge to produce a knowledge state in a given moment.

In fact, the three models are not simply additive. They compete in strength and prominence and they constraint each other and the resulting knowledge state is a compromise among them. This compromise involves a definition of the prominent level that must be the most accessible to subject's awareness. In most situations (including comprehension of narratives) the more activated model might correspond to the psychosocial parameters, whereas the ecological and the self model are in the background.

During the comprehension of discourse our knowledge state gradually changes. This change can be interpreted as the unfolding of the three-way model. All the relevant parameters -belonging to the ecological model, the psycho-social model and the self model- are updated as the incoming text is processed. This can produce breaks or transitions in the knowledge state (the three-way model state). Thus, in a given moment, the text describes that the character has reached a goal and the corresponding intention might be deactivated in the reader's model, perhaps new intentions and goals became activated, and the new actions involve a different temporal and/or spatial scale than the previous one, and so on. Gersnbacher (1985) calls «processing shifts» to these breaks in the representational continuity. According to her hypothesis an ongoing «substructure» is kept while the incoming information is coherent with it. When information is less coherent (changes in topic, point of view, place, time, etc.) then a new substructure starts. These breaks of shifts in our representation of reference have several empirical effects that I will describe in the next section.

Computational principles

Mental models must be computable (Johnson-Laird, 1983, 1988). However, up to now the notion of mental models has been difficult to implement and it remains as an intuitive notion. However, some empirical and theoretical constraints can be established on an eventual computational theory of mental models.

Building blocks. Our modeling capabilities must require a limited set of elementary units or «primitives». These primitives might be universal entities such as «time», «space», «cause», «event», «object», «person», «intention», etc. (e.g., Miller & Johnson-Laird, 1976; Johnson-Laird, 1983). Primitives should be understood as variable entities rather than as fixed and discrete semantic values. A primitive is actualized in different ways according to the value of the other primitives concurrently activated in the model. We already have described some examples of this interactive actualization of primitives: the contextual set up of dimensions such as time, size, quantity, etc. In the same vein, cause is not a fixed, and abstract relationship but a specific content-dependent link (compare: «the collision of a stone causes the breakdown of a glass», «her love causes his happiness»).

Structural limitations. Mental models presumably are resource demanding, as they likely consume working memory space. There is some evidence of the cost of mental models in terms of cognitive resources. Johnson-Laird and Bara (1984) demonstrated that the larger the number of mental models required by deductive problems the more time was spent by subjects and the larger was the amount of errors. On the other hand, to build a mental model from a text segment takes longer than a more superficial

processing of the text. Thus, subjects who were presented with predictive tasks, spent more reading time on the scenario inducing source (a single case or individual information) than in the less salient quantitative source (Rodrigo, de Vega & Castañeda 1990). The high resource-demand of modeling was also illustrated by a study of de Vega & Díaz (1990). Subjects who read short texts, spent more time in reading the first sentence, as well as the next filler sentences, when the starting sentence included an scenario inducing word rather than a generic or indeterminate term.

Intermittent up-dating. As we have mentioned above the foundation and updating of a mental model is not a continuous process. Instead, there are breaks or shifts generally located at the end of the minor or major constituents of the text (clauses, sentences, and paragraphs). This is an important difference with other text processes, such as phonological processing, lexical access, and syntactic parsing, that take place immediately or on-line (e.g., Marslen-Wilson, 1975).

There are some empirical findings that support the end-of-constituents locus of integration or mental models updating. First, there is a memory lose of the words' surface codes immediately after the reader has crossed a clause boundary (Jarvella, 1979; Gernsbacher, 1985). This suggest that the reader, at the end of clauses, shifts from the lexical codes to some high-order representation. Secondly, studies with on-line techniques have shown that the reader makes long pauses in the last word of each constituent (Just & Carpenter, 1980; Haberlandt & Graesser, 1985; Daneman & Carpenter, 1983; de Vega et al., 1990). These last-word pauses are functional as they are related to several text parameters. Thus, the pauses duration is a function of the number of «new ideas» in the constituent (Haberlandt & Graesser, 1985; de Vega et al., 1990); pauses are also longer when subjects receive instruction stressing memory rather than comprehension (Haberlandt et al., 1986); finally, pauses increase when the sentence include a desambiguating «garden-path» word, suggesting that, at the end of constituents, subjects make a semantic assessment of the whole constituent (Daneman & Carpenter, 1983).

There are some alternative interpretation of end of constituent pauses. Particularly, Kintsch and van Dijk maintain that at these positions the reader actualizes the macrostructural representation of the text (Kintsch & van Dijk, 1978; van Dijk & Kintsch, 1983; Kintsch, 1988). According to Kintsch & van Dijk, the macrostructure is not a mental model but a propositional code. They predict and found out that sentences reading times increases as a function of the number of underlying propositions (Kintsch & Keenan, 1973). However, the number of propositions can be confused with other variables such as the number of new concepts. Some recent studies that rule out the effect of other variables did not find any significant effect of the number of propositions neither on the sentence reading times nor on the end of constituent pauses (Haberlandt & Graesser, 1985; de Vega et al., 1990).

Isomorphism. Several authors assume some perceptual-like properties of mental models but usually they do not elaborate much about it. In principle, it can be proposed that mental models format is a conventional propositional one (e.g., van Dijk & Kintsch, 1983). However, rather than conceiving the encoding of the referent in terms of any sort of lingua mentis, I propose that some of the referent properties are encoded in an analogical or isomorphic format.

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Of course I do not assume a first order isomorphism, nor any sort of «picture in the head» metaphor. Rather I am thinking on a second-order or functional isomorphism: Some processing components are shared by direct perceptual experience and the modeling of a linguistic source (see similar notions in Shepard & Chipman, 1970; Finke, 1980; de Vega, 1988). These are some proposed isomorphic dimensions and properties of mental models: (a) Static spatial properties like position and distance among represented entities; (b) Temporal structure. For instance, the serial order of events in the model has a one-to-one correspondence with the perceived order of world's events, or the relative duration of events can be also mimicked in the model, (c) Kinematic patterns such as mental rotation and mental scanning (Shepard & Cooper, 1982; Kosslyn, 1980; Denis, 1988); (d) Some episodic associative links between entities mimic the world structure of phenomena. For instance the attachment between objects and characters in the mentioned experiment of Glenberg et al., 1987).

The advantages of an analogical processing of some parameters is that it avoids the practical shortcomings of the frame problem, typical of a purely deductive system. The updating of change might be unsolvable if we assume that the subject represents in a declarative format all the ongoing knowledge and he applies some predicate calculus to this massive data base. Even if this were computationally possible (a propositional data base plus some deductive algorithms can be a virtual Turing machine) it would be unsuitable for practical reasons. A psychological theory of change representation has to be able to make the appropriate computations at the appropriate times, namely it has to make computations on-line in order to fit adaptive and efficiency requirements.

On its side, a system that is able to represent analogically some entities and their transformations on-line can figure out many consequences of change without much effort, by simply «inspecting» the outcome of the dynamic transformations. These analogical transformations have been demonstrated in the research field of mental imagery (Shepard & Cooper, 1982; Kosslyn et al., 1978; de Vega 1988), and it has been suggested that they play an important role in understanding text with spatial descriptions (Denis, 1988).

Multiple constraints. Mental models emerge when the conceptual pieces conveyed by a sentence or text are integrated. Integration is holistic as every concept (either explicit or implicit) modifies its semantic value depending on the whole conceptual matrix implicit in the model. The end product is not a simple addition of lexical traces or semantic features but an interactive composed trace that is the outcome of some kind of «goodness» function. The notion of «variable constraints» proposed by Rumelhart & Ortony (1977) in their schema theory is very similar. They proposes that the instantiation of a given schema component is context-dependent, as its particular value is modulated by the other components currently activated.

The interactive nature of integration is supported by several facts that I have described: the attributes instantiation phenomena (context activates a subset of conceptual attributes), the computation of implicit parameters (spatial and temporal scales, level of intentions and actions, etc.), and the computation of some remote consequences of changes.

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