

**COGNITIVA 87**

de l'intelligence artificielle aux biosciences  
from artificial intelligence to biosciences

**MARI 87**  
Machines, Réseaux Intelligents / Intelligent Networks and Machines  
Paris, La Villette, 18-22 mai / May 1987

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**Revision of "interpretation" in Episodic memory**  
by  
**using chemistry instead of reason maintenance systems**

**Révision d'interprétation en mémoire épisodique**  
en  
**utilisant la chimie plutôt que les systèmes de justification**

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**RESUME**

Alors que la plupart des recherches actuelles en Apprentissage portent sur la construction et la modification de la partie proprement sémantique de la mémoire, c'est-à-dire sur la détermination des concepts et des types d'arcs pouvant les lier, nous nous attachons dans ce papier au mécanisme avec lequel peut se réaliser la révision et la modification d'une "interprétation" en mémoire épisodique constituée d'un réseau sémantique. Ce qui implique la compréhension non monotone et la rétraction judicieuse des inférences erronées.

Dans le modèle proposé ici, les interprétations possibles d'un ensemble d'informations sont considérées comme des états d'équilibre local. Une ré-interprétation a lieu lorsque des perturbations, provenant soit de nouvelles informations issues du monde extérieur, soit de modifications internes similaires aux rêves éveillés, poussent le système vers un nouveau minimum de la fonction potentielle définie par une mesure de l'"adéquation" de l'interprétation.

Un programme appelé INFLUENCE qui implémente ce modèle est présenté, et des observations sur son application à des problèmes concrets tels que la compréhension de texte conduisent à des considérations sur l'expressivité des systèmes de représentation des connaissances courant. En particulier, le rêve du "calcul moléculaire" de réaliser des raisonnements profonds grâce à une manipulation "superficielle" de la représentation de la connaissance est discutée.

**SUMMARY**

Whereas most current research in Learning focus on constructing and modifying the semantic part of memory (concepts and types of links), we concern ourselves here with the mechanisms by which can occur the **modification and revision of an "Interpretation"**, or model, in the **Episodic Memory** represented as a semantic network. This implies non-monotonic understanding and the judicious retraction and modification of erroneous inferences.

In our model, possible interpretations of a given set of inputs are seen as local equilibrium states. Re-interpretation occurs when perturbations, either external like new-incoming data, or internal, akin to day-dreaming, push the system to a new minimum of the potential function defined by a measure of the "fitness" of an interpretation.

A program called INFLUENCE which implements this model is presented. And observations about its application to text understanding tasks lead to considerations on the "vividness" of current knowledge representation schemes. In particular the molecular computing dream of reasoning through shallow manipulation of the representation is discussed.

Publication [2]

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## Revision of "interpretation" in Episodic memory

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### 1. Introduction : a personal account.

When I started the line of research which led to the results in part reported here, I had several interrogations with as many not well-founded convictions playing catching game in my mind. Very impressed by the many examples of *self-organized adaptive systems* found in nature, I thought, as many before me including Turing (see [Turing,1952]), that that was *the way*, and likely the only one, to a truly general theory and mechanism of adaptation and learning - I still believe this with qualifications. Furthermore, I believed also that a fundamental flaw of "traditional AI" was its founding on the *symbol level* as defined by [Newell,1980] with symbols representing meaningful - for us - concepts. I was convinced that this level of representation and manipulation didn't offer enough flexibility for a universal learning mechanism to be discovered, and I therefore was sympathizing with the search for a subcognitive level as advocated by [Hofstadter,1982]. I studied Synergetics and System Theory in general and thought a lot. Brilliant ideas were born in the morning and dead the same evening. I enjoyed the company of agreeable and magnificent concepts and felt several times that I was on the right track, but overall the result was little more than wishful thinking.

While still believing in the soundness of my concerns, I decided however to try the other way around. Take existing knowledge representation schemes, try them at self-organizing tasks, and show their fundamental inadequacies.

Partly for reasons of previous experience, I was interested in problems of re-planning, ambiguity resolution and re-interpretation in general, and they seemed perfect goal domains for a self-organizing knowledge base. Considerations detailed in the following led to the choice of frame-based systems as underlying testing representation framework. And the search started.

One year or so later, there exists a model - implemented as a program called INFLUENCE written in Experlisp on a Macintosh - for re-interpretation of episodic memories using frame-based systems. This belief revision process is distributed and demonstrates spontaneous re-interpreting behaviour. Thus far it appears that the search is a success. And a failure! It has produced an interesting process model for belief revision, but it has also shown that that was possible with existing representation levels, just what I didn't expect. But has it? Actually, and this is the second part of the results obtained so far, it has not really. One essential, and not consciously foreseen, conclusion of this work is the importance of the *vividness hypothesis* raised in [Levesque,1986]. A vivid knowledge base is one where shallow syntactic manipulations of the representation corresponds to meaningful deep reasoning. Frame-based systems don't seem to have enough of this property to combine gracefully with my belief revision model to exhibit spontaneous meaningful re-interpretation. Is this a fundamental limit, and does it demonstrate the inadequacy of this level of representation? This research

is not, at the time of this writing, conclusive. More work is needed, especially experimenting INFLUENCE with many examples. But the perspectives seem interesting.

This paper deals mainly with the first issue : the design of INFLUENCE as a kind of re-interpretation engine. Several considerations and properties are developed, some of them rather new to AI. The second issue, that of vividness, is just sketched and is addressed more fully in [Cornuejols,1987] submitted to the AFCET/INRIA 1987 conference.

### 2. Re-interpret : what do you mean?

One of the inescapable challenge to systems that must interact with the real world is having to make decisions based on an incomplete and insufficient knowledge of their environment. Therefore the necessary assumptions and inferences needed for the understanding process and decision making may later turn out to have been mistaken. This is the case of a company direction who misjudged the public demand before launching the fabrication of a product, or of a robot who planned to go through door A and can not open it. Facing this kind of situation, where the perceived world doesn't fit anymore its former view, the system must then be able to revise its model of the world, that is, its knowledge base and particularly its set of assumptions, by removing or refining some of them. This is the essence of non-monotonic reasoning.

The following slightly extended archetypical example of story understanding [Collins,1980] should illustrate some characteristics of the problem

*"He plunked down \$5 at the window. She tried to give him \$2.50 but he refused to take it. So when they got inside she bought him a large bag of pop-corns while waiting for James Bond to show up."*

In this context most people first assume that "she" is the cashier of a movie theater, and then, on encountering "... when they got inside, she bought him a large bag of pop-corns" re-attribute "she" to be the date of "he". Other people don't recognize at first a movie theater scene but instead a betting place for horse races for instance, and must modify their view accordingly in the course of reading the whole text. Finally most readers stay uncertain about the interpretation of the last line : are "they" waiting for a man named James Bond, or are "they" waiting for a James Bond movie to start? Interestingly you can't keep both interpretations at the same time, but you may flip between one and the other as in the famous Necker cube or when reading "*I saw a man on the hill with the telescope*" which admits at least four different interpretations

Other features as well are characteristic of human re-interpretation, change of mind, or shift of paradigm in history of science and should therefore appear in the behaviour of a model of belief revision

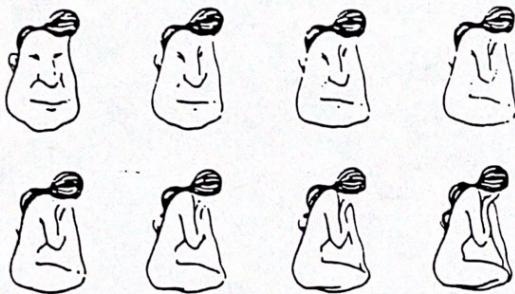
First of all, an interpretation of the world must be obviously as *coherent* as possible with the inputs perceived, but it is all the more better and efficient as it is *parsimonious* and involves as few as possible auxiliary hypotheses. This is the famous Occam's razor principle. Think of the formidable Ptolemy's model of the solar system with all its epicycles compared to the simple and elegant model of Kepler.

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Second, as was already observed, a system must be attached to only one interpretation at a time unless being prone to confusion and cryptic and ambiguous behaviour.

Third, it is a remarkable fact that an hysteresis effect show up when one is balancing between two different interpretations of a given set of data as should be apparent if you look the following sequence of drawings first from top left to bottom right and vice versa and notice at what point you modify your interpretation, this point should be different in either case.



The questions now are what makes an interpretation better than another one\_ how does that translate in the knowledge representation\_ and how to change from one to the other?

Previous works on this topic usually start from the detection of an inconsistency somewhere in the knowledge base and then rely on diverse reason and justification maintenance networks to guide a revision process which in most cases is a variation of backtracking. These technics reveal to be cumbersome, inefficient and awkward (see [de Kleer,1984]). But above all we found this approach unsatisfactory because it supposes a kind of external process or interpreter which observes the knowledge representation from "above" in order to proceed to judgement and correction. A re-interpretation process, and for that matter any other inference process, to be spontaneous should be integrated in the texture itself of the knowledge representation and be undissociable of its natural functioning. That is what we aimed at in this research.

Because frame-based knowledge representation schemes have been designed and are widely used to embed in an easy way expectations, we have adopted this framework as a starting hypothesis and testing ground to develop a new methodology for non-monotonic understanding. Let us briefly see how it looks like before entering the details of the belief revision algorithm.

### 2.1 Frame based memory.

The concepts of frame based representation and semantic networks are not precisely defined or standardized. Actually there doesn't even exist a well agreed upon prescription of how to represent something with this technics. This is one of the difficulties plaguing the field in that every one has more or less his/her own ad hoc way of doing things. One hope of this research is to help clarify and present some desirable properties for this type of representation.

Since we were more interested in Natural Language understanding tasks for a first approach, we chose to work on a representation scheme close to the one developed by Shank and his collaborators over the years, and inspired particularly from the BORIS system [Dyer,1983], which somewhat sums up the previous works of the Yale school.

### 3. A new approach : stability and perturbations.

#### 3.1 The guiding principles.

The first observation is that if the system is to change its model of the world only when a better one is available, which seems reasonable, then the first question is no longer how to detect a discrepancy in memory, but rather how to detect that a better interpretation is possible. Therefore the problem is turned over : the detection of contradictions or awkward structures becomes a side-effect of the main process of re-interpreting.

The second point is that we want the re-interpretation process to occur spontaneously. By that we mean that it must be the product of an internal essential necessity of the knowledge representation scheme, and not the result of the decision of some external omniscient and omnipotent "mega-demon". To give an image, complex molecules or crystals in chemistry reconfigure automatically themselves when the necessity arises (collision with other molecules or new stresses). They don't wait for the chemist to measure their energy and give them instructions to reconfigure.

More concretely, that implies that the acting forces of re-interpretation will be found at the local level of knowledge representation, i.e. in the frame-based paradigm, at the level of the links between different pieces of data.

A remark is in order here. Most research in Learning are concerned with Semantic Memory : how to acquire new concepts, or new rules, how to refine them. This paper on the other hand takes for granted the building blocks of the semantic memory, and is concerned "only" with the interplay of these blocks in episodic memory to achieve re-interpretation. This research is therefore centered on the spectrum between rote learning (pre-digested accumulation of data and procedures in classical data bases) and semantic learning or learning of new concepts by discovery.

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The last necessary feature of a re-interpretation model is **perturbations**. That is apparently random modifications of connections and data even during periods when there is no input to the system, so as to allow it to question its own knowledge and test tentative alternatives permanently.

But then what makes a satisfactory interpretation? On what grounds to compare two models of the world?

### 3.2 The value of an Interpretation : its fitness function.

Two properties seem to be required of any good model of the world. One is to give the "right" answers when asked. The second is to obey the parsimony principle advocated in science : don't multiply unnecessary hypotheses.

Basically a frame-based memory is made up of instantiated frames tied together by links. In a story understanding system for instance, frames includes MOPs, scenes, goals, plans [Schank,82], TAUs [Dyer,83], and so on, and are linked together with various types of connections like Intentional-links, Enablement-links, and so on. When a question is asked to the system, the proper frame is selected and the related link traversed to retrieve the answer.

It is therefore apparent that in order to be able to answer questions, a knowledge structure must possess, in addition to the adequate frames, a rich interconnection network between them.

The parsimony principle on its side dictates that questions should be answered by involving the least possible number of assumptions. In particular arbitrary and otherwise unnecessary assumptions \_frames in our model\_ should be chased away.

Thus a characterization of a good structure in episodic memory is one which presents the **maximum ratio of links per frame**. We will call this objective the **fitness function**. The measure it provides over the set of possible interpretations defines a potential. The minima of which corresponding to stable and good, as defined above, interpretations.

### 3.3 The re-interpretation model.

At the local level the fitness function defined in 3.2 translates in : if each pending link of each frame considered as an autonomous entity tries to establish a connection with the most connected candidate frame, and if each isolated frame is then discarded, it ensues as a consequence that the whole memory will present the maximum ratio of links per frame which is our objective.

The second feature is perturbation.

Finally the last desirable characteristic is that the system commits itself to only one interpretation at a time as we saw earlier.

These requirements are met in our algorithm where links are the acting entities.

First, a link is characterized by a **belief coefficient**  $\kappa$  ( $0 < \kappa < 1$ ) corresponding to the confidence we put in the it. For instance, in analyzing "*Mary received a letter from John*", we can reasonably be confident that the slot *sender* of the frame *LETTER* (if such a frame exists) is

filled with the instance *John* (although maybe we didn't hear correctly, and that was *Jane*). The belief coefficient of this link should accordingly be high, as opposed to the situation : "*John was in town (...)* *Mary received a letter from him*" where it might be conceivable that a certain incertitude remains about the actual identity of the sender that only an inference based on some syntactic considerations filled. The determination and computation of these beliefs coefficients are domain-dependent and will not be studied any further here. The main idea is that in a semantic network constructed by an interpreter from inputs and knowledge stored previously, at least part of the unavoidable uncertainty remaining can be captured by belief coefficients attached to each link. For our purpose here these coefficients determine the **stability of the connections**.

The basic mechanism is that at any time, with a frequency determined by  $\kappa$ , a connection may "decide" to "uncommit" itself from its target frame and look for another candidate corresponding to similar specifications. For instance, returning to our previous example, the link connecting *sender* to *John* might uncommit, that is look for any candidate presenting the same profile, say, be of the class HUMAN-BEING or INSTITUTION, and on finding one, by means described below, disconnect from its old target and connect to this candidate, possibly its former target.

Second, the frames are indeed organized in types (as GOALS or AFFECTs), actually further differentiated by profiles, and advertise for themselves with an "*Influence*" I directly related to their own current connectiveness (function of the number and influences of other frames they are attached to). The formula we used in our algorithm is :

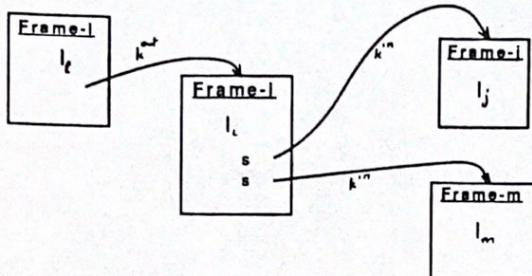
$$I_i = I_{i0} + \sum_{s(i), j(s)} k_{ij}^{in} \cdot I_j + \sum_{j(s) > i} k_{j,s}^{out}$$

Its form is complex, but its content is simple and intuitive. It says that the influence  $I_i$  of the frame  $i$  is the sum of its initial influence, determined a priori by the user (who for instance wishes to enhance the importance of the Goal G-WEALTH), and of the influence it gains from being connected with other frames  $j$ . This last part is itself the sum of two distinct phenomena. The first one corresponds to the fact that an assertion gains credence if it is detailed, for instance a witness saying "*I saw a man running in the street. He was limping and wore a green trenchcoat*" gives more weight to this man than another report that would just mention a man running.  $s(i)$  denotes the slots of the frame  $i$ ,  $j(s)$  denotes the frame  $j$  target of the link associated with the slot  $s$ , and  $k^{in}$  means the gain from the details. The second one says that if a frame is the target of slots from some other frames  $j$ , then it gains influence.  $k^{out}$  thus means the gain given by the frames  $j$ .

The following drawing should clarify the functioning of the formula.

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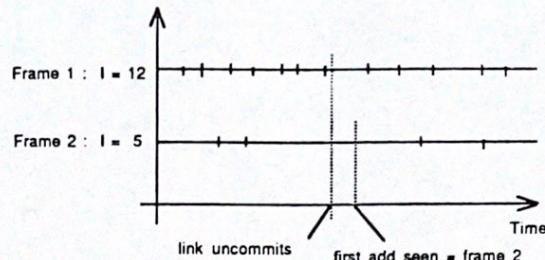


**Figure 2 :** In the situation depicted here, the influence of Frame-i would be :

$$I_i = I_{i_0} + k^{in}(l_j + l_m) + k^{out}l_j$$

The determination of the coefficients  $k^{in}$  and  $k^{out}$  is once again domain-dependent.

This Influence  $I_i$  determines the rate with which the corresponding frame  $i$  posts randomly an "add" on the board. The board is organized around types of frames, very much as the adds section of a newspaper is organized around topics like "Real estate" or "Cars", and each activated frame present in Episodic Memory at the current time posts adds for himself on this board with a frequency proportional to its own Influence. That means in particular that frames already heavily connected will be advertising more often and thus will tend to attract uncommitted links of their "league" (looking in this section of the board) at the expense of weaker ones. The figure-3 and figure-4 show a board organization and the times at which two frames would advertise according to their respective influences.



**Figure 4 :** The two horizontal lines above show the instants at which frame-1 and frame-2 put an advertisement on the board. Here, we suppose that a link uncommits at a certain time and re-connects on the first frame that advertised after it uncommitted. It happens that this is frame-2, even though its influence, and therefore its frequency of advertising, is lower than that of frame-1.

Therefore the evolution of the system is stochastically governed by the influences of the frames. When an uncommitted link attached itself to an already well connected frame it certainly improves the fitness function defined above by depleting the not so well connected frames (i.e. auxiliary hypotheses) of their connections and thus of their impact on the current interpretation. But, as shown in figure 4, this needs not to be the case and it might as well happen that a link will connect to a "poor" frame, giving it a chance to improve its influence and thus maybe eventually to affect the whole interpretation. This is a useful feature that in a way recalls the simulated annealing process used in optimization problems with many variables [Kirkpatrick,1983]. It allows one to escape from local minima where it could find itself in the first place.

It should be noted here that in the process of unconnecting and reconnecting, a link may change its connection strength  $K$  according to some rules. This possibility is interesting and certainly essential for the good adequacy of the model to the semantics of the world. Yet it has not been studied in details in the present work, and all the simulations made so far with INFLUENCE have assumed fixed connection strengths.

Another addition to the model could be to have a decreasing influence of frames with time to avoid jamming the board and to enhance the effect of recent events upon past ones.

The first simulations, though still very crude for reasons that will appear in the following, have nevertheless validated our first ideas about a model for re-interpretation. Given a network of interconnected frames with the corresponding influences and connection strength, the model converges toward a stable state (that is one with few random changes) where it stays for a long time before changing to another stable state for another long period of time. What is remarkable is that the change delay between two stable states is short compared to the time the system stay in these states. That means that indeed the re-interpretation process, preceded by many unsuccessful attempts (large variations around the stable state), is rapid compared with the time an interpretation holds. A whole series of experiments is now aimed at precising these results, trying particularly to find a relationship between these delays and the stability or strength of the corresponding interpretations.

Scenes	Human-beings	Taus
- Theater-7 - Birthday party-2	- John-0 - Lucy-0 - Lucy-1 - Bob-14	
Pièns		Affects
- Going out		- Love
Goals	Mops	
- Seduce	- M-Restaurant	

**Figure 3 :** A board organized around types of frames.

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A very provocative consequence of this model is that we should observe radically different interpretations when the system is working in a slowly evolving environment, with a low rate of new inputs, and when it is submitted to a rapid inflow of informations. This possibility is at least raised by similar observations made by Prigogine on dynamic systems. If this phenomenon was to be observed, it would open the door to new pre-occupations connected with the possibility of real-time artificial intelligence, where it could be determinant on its qualitative performance to adjust the internal kinetics of the system to the task at hand. Investigations along this line are planned. Until now INFLUENCE was given all the elements of the episode at once.

Still these experiments are more about a dynamic model, as interesting as it may be, than about semantic re-interpretation.

This is why the efforts of the last few months have been oriented toward the application of INFLUENCE to real tasks such as the interpretation of the James Bond story given in the beginning of this paper.

### 4. Can shallow mean deep ? The molecular computing dream.

While trying to cast natural language stories into a frame based system and see what INFLUENCE would do with them, two related problems rapidly turned out.

It is clear that the mechanism described above tends to structure the episodic memory around well-connected frames and to discard with time "auxiliary" hypotheses that have dwindling influences and may finally lose all connections with the rest of the episode. That means that given a "story" (it might as well be an image) and left without further informations about it, the memory will converge toward a "caricature" of the input, that is keep only its main lines. (E.g. given the representations of a few simple stories about terrorism, our system attributed finally them all to a single character). The only constraints that prevent the system from collapsing into a kind of semantic black hole (caricatural and in the end absurd) are first the a priori influences  $I_0$  that are given by the user and are not subject to the equilibrium and revision process (an otherwise lightly connected frame can still be influent), second, the connection strengths  $\kappa$  (a link cannot unconnect if  $\kappa=1$ , and generally disconnects itself all the more reluctantly that its strength  $\kappa$  is close to 1), and third the division of the board into types of frames, this last constraint preserving the semantic of the network, e.g. an intentional-link will always connect to a GOAL frame.

The second problem shows up in the James Bond story example. If we assume that when reading the first two sentences "*He plunked down \$5 at the window. She tried to give him \$2.50 but he refused to take it.*", the system chose the Base-ball game SCENARIO and started accordingly to instantiate its associated script: (Pay cashier/get ticket (and change)/enter/find a seat/watch game/...), and then read the third sentence "*So when they got inside, she bought him a large bag of pop-corns*". This doesn't fit into the previous script. But then what does mean "to fit", after all, may be there is no other

SCENARIO that fits the situation as well. Another question, in the case of INFLUENCE, is what would happen if finally, leaving aside the details of the process, the system discarded the base-ball SCENARIO for a movie-theater SCENARIO? As it is, all the recorded details of the script, which, as far as we know are still valid, would be discarded as well. That means that the system would potentially forget a lot at each change of frame.

Lack of place prevents us to give a more substantiated account of these problems, and of some other related to the inheritance of properties (another powerful source of constraints and differentiation among frames). (For more details see [Cornuejols,1987]).

The key insight here however is that we ought to be able to allow further differentiation of the frames according in particular to instantiated parts of scripts and inherited properties. In particular, a candidate frame should be all the more attractive, i.e. influent, that it fits well the "shape" of the constraints.

I call this "*shape fitting*" or "*site matching*". The current context, expressed in the memory network, defines sites where other network parts can fit. These sites or shapes represent the particular knowledge corresponding to this part of the network. The point is to define a measure of pattern matching between constraints, part of them semantic as "a cashier doesn't get inside the projection room", and part of them learned through information gathering, as with scripts instantiation.

This kind of information processing through pattern matching or pattern recognition with learning through dynamic evolution and selection has been called **molecular computing**. If the advantages it offers seem certain, it requires on the other hand that all relevant knowledge be expressible as "patterns", that is as shallow features of the representation scheme, as opposed to the symbolic representation processed from outside by an interpreter. This is another version of the vividness hypothesis.

The question is, is it in principle possible to express vividly, i.e. with shallow features, the constraints and processing capabilities on which lay such deep reasoning activities as exhibited in chess game, in a Sherlock Holmes detective story, or in the course of text comprehension? This question is central to systems like INFLUENCE, where the processing is completely local, here at the level of the links.

The first attempts to explore the matter with frame based systems demonstrated the difficulty to mean deep with shallow processing. But we are very far from settling the question.

My feeling, at this point however, is that lower level symbols and distribution of knowledge throughout memory will be required to reach the molecular computing dream.

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### 5. Conclusion.

The basic question that motivated this research was: is it possible to realize spontaneous re-organization of a knowledge base, either in face of new pieces of information contradicting previously held beliefs, or because a better interpretation, as coherent and simple as possible, is at hand. Another to put it is: is it possible to adapt existing knowledge representation systems, such as frame systems, based on high level symbols, so as to realize spontaneous belief revision?

The concept of using a kind of potential, the fitness function, on the space of the possible interpretations was introduced. And its translation to the local level of the semantic network has been realized with the program INFLUENCE. The resulting dynamic model exhibits the desirable properties of a re-interpretation mechanism: rapid transitions between states, hysteresis effect, parsimony. In addition it suggests interesting properties: the internal kinetics of the system could control qualitatively different behaviours, and, even more daringly, the algorithm itself could be expressed as a semantic network and thus be applied to itself for self-adjustement. Research is on-going on these problems, the important point being that this scheme offers an alternative to the cumbersome Truth Maintenance mechanisms.

At the same time however, difficulties showed up when attempting to apply INFLUENCE on real-world applications such as text understanding. Indeed, current knowledge representation schemes are not well designed for the local expression and processing of constraints on which is based INFLUENCE, and a necessary condition to achieve vividness, molecular computing and more generally self-organization and adaptiveness. This raises the question: is deep reasoning (always) possible by shallow means? Much research is needed on this.

I hope this research will bring new ideas, concerns and encouragements to Artificial Intelligence, and challenges it to probe deeper (even if with shallow technics) the phenomenon of self-organization and emergence of global behaviour out of local process.

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