Psychologica Belgica1993, 33, 311-328

TEMPORAL REASONING AND REASONING THEORIES A CASE STUDY IN ANAESTHESIOLOGY

J. Sougné, A. S. Nyssen & V. De Keyser
Service de Psychologie du Travail
Université de Liège

The purpose of this article is to clarify the theoretical base necessary for the design of a computer-based simulation of temporal reasoning. Simulation allows a better understanding of phenomena that appear in working situations and, even, understanding and preventing some human errors. In order to illustrate theoretical concepts, we will provide examples of a situation in which the dynamic character of the evolution, the critical character of the planning and of the synchronization force temporal reasoning. This situation will be that of anaesthesia.

The simulation of human behaviors on computer relies on cognitive theories in order to program the computer in such a way that its behaviors, if they were of human origin, would be qualified as intelligent. This method brings a contribution because an essentially verbal theory can conceal numerous flaws which remain hidden until someone begins to program it. The simulation is, on the one hand, a tool for refining theories, and on the other hand, a means of generating hypotheses.

It is paradoxical to observe that in order to create a model of temporal reasoning, artificial intelligence hardly calls on time psychology. Is time psychology poorly circulated or has it not been operationalized enough to allow a computer simulation?

On the one hand the study of temporal reasoning in time psychology is centered around the nature of time, on the foundation of temporal reasoning, on temporal information; and very little is centered on the process itself. Hence, for Piaget (1946), temporal reasoning flows from space and speed, for Fraisse (1977), from perceived changes. For Montangero (1977), in a physical mode, temporal reasoning flows from the content of events: from work, from speed and sometimes from orders, and in a logical mode, from relative temporal orders. For Levin (1977), temporal reasoning is based on cues and on relationships between cues. Michon (1977, 1992) focuses on time as information. Nevertheless, authors such as Crépault (1989), Wilkening (1981), Siegler & Richards (1979) or Piaget (1946) use natural rules to describe temporal reasoning. The notion of mental model has also be called on (Vandierendonk & De Vooght 1992). Studies in temporal reasoning hardly ever make reference to theories of reasoning. At best, they are briefly mentioned in the work of Crépault (1989). These facts give the impression that temporal reasoning is enclosed within time psychology and at a distance from artificial intelligence and theories of reasoning.

In this article, we would like to analyse temporal reasoning starting from theories of reasoning. We will first present a definition. Then, we will stepwise explain the content by focusing mainly on the different currents of theories of reasoning illustrated with examples taken from a case study. Finally, we will lay the foundations for a simulation based on these theories.

A DEFINITION OF TEMPORAL REASONING

We propose to define temporal reasoning as a process which uses procedural knowledge allowing to derive conclusions (deductive, abductive or inductive inferences) based on declarative knowledge, data, facts or observations which give information about a dynamic process. The conclusions inferred through temporal reasoning can reflect three aspects of psychological time (cf. Block 1990): succession, duration or temporal perspective.

- Concerning succession, the inference can derive from relations between events or actions. The sequential relations can be of several types as described by Allen & Koomen (1983): before, after, equal, meets, overlaps, starts, during, ends. By superimposing on the relationships a character of causality between events or actions, they end up with the synchronization of actions and their planning. When you have to do errands in town, you derive an inference concerning the sequential relationships between your different purchases on the basis of data (you have to go to the bookstore, to the post office, to the photographer's and to the butcher's) or a set of declarative knowledges (the spatial location of each store, the average wait time at the cash register, the preparation duration of your purchases: the photographer will take 1 hour to develop your film).
- The inference can also indicate the duration of an event, of an action or of a set of events or of actions. Hence, based on the sequence of purchases inferred above and on the time it will take you to get from your home into town, and from town to home, you infer the duration of your purchases.
- Finally, an inference can also involve an aspect of a “temporal perspective”, a conception of the past, present or future of the individual. Imagine that while on your way to or from town your notice a splendid house for sale. You would derive a series of inferences about your possible future in this dwelling.

Other distinctions common to all inferences should be pointed out. The first is the classical difference between deductive, abductive and inductive inferences.

A deductive inference is a logically correct conclusion derived from premises. The data are sufficient to reject any doubt about the conclusion. A logically valid deduction is always true if the premises are true.

An abductive inference derives a conclusion that explains premises. Medical diagnosis proceeds abundantly by abductive inferences: on the basis of a few symptoms, the doctor will infer an illness. He/she explains the observed symptoms by his conclusion. Typically abductive inference takes this form:

From *Symptom a, symptom b, symptom c.*
For all x, if x suffers from this illness then x has symptoms a, b, c
Infer: *x suffers from this illness.*

A valid abduction may be false because it inverts a rule like "for all x, if x suffers from this illness then x has symptoms a, b, c".

Finally, the inductive inference is the product of the repetition of the same observation. The subject generalizes the observation to the rest of the population. An inductive inference has the following form:

From: *Q(a), Q(b), Q(c),...* *Infer:* *For all x, Q(x).*

Even valid inductive inferences may be false because we can't be sure that a counter-example does not or will never exists.

Another important distinction, but one rarely brought out in the literature on reasoning, is to be made between implicit and explicit inferences. Alongside the explicit inferences, which require an effort of concentration from the subject, who takes into account all of the information, and generally derives valid conclusions, there exists much more common inferences which do not require an effort and which are not verbalize able; they are qualified as "implicit". We carry out implicit inferences constantly and without realizing it. In this case, the information taken into account is not sufficient enough to infer a solid conclusion. A series of unverified presuppositions are added on in order to derive the inference. The inference is then generated in a nearly automatic manner. The problem with this type of inference, as Johnson-Laird points out (1983), is that it is generally false. Its validity depends on the "flair" and experience of the individual deriving them. They are not logical but sometimes efficient. Certain human activities resort extensively to implicit inferences. Hence, when we read, we constantly infer the rest of the text without having read it. The capacity of the reader to derive valid implicit inferences, according to

Oakhill (1982), distinguishes good readers from mediocre ones. This human tendency to generate implicit inferences could be at the source of many human errors that lead to catastrophes.

In order to finish up with the definition of temporal reasonings, it still remains to describe which could be the nature of procedural knowledge processing information and allowing to derive temporal inferences. We will resort to theories of human reasoning and will illustrate our remarks with examples from anaesthesia, paradoxically, not to help the reader succumb to the charms of Morpheus, but rather to assist with the work of Athena.

Conducting a general anaesthesia does not consist, as one could naively imagine, of putting the patient into a state of sleep by means of an injection, but rather of managing the body's tolerance to the surgical act. It is inserted within a collective and dynamic work situation where the precision of temporal reasonings, derived notably from the requirements of synchronization with the surgical act, is crucial to the very life of the patient. Certain operations such as intubation and extubation of the patient must take place at precise moments, both in relation to the operation and to the patient's respiratory state (De Keyser & Nyssen, in press).

The theories of reasoning can be separated into three currents: the first supposes the presence of general inference rules, the second postulates that inferences are specific to the domain or context, and the third proposes the notion of a mental model.

GENERAL PURPOSE INFERENCE RULES

According to authors like Inhelder & Piaget (1955), Beth & Piaget (1961), Beth, Grize, Martin, Matalon, Naess & Piaget (1962), Braine (1978), Braine & O'Brien (1991) or Rips (1983, 1990), humans possess a mental logic. This formal natural logic describes and determines the nature of human reasoning. When faced with a problem, the subject translates its content into an abstract representation onto which inference schemas are applied. Once the inference is generated, it is channelled towards the real domain.

Time does not escape this mental logic according to Piaget who wrote: “il existe un *temps opératoire* consistant en relations de succession et de durées fondées sur des opérations analogues aux opérations logiques.”(Piaget 1946, p. 2).

Piaget (1946) distinguishes qualitative from quantitative time. Qualitative time is made up of two groupings that concern (1) the interlocking of durations whose relationships are commutative and (2) the arrangement of instants whose relations are not commutative. These two groupings can correspond to each other on the qualitative level, making one deductible from the other and vice-versa. But they can also join on the quantitative level to form a group: metric time.

Let's take an example: during long surgical interventions, the anaesthetist must successively regulate the doses of anaesthetic products used to maintain the depth of the anaesthesia. To each drug corresponds and action delay α after an injection I, an action duration β (Interval AB) and an elimination delay γ before the drug loses its effect at C.

$$\boxed{I_1 \xrightarrow{\alpha} A_1 \xrightarrow{\beta} B_1 \xrightarrow{\gamma} C_1}$$

The anaesthetist will have to infer when to inject an additional dose. Through the arrangement of instants, with the introduction of a relationship of simultaneity $\xrightarrow{0}$, the anaesthetist will partly be able to put in order the successive states of the diverse injections.

$$\begin{array}{l} I_1 \xrightarrow{\alpha} A_1 \xrightarrow{\beta} B_1 \xrightarrow{\gamma} C_1 \\ \qquad\qquad\quad\ \downarrow 0 \\ \qquad\quad I_2 \xrightarrow{\alpha} A_2 \xrightarrow{\beta} B_2 \xrightarrow{\gamma} C_2 \end{array}$$

Hence, the end of the action of the first injection B_1 must correspond to the beginning of the action of the second A_2. It is then possible to infer that I_2 comes before B_1.

Through the interlocking of durations, one can focus on the symmetrical interval relationships such as: $I_1 \xleftrightarrow{\alpha} |A_1$, or the interval comprised between I_1 and A_1. One can then add up and subtract the durations. It is then possible to infer that:

$$\boxed{I_1 \xleftrightarrow{\delta} |I_2 = I_1 \xleftrightarrow{\alpha} |A_1 + A_1 \xleftrightarrow{\beta} |B_1 - I_2 \xleftrightarrow{\alpha} |A_2 = I_1 \xleftrightarrow{\beta} |I_2}$$

That still does not tell the anaesthetist when he/she must inject the second dose because no relationship of simultaneity is tied with I_2. In order to do this it is necessary to refer back to a metric. Metric time will allow him to refer to a fixed unit m and to compare the intervals not included. Hence, knowing that β=20m, one can infer that interval I_1I_2 is 20m.

According to Evans (1989), Johnson-Laird (1983) and Johnson-Laird & Byrne (1991), the followers of this theory have not sufficiently described the processes at work, nor the model of the cognitive processes that have to be described in order to apply the rules of inference to deduction. Indeed, besides Rips (1983), this current has not been described enough to be operationalized. Moreover, Evans (1989) states that no author within the current of general purpose rules has proposed a specific mechanism of encoding a content in an abstract mode, nor one of decoding inferences in an original mode.

In general, the theoretical current of general purpose rules poorly explains the effect of content on reasoning. The study of this effect can be conceived as the investigation of relationships between procedural and declarative knowledge. For Piaget, memory (declarative knowledge) and reasoning are separate systems. The subjects possess logical procedures made up of inference rules. These schemas of abstract reasoning could be applied to all problems with the same logical structure.

The fundamental criticism of the effect of content is supported by what is commonly called “the content effects in the Wason selection task”. Wason's problem consists of giving subjects a series of cards which have on one face a number and on the other a letter. In Wason's original experiment (1966), the subjects received a rule: *if there is a vowel on the card, then there is an even number on the other side.* A series of cards was presented; for example: *a, b, 4 and 7* and the subjects were asked to only turn over the cards which allowed them to determine the validity of the given rule.

The right answer consisted of turning over card *a* in order to verify that there was an even number on the back and card *7* to determine that there is no vowel on the other side. Faced with this problem of relatively abstract content, a minority of adult subjects provided the right answer. The classical error committed by the subjects is to turn over cards *b* and/or *4*. They consider the condition as a conjunction while nothing in the rule states that a card with a consonant cannot have an even number on the back, nor that a card with an even number cannot have a consonant on the other side.

Wason and Shapiro (1971) discovered that rendering the content of the problem more concrete raises the proportion of right answers. The name of a city was written on one side of the cards, and, on the other side, a means of transportation. The subjects were informed that each of these cards represented a day of travel for the experimenter. They were asked to verify the assertion that “every time I go to Manchester I travel by train”. The proposed cards were: Manchester, Leeds, Train and Car. A significantly higher proportion of subjects gave the right answer with this concrete content than with the abstract data of letters and numbers. The facilitating effect of the concrete content has nonetheless been questioned by Manktelow & Evans (1979). These authors discovered concrete contents for which no facilitation was observable. More recently Pollard & Evans (1987) introduced a new variable into the problem: the scenario. It seems that an adequate context and content are required in order for a facilitation to show up. According to Evans (1989), content and context must be rather coherent in order for the subject to apply actions that would be appropriate in real life.

This effect of content seems to be sufficient to reject the thesis of formal general purpose rules even if the followers of Piaget were to say that the subjects can misinterpret statements by basing them on implicit knowledge or if they state that certain people never reach the stage of formal operations. It would be difficult for this argument to account for the performances of college students tested in these experiments. The argument of Rips (1983) is not much more convincing: he maintains that the general inference rules can be inaccessible either through alteration of recovery, through the inability to recognize the rule as applicable, or through the difficulty of applying it correctly. In the ANDS model, Rips determines the degree of availability of each rule. Knowing which rules can be applied to prove an argument, he predicts the proportion of subjects who will evaluate the argument correctly. This model does not take into account the effect of content in reasoning since, with an equal logical structure but different content, this model would predict the same proportion of success.

CONTENT SPECIFIC INFERENCES

A father warns his daughter: “if you drink your soup you will have a dessert”. One can derive temporal inferences about event succession (e.g.): “if the child does not drink her soup, she will not have any dessert”. General purpose inference rules theories could not explain such an inference. Premises do not logically specify that no dessert will be provided if the soup is not drunk. But everyone knows that in this context, the daughter will not have a dessert if she does not drink her soup. This example shows that at least some temporal inferences need to be described according to the content or the domain.

The theoretical approach described here takes into account the effect of content on reasoning. This current will distinguish logic and reason, observing that human thought is generally neither rigorous nor logical.

Three positions characterize this current. The first postulates that reasoning proceeds through recall of specific examples stored in the memory (for example: Grigg & Cox 1982). The corresponding position in artificial intelligence is that of “Case-based reasoning” models. The second is connectionist and postulates a distributed activation of simple units which, once stable, tend to form a schema which will be activated by a system input pattern (e.g.: Rumelhart 1980, Rumelhart, Smolensky, McClelland & Hinton 1986). This position is represented within artificial intelligence by the field of artificial neural networks. The third position asserts that reasoning is ensured by domain specific rules (see Cheng & Holyoak 1985, Holyoak & Thagard 1989 and Smith, Langston & Nisbett 1992). Specialized production rule systems represent this latter position in artificial intelligence.

As an example, we will describe the pragmatic theory of Holyoak. This theory considers that the inference as much as the analogy must be understood in a pragmatic manner, by taking into account the goals and intentions of the subjects (see Holyoak & Thagard 1989).

Holyoak's theory of pragmatic reasoning describes schemas which are structures that are more abstract than knowledge specific to the content, but more particular than the general purpose inference rules. Reasoning is neither based on rules independent of context as in Piaget, Braine or Rips, nor on the memory of specific experiences as Grigg & Cox (1982) suggest in their “memory cueing hypothesis”. The subjects instead use abstract structures of knowledge induced by everyday life, which are called pragmatic schemas of reasoning. Cheng and Holyoak (1985, p. 395) define them as follows: “A pragmatic reasoning schema consists of a set of generalized, context-sensitive rules which, unlike purely syntactic rules, are defined in terms of classes of goals (such as taking desirable actions or making predictions about possible future events) and relationships to these goals (such as cause and effect or precondition and allowable action)”. As we see it, the intention, the goal and their relationships make up the organizing structure of the application of a schema. This offers the advantage of allowing analogical reasoning.

The rules are hierarchically organized, the “default hierarchies” allowing more specific exception rules to be applied to the detriment of general rules which would lead to over-generalizations (Holland, Holyoak, Nisbett & Thagard 1986). Cheng & Holyoak (1985, 1989) describe schemas leading to logical responses. These schemas carry a permission: action requires a precondition to be satisfied, or an obligation: an action must be put forward if a precondition is present. Other schemas are weaker, they involve for example causality. Causality has a form: if <cause> then <conclusion>. This type of schema easily leads to an error because the events are often perceived as having a single cause. Thus, the problems that bring up a causality schema have a chance of generating an inference of opposite direction: If <evidence> then <conclusion>. Other reasoning errors result from the application of schemas non-isomorphic to formal logic. An abstract declaration like the one in Wason's selection task has no tie with past experience and does not bring up a reasoning schema. The subjects confronted with this task try to interpret the problem with their pragmatic reasoning schema. Since this does not work, they generate a conclusion based on their knowledge of formal reasoning which may not conform to logic (Cheng and Holyoak, 1985, 1989).

Applied to temporal reasoning, the Holyoak's pragmatic theory brings an original contribution to the extent that the rules are diachronic. They describe how the environment should change over time.

Let us try to describe a possible pragmatic schema of "patient awakening", a delicate phase in anaesthesia. This schema is organized around the goal of "waking up the patient" and has relationships with other goals such as : restoring the patient's autonomous respiratory function and all the other vital functions on which drugs act, and, sometimes, respecting the hospital schedule.

Preconditions ⇒ obligatory actions rules form a default hierarchy. The General rule states *when the anaesthetist detects the return of the autonomous respiratory function, he/she then extubes the patient as rapidly as possible. An Exception rule might be: If the patient is a child and the return of the autonomous respiratory function is detected, then he/she must verify that this autonomous function will last.*

Rules of the type: preconditions ⇒ allowed actions could be: *If the surgical act ends while the drugs used are still having an effect, then either the anaesthetist can wait for their elimination or can inject their antidote in such a way as to reduce the total duration of the awakening phase*.

This schema should allow the anaesthetist to derive conclusions leading to the organization of goal-directed actions. An error could be produced if, for example, the exception rule is not activated or if it does not match with the good form: "precondition ⇒ obligatory action" but rather with a "precondition ⇒ allowed action" form.

THE MENTAL MODELS OF JOHNSON-LAIRD

The theory of mental models of Johnson-Laird specifies that a logical reasoning can be attained without using either general or specific rules (see Johnson-Laird 1983; Johnson-Laird & Byrne 1991).

According to this theory, logic is a set of procedures allowing to establish the validity of a given inference. However, an inference system can behave in an entirely logical manner without using inference rules or any other formal machinery. It would thus be useless to postulate any type of mental logic. When a subject reasons he / she only tests if the conclusion is true, knowing that the data are true.

A mental model is a structure analogous to the world which allows the possibility of testing its veracity. When a subject reads the premises of a problem, he / she constructs a mental model to represent the possible states of the world which are consistent with the available information. The subject constructs a provisional inference based on true propositions of the model. In order to ensure the validity of the inference, the subject looks for counter-examples by the construction of alternative models for which the data remain true, but not the conclusion. If no counter-example is discovered, the inference is held to be true.

Johnson-Laird distinguishes several reasons which might explain limitations in certain logical tasks. The subject may construct new models on a random basis and lose most of his time exploring unpromising paths. He / she may also lack for an efficient principle to derive reliable conclusions. Moreover, the limited capacity of the working memory restricts performance. Indeed, as the alternative models are stored in the limited working memory, (cf. Miller 1956), the more the subject ought to test alternative models, the more he / she will commit errors. Let us add that temporal constraints can produce the same flaws. In an emergency, the subject has hardly any time to test several alternative models (Nyssen & De Keyser 1991, De Keyser & Nyssen, in press).

A mental model must have the same structure of relationships as the process it imitates. It is an internal construction of certain aspects of the external world. A subject controlling a process has constructed a mental model whose structure is analogous to this process. This model can be manipulated to generate inferences, among which temporal ones. The physical references that a subject uses to manage time are integral parts of the model he / she did construct.

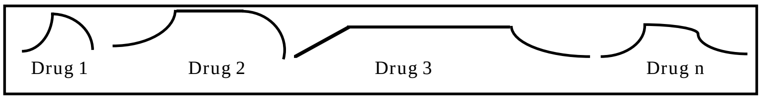
Johnson-Laird (1983) proposes a typology of mental models. Firstly, he distinguishes the physical models representing the physical world from conceptual models representing more abstract subjects. Within these physical models Johnson-Laird classifies:

- the relational, static models, which represent physical entities by signs, by their relations as well as their properties;

- spatial models which represent spatial relations between physical entities in dimensional space;
- temporal models which represent a sequence of spatial frames according to the temporal order of events;
- cinematic models which represent the changes or movements without temporal discontinuity;
- the dynamic models which add causal relations between events to the cinematic models;
- the images which represent a three-dimensional space or a state centered on the subject's view.

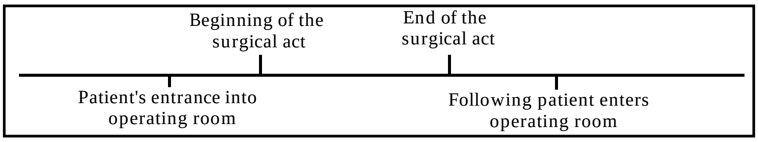
As an example, we will describe a temporal reasoning carried out by an anaesthetist during the planning task. This reasoning produces a dynamic model of the use of drugs, compatible with the model of the patient, with the temporal model of the surgical act and with the hospital schedule. We consider that the temporal model of the surgical act is already constructed and can be considered as a premise. The declarative knowledge of the anaesthetist contains cinematic models of the anaesthetic effect of different drugs.

These cinematic models are described here by curves whose ascending portions correspond to action delay, the high parts to the duration of action, and the descending portions to the elimination delay.



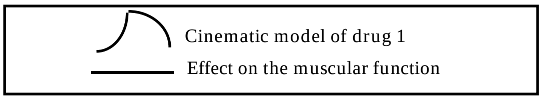
Cinematic models of drugs

The temporal model of the surgical act and of the hospital schedule is described as a sequence of points corresponding to certain events.

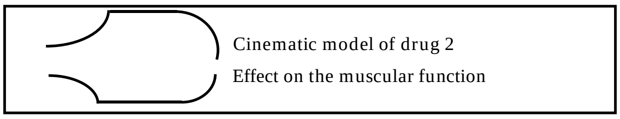


Temporal model of the surgical act and of the hospital schedule.

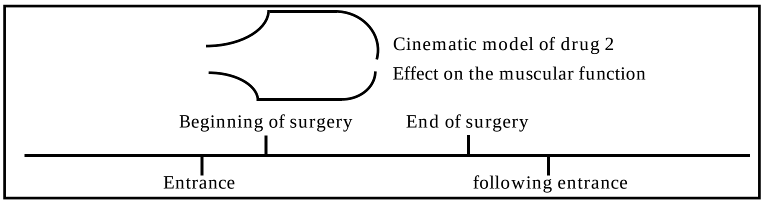
The anaesthetist must, for example, determine which drug to use to inhibit the muscular function of the patient and thus facilitate the surgical act. A first dynamic mental model creating a correspondence between the cinematic model of a drug with its effect on the patient's muscular function is created:



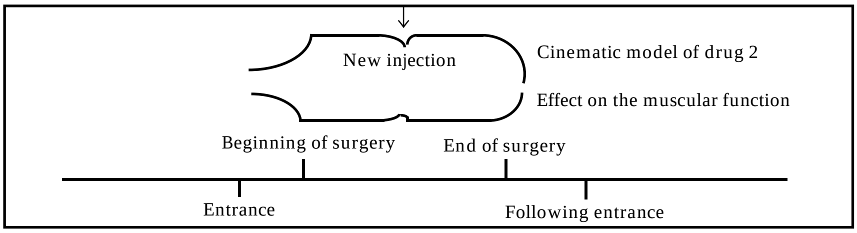
The subject will mentally test this model by confronting it with data. Since drug 1 has no effect on the muscular function, the subject will search for a new model:



This model is consistent with the inhibition of the muscular function being sought. The subject will draw one conclusion: use drug 2 to inhibit the muscular function of the patient. Thereafter the subject can search for new interpretations of data which would falsify the conclusion. He/she will then confront this model with the model of the surgical act:



The conclusion of this model is that drug 2 is no longer suitable since it does not cover the end of the surgery. Since the last two conclusions are no longer consistent with each other, the subject will be led to find a model consistent with all of the data.



From this new model, the subject infers that drug 2 can be used if the injection is renewed at the moment its effect decreases.
The inference is considered valid if the conclusion cannot be falsified by another interpretation of the data.

The theory of mental models of Johnson-Laird is not exempt from criticism. Firstly, it appears to us to be too universal. By claiming to take into account too many phenomena, it is difficult to refute. Hence, it explains errors in reasoning by either a limitation of motivation, or of the working memory of the subject, or by lack of an efficient principle for searching counter-examples to the mental model. This set of assertions does not let any chance to be refuted. Moreover, it seems to us that Johnson-Laird does not sufficiently describe how alternative models are generated.

CONCLUSIONS

The first theoretical current that we described considers reasoning as the product of general inference rules consonant with a “natural logic”. This thesis is at the least insufficient since it does not explain the effect of content on reasoning involving mainly a *modus tollens*. It thus is necessary to attach a content specific character to human reasoning in the form of invocating examples stored in memory or applicating content specific rules. We share the thesis of Smith, Langston & Nisbett (1992), according to which reasoning can be produced by resorting to examples stored in memory, by application of rules but also by a combination of both. In the latter case, the premises invoke either an example which itself gives access to a rule, or an activated rule which invokes an example.

Despite our criticism, the concept of the mental model remains nonetheless enticing. It is possible that mental models are located on another level than the rules and examples, whether they are a more elaborate structure, the product of rules and examples or even interpreted by rules to produce an inference.

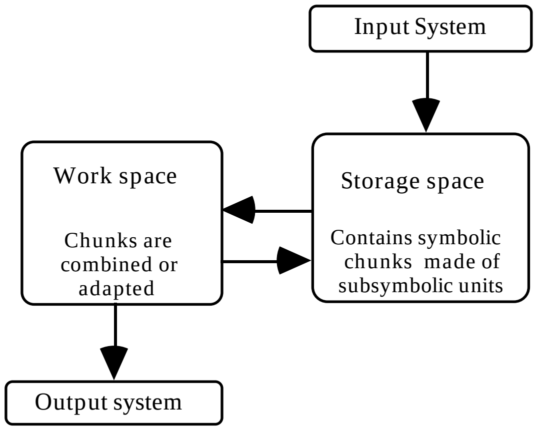
As for the connectionist current, it can also be integrated into other theories as a micro-structure. For example, a rule can be represented by a symbolic structure made up of a set of non-symbolic and distributed units.

These ideas are supported in our simulation works. We program actually a computer simulation of reasoning. As mentioned, the scientific contributions expected from this simulation are the operationalization of theories, the production of hypotheses and, as a consequence, a better understanding of phenomena that appear when people manage dynamic environments.

The model of reasoning and in particular of temporal reasoning that we propose contains four systems: an input system, a work space, a storage space and output system (see figure below). This model is inspired of classifier systems. The input system provides temporal cues, goals and constraints (temporal and others).

In the storage space, a meaningful set of sub-symbolic units can form a symbolic message. Symbolic messages are associated in order to form chunks. Chunks have the following structure: <activator message> <activated message>.

Chunks are triggered in parallel and place their activated messages in the work space. The only chunks whose activator messages match the current content of the work space are triggered. Activated messages placed in the work space can trigger an action through the output system or constitute a message to other chunks.



This message passing system enables different structures to be used. A chunk may constitute an "If <condition> then <conclusion>" rule, or a "<stored input pattern> <conclusion>" example.

A combination of chunks may construct a model and a sequence of chunks can form a plan. Moreover, some chunks can interpret other chunk's activated messages.

We proposed to define temporal reasoning as a process which uses procedural knowledge allowing to derive conclusions (deductive, abductive or inductive inferences) based on declarative knowledge, data, facts or observations which give information about a dynamic process. The procedural knowledge in our model is represented by chunks that point to other ones and by chunks that modify messages. The declarative knowledge is contained in rule and example chunks. The temporal data are treated as other data through the means of the input system, by sequences of co-acting chunks.

This model propose a simple structure permitting inferences to emerge from the activation of many sub-symbolic units. This quality has the advantage to let the system smoothly adapt to environmental changes while enabling high cognitive abilities like planning to appear by its symbolic parts. Another characteristic of this model is that it uses the same principle for temporal reasoning and for other reasoning. It is also compatible with the three currents of reasoning theories.

Our model aims at opening the domain of temporal reasoning to reasoning theories. Too few links have been established so far between time studies and general theories of reasoning. The study of temporal reasoning by time psychology is essentially centered on temporal information, on relationships between time and other parameters and on a process made up of general purpose inference rules. By opening the domain to other theories this paper brings new perspectives for human temporal reasoning modelling.

REFERENCES

Allen, J. F. & Koomen, J. A. (1983). Planning Using a Temporal World Model. *Proceedings of the 8th International Joint Conference on A.I.* 741-747.

Beth, E. W., & Piaget, J. (1961). *Epistémologie mathématique et psychologie.* Paris: PUF.

Beth, E. W., Grize, J. B., Martin, R., Matalon, B., Naess, A. & Piaget, J. (1962). *Implication, formalisation et logique naturelle.* Paris: PUF.

Block, R. A. (1990). Models of Psychological Time. In R. A. Block (Ed.) *Cognitive Models of Psychological Time,* Hillsdale: Lawrence Erlbaum Ass.

Braine, M. D. S. (1978). On the Relation between the Natural Logic of Reasoning and Standard Logic. *Psychological Review, 85,* 1-21.

Braine, M. D. S. & O'Brien, D. P. (1991). A Theory of If: A Lexical Entry, Reasoning Program, and Pragmatic Principles. *Psychological Review, 98,* 182-203.

Cheng, P. W. & Holyoak, K. J. (1985). Pragmatic Reasoning Schemas. *Cognitive Psychology, 17,* 391-416.

Cheng, P. W. & Holyoak, K. J. (1989). On the Natural Selection of Reasoning Theories. *Cognition, 33,* 285-313.

Crépault, J. (1989). *Temps et raisonnement : développement cognitif de l'enfant à l'adulte.* Lille: Presses Universitaires de Lille.

De Keyser, V. & Nyssen, A. S. (in press) Les erreurs humaines en anesthésie. *Travail Humain.*

Evans, J. S. B. T. (1989). *Bias in Human Reasoning: Causes and Consequences.*. London: Lawrence-Erlbaum Ass.

Fraisse, P. (1977). Des différents modes d'adaptation au temps. In P. Fraisse, F Halberg, H. Lejeune, J. A. Michon, J. Montangero, J. Nuttin & M. Richelle (Eds.) *Du temps biologique au temps psychologique.* Paris: PUF.

Grigg, R. A. & Cox, J. R. (1982). The Elusive Thematic-Materials Effect in Wason's Selection Task. *British Journal of Psychology, 73,* 407-420.

Holland, J. H., Holyoak, K. J., Nisbett, R. E. & Thagard, P. R. (1986). *Induction : Processes of Inference, Learning and Discovery*. Cambridge: MIT Press.

Holyoak, K. J. & Thagard, P. (1989). Analogical Mapping by Constraint Satisfaction. *Cognitive Science. 13,* 295-355.

Inhelder, B. & Piaget, J. (1955). *De la logique de l'enfant à la logique de l'adolescent.* Paris: PUF.

Johnson-Laird, P. N. (1983). *Mental Models: Towards a cognitive science of language, inference, and conciousness.* Cambridge: Cambridge University Press.

Johnson-Laird, P. N., & Byrne, M. J. (1991). *Deduction.* London: Lawrence-Erlbaum Ass.
Levin, I. (1977). The development of time concepts in young children: reasoning about duration. *Child Development. 48,* 435-444.
Manktelow, K. I. & Evans, J. S. B. T. (1979). Facilitation of Reasoning by Realism: Effect or non-effect? *British Journal of Psychology, 70,* 477-488.
Michon, J. A. (1977). Le traitement de l'information temporelle. In P. Fraisse, F Halberg, H. Lejeune, J. A. Michon, J. Montangero, J. Nuttin & M. Richelle (Eds.) *Du temps biologique au temps psychologique.* Paris: PUF.
Michon, J. A. (1992). Representing Time. In F. Macar, V. Pouthas & W. J. Friedman (Eds.) *Time, Action and Cognition Towards Bridging the Gap.* Dordrecht: Kluwer Academic Publishers.
Miller, G. A. (1956). The Magical Number Seven, Plus or Minus Two. *Psychological Review, 63,* 81-97.
Montangero, J. (1977). La genèse des raisonnements et des concepts temporels. In P. Fraisse, F Halberg, H. Lejeune, J. A. Michon, J. Montangero, J. Nuttin & M. Richelle (Eds.) *Du temps biologique au temps psychologique.* Paris: PUF.
Nyssen, A. S. & De Keyser, V. (1991). Human Reliability in Anesthesiology. *Proceedings of the Conference of Human Error in Anesthesiology*. Monterrey, Ca.
Oakhill, J. (1982). Constructive Processes in Skilled and Less Skilled Comprehenders' Memory for Sentences. *British Journal of Psychology, 73,* 13-20.
Piaget, J. (1946). *Le développement de la notion de temps chez l'enfant.* Paris: PUF.
Pollard, P. & Evans J. S. B. T. (1987). On the Relationship between Content and Context Effects in Reasoning. *American Journal of Psychology, 100,* 41-60.
Rips, L. J. (1983). Cognitive Processes in Propositional Reasoning. *Psychological Review, 90,* 38-71.
Rips, L. J. (1990). Paralogical reasoning: Evans, Johnson-Laird, and Byrne on liar and truth-teller puzzles. *Cognition, 36,* 291-314.
Rumelhart, D. E. (1980). Schemata: The Building Blocks of Cognition. In SPIRO, R. J., Bruce, B. C. & Brewer, W. F. (Eds.) *Theorical Issues in Reading Comprehension,* Hillsdale: Lawrence Erlbaum Ass.
Rumelhart, D. E., Smolensky, P., Mc Clelland, J. L. & Hinton, G. E. (1986). Schemata and Sequential Thought Processes in PDP Models. In Mc Clelland, J. L., Rumelhart, D. E. & The PDP Research Group. *Parallel Distributed Processing. Vol 2.* Cambridge: MIT Press.
Siegler, R. S. & Richards, D. D. (1979). Development of Time, Speed and Distance Concepts. *Developmental Psychology, 15,* 288-298.
Smith, E. E., Langston, C. & Nisbett, R. E. (1992). The Case for Rules in Reasoning. *Cognitive Science, 16,* 1 - 40.
Vandierendonk, A. & De Vooght, G. (1992). *Is Reasoning with Time Concepts based on a Spatialized Representation of Time?* Tec. Report n°2, University of Ghent.
Wason, P. C. (1966). Reasoning. In B. M. Foss (Ed.), *New Horizons in Psychology 1.* Harmandsworth: Penguin.
Wason, P. C. & Shapiro, D. (1971). Natural and Contrived Experience in a Reasoning Problem. *Quarterly Journal of Experimental Psychology, 23,* 63-71.
Wilkening, F. (1981). Integrating Velocity, Time, and Distance Information: a Developmental Study. *Cognitive Psychology, 13,* 231-247.