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THE ATLAS PROJECT:
A JOINT INDUSTRIAL AND SCIENTIFIC DEVELOPMENT UNDER THE COGNITIVE PARADIGM OF INFORMATION PROCESSING

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ABSTRACT:

The paper presents some general features of ongoing research on a project dealing with multimodal information concerning the human brain. The central motivation is to help physicians prepare surgical interventions. In the first part we introduce the general framework in which our work is situated; such a project has necessary relations with semiotic aspects of information and thus is well related to cognitive approaches. In the second part we discuss the industrial and scientific context of the project; our aim here is to show that from both industrial and scientific points of view such a project does not emerge as a peripheral concern but deals rather with central problems of current general international research and industrial development. In the third part, we give a rough sketch of the project itself; in this, we follow a presentation that makes explicit its paradigmatic character. In the fourth part, we discuss some technical ideas about the underlying system in order to give an idea of the overall approach illustrated in its real complexity; this part is followed by a summary of already obtained key results. Finally, we point out some perspectives that such a project may

generate concerning industrial interest and scientific importance.

1. INTRODUCTION

Every educated man knows that the notion of information has an industrial connotation in particular. But it is not so widely accepted that information is not only a quantitative entity. In fact, once one construes the notion of information as a communication unit, its impact in an industrial context is almost self-evident; nevertheless, if this piece of evidence looks well-founded, its strictly quantitative reference seems questionable from one day to the next. One of the aims of our conference is undoubtedly to shed some light on the root of such a problem. Indeed, the notion of information as an exact quantity, *i.e.* as a well-defined and unambiguously computable individual, is a matter of tradition; but the conception which superposes qualitative features on the traditional notion is the very sign of a new scientific paradigm that we can commonly call the "cognitive paradigm".

How should we understand such "qualitative features"? and, correlatively, in which sense do they engage industrial development? There is, maybe, no harder question than the first one in the domain of the science of information. Let us try to detail some general characteristics implied by such a question in order to make more intelligible what we shall present in the sequel.

In industrial development the overall analysis of a problem is established on well-established notions such as "management", "productivity", "competitivity", "quality control", "cost", "risk", "adaptativity" etc. What makes these notions tightly related to the notion of information is their affinity with decision making theory and methodology; indeed, such notions are commonly engaged in multiform decision finalities founded on sets of information gleaned here and there. Clearly, the problem of decision making very soon becomes equivalent to that of finding the appropriate class of information and structuring it in such a manner that the required decision is an implication of the formal content of the elaborated structure ([Granger 82]). This generic idea not only sounds plausible but, from an epistemological point of view, appears as the only one. Most of the exploitation and performance requirements can be "translated" into formality without any contest about the sustaining informational nature: mechanical performance and, more generally, automated productive tasks, viewed as parts of a global industrial body, need only computational means in order to deal with complexity which emerges as a necessary epiphenomenon of highly structured data; of course, the data taken into account are seen only through their quantitative aspects translated into standardized computation protocols.

But once the information has to be processed by humans at any point of the industrial chain, then the whole landscape changes "significantly". The reason is that the human element is a cognitive agent and as such he operates not only with computational and logical criteria but also - and rather essentially - on the basis of cognitive principles; the long adventure of the Artificial Intelligence approach, corroborated by the parallel progress of Cognitive Psychology, has taught us that human knowledge cannot be covered only by the logical-computational approach; on the other hand, knowledge is the very seat of any decision task and so, unless every human agent is evinced from an industrial chain, the cognitive approach is revealed as inescapable.

This is what one may reasonably pretend to be the qualitative shift of the notion of information. Certainly, cognitive agents are, like humans, not likely to deal with large complexities or extended inferential materials; there are limitation laws, of a psychological nature, that imply such a fact; they concern the general memory functioning, mnesic capacities, conceptualization modalities and forms of reasoning; but even with restricted computational resources a cognitive agent may demonstrate high quality decision performances. One may interpret this as an opposition between information

and the quality of decision. The only plausible hypothesis that sustains such an empirical fact is, precisely, that humans take into account qualitative aspects of the information which escape from the traditional notion of information. But any meaning, even partial, that decision making processes are equally founded on qualitative aspects, needs to reconsider the very nature of available information and, of course, aims at developing new tools and methods which could catch something of the so-called non-quantitative informational nature.

The main hiatus between the two information paradigms has to be looked for in the fact that the latter envisages the notion of information not only as a physical support of symbolic features but also as semantic locus. As such, information has an individual, instrinsic meaning for a cognitive agent and therefore, an information structure has to be visualized as an emergent meaning, elaborated as a whole on the basis of an organized meaning unit. Furthermore, semantically connotated information manifests not only individual intrinsic features of meaning but also, as a semantic locus, contextual dependences: unlike the former information paradigm, where the individuality of an item of information is a principal consequence, here the individual meaning of a particular item of information is, in one way, the combination of internal, structured semantic constituants and contextual semantic contingencies. In other words, what makes the difference irreductible between them is that, in the cognitive approach, information does not have a complete informational identity unless put into specific contexts; this means that, in real conditions, the notion of information is of a certain dynamic nature, articulating potential "internal" aspects and actual "external" factors including the human agent himself as a semantic constituent.

The correct formulation of the question in an industrial context is therefore of consequence; it clearly consists of two aspects: the first one, properly technological, and the second, generally formal. In the first part, one asks about new technological media able to pick up and manage the qualitative aspects of a given set of data; it is, certainly, a matter of long-term developments; in the second part, one wonders how one may suggest partial alternatives, based on current technology. The problem is, of course, not how to supersede the cognitive agent in an industrial organization but rather how to help him perform his task faster and, mainly, better by conceiving alternative formal and methodological devices; in other words, the real question in combining Cognitive Sciences and Industry is how to mix together the human semantic function and the computational power of the machine.

The project we present in the following paragraphs is voluntarily inscribed in this second aspect. We first roughly describe the basic underlying industrial context; in the sequel, we present how a specific relevant demand emerges, articulating industrial and scientific expectations. Finally, we give the fundamental traits of our approach; it should be said immediately that this concerns ongoing modelling work; the cognitive informational paradigm is thoroughly assumed. We close our communication by a general discussion on perspectives implied by such an approach.

2. THE THREEFOLD CONTEXT OF THE ATLAS PROJECT: SOCIAL, SCIENTIFIC AND INDUSTRIAL

In the health sector, the potential European market value has been estimated at between thirty and

hundred billion ecu over a ten year period[1]. Investment in health information systems and services is 1-2% of the hospital budget, half the relative investment rate of other sectors. The different parties are mainly hardware and software companies, system integrators and networks operators. Indeed, a main part of underlying development is closely related to telematics. Clearly, telematic systems and services in health care have direct and indirect retroactive positive effects on medical/biomedical equipment manufacturing and on the pharmaceutical industry, in terms of product development and access to the market.

European countries have for the most part very similar goals and needs in the health care sector. Main needs are already well-defined and determine short and long term objectives such as the provision of comprehensive ranges of services without escalating costs, improvment of the quality, efficiency and effectiveness of services etc. There is a general concensus that, in order to increase the quality and efficiency of the medical professions and improve health care management, new services and systems must be provided for. In particular, this involves work on integrated hospital information systems. Issues to be addressed include medical equipment, image archiving and transmission, knowledge based decision support systems, remote access to distributed multimedia databases for clinical information, virtual environments, resource management etc.

Our project concerns the elaboration of a knowledge based decision support system (YAKA - **Y**et **A**nother **K**nowledge-based **A**tlas) aiming at developing a computerized brain atlas for clinical research and teaching applications in neurosurgery. Research in this field is very active: comprehensive mapping of the humain brain is becoming a reality. The interest is not secondary: the capacity to rigourously compare and correlate brain maps across modalities and individuals will greatly enhance the understanding of the normal brain and the treatment of pathological ones and consequently increase the effectiveness of image guided brain therapy procedures. This added value arises from the capacity to manage and provide access to complex, pertinent and rapidly evolving medical knowledge concerning the humain brain.

The latter joints precisely the basic requirement of the cognitive approach related to any problem involving men in an industrial context *i.e.* how to integrate in synergic interaction the computational capacities of the machine and the semantic dimension of the human being. Clearly, the problem is not how to develop an information system in a traditional fashion but rather to analyse, as far as possible, cognitive aspects contributing to a decision at any point of the diagnostic and/or the therapeutic chain and construct a system which makes it possible to facilitate and enrich the synthetic semantic activity of the human agent. Of course, evaluative criteria are easily to establish; they concern not only subjective appreciation - which remains, anyway, the main concern - but also quantitative results expressed in terms of traditional industrial connotation (time spent, cost of preparation, quality of final results...).

Thus, from an industrial viewpoint, the interest of computerized brain atlases exists both in the short and long term. In the short term, products should arise to assist neurosurgeons (as well as other clinicians involved in image guided brain therapy, like neurologists, neuroradialogists and radiotherapists) in many clinical situations (image interpretation, diagnosis, surgery, planning, robot assisted surgery, surgery etc.). Basic features, like the registration between the data to be interpreted and the atlas data could be provided (using simple deformable models), as well as basic information

[1] General information about european health sector is borrowed from AIM (Advanced Informatics in Medecine) office (DG XIII).

related to major brain anatomical features being managed. The results of the previous phases of AIM program (EU program called “Advanced Informatics in Medecine”) have clearly demonstrated the interest and the feasibility of these systems (cf., for example, MMOMS, SAMMIE, COVIRA etc.). These projects include several industrial companies. Some of these systems are closely related to the objectives of the YAKA system: for example, the COVIRA project provides a computer vision system for neuro-radiological diagnosis and treatment planning by means of a digital atlas and a knowledge base system; the SAMMIE project developed the BRAINWORKS software system, which is an integrated medical workstation to help radiologists and neuroclinicians make better use of medical images in the field of the neurological sciences. Moreover, brain mapping projects are starting up in North America.

Such systems are typical software developments set up mainly in order to improve the technical aspects of working conditions. They are thought of rather as tools than as organic complements of a part of the information involved: they undoubtedly have a direct and indirect impact in decision making problems, sometimes maybe an essential one; but their lack of organic synergy with the human being can be attributed to the small number of retroactive possibilities they offer: one looks not only for technical devices improving working conditions but also, and essentially, for means that help to improve the way of thinking out the problem. The turning point for a cognitive approach is the contribution of the machine to revealing new possibilities of synthetization and integration (and so interpretation) of the data under process.

In the mean and long term, one can foresee more ambitious systems involving access to a large amount of data. The definition of more complex representations, involving more sophisticated multi-subject data fusion and taking into account the subtle cognitive aspects of physicians in real working conditions, is a critical issue for the development of advanced therapy applications.

3. THE ATLAS PROJECT: A SUMMARY

Let us briefly describe the generic characteristics of the problem in order to make clear the conceptual environment in which an answer is required.

Severe epilepsy can be treated by means of surgery; this requires a complex procedure which aims at defining the very specific strategy, tailored to the case of each patient, in order to guarantee good therapeutic results, *i.e.* the disappearance of epileptic seizures without any functional deficit.

The first step in this procedure involves a detailed analysis of behavioral signs associated with the seizures, which provide precious indications about one or several eventual epileptogenic foci, responsible for the initiation or development of the seizures.

A second step consists in introducing depth electrodes into the patient's brain in order to record the intracerebral electrical activity during and between the seizures. The site of implantation of these electrodes is defined jointly by the neurologist and the neurosurgeon, according to the previous preliminary analysis. The objective is to get more evidence about eventual foci and propagation paths. MRI (Magnetic Resonance) and angiographic images are used to identify the anatomical structures to be explored (e.g. the cortical gyri) or avoided (the blood vessels and some critical functional areas), and precisely define the site of implantation of the electrodes.

Once the intracerebral EEG has been recorded, extensive anatomo-electro-clinical correlations allow the delineation of pathological areas to be refined and a surgery is proposed, discussed and

carried out. The objective of the surgery is the resection of epileptogenic tissues, while preserving normal tissues, and avoiding any damage to sensori-motor or language functional areas.

It should be clear that such a task is based on a plurality of competencies, e.g. in anatomy, neurology, neurophysiology, neurosurgery, neurobiology etc., usually considered as independent of each other. But in fact, this is only a convenient classification; in such tasks the real frontiers between specialities is less obvious: specialists have not only to exchange mutually significant information but also to know much about the domains of the others: at any time, they share a common culture about the brain. This means that the analysis of a case, even in partial or intermediary forms, is never circumscribed into well-defined academic categories; it consists systematically of a synthetic schema where each piece of information, obtained from each speciality concerned, possesses a proper organic place in the global enterprenential structure. We shall have something more to say about the implications of such a fact later. For the moment let us only note that the case of epilepsy surgery, although it is particularly complex, is not the only case concerned by this analysis: many other tasks need synergic collaboration of several specialities and are necessarily assessed on a highly significant information.

On the other hand, one ought not to disregard that if a surgical task needs anthropocentric entreprenential acuteness, the quantity and quality of information have a principal role in the final outcome which can be dramatically invalidated by inappropriate informational support. But what kind of information do the interested parties deal with?

From the point of view of the informational form, one has to deal with all pictorial, numerical and symbolic information. Clearly, each form stands as an informational genus; they are not uniform *i.e.* they are divided in several species which suppose proper organizations and contents. Thus, from the point of view of the information species involved, one has to deal essentially with:

i. *a pictorial genus* of information, like morphological images (such as MRI, CT or DSA), or functional data (like PET or EEG etc.);

ii. *a symbolic genus* in the form of texts, discursive descriptions of structures, labels, metalinguistic symbolizations etc.; moreover, such information often occurs under multilingual non-standardized terminologies;

iii. finally, *a numerical genus*, such as statistical data illustrating the inter-individual variability (anatomical, functional...) as well as pure numerical models that serve as general references of what a typical normal brain should be like.

Yet, we are very far from the end of our problems, due to the multimodal information involved in such a context. Indeed, each informational species is itself governed by proper semiotic principles and laws and elaborates its significant structures using authentic constructive features; this means that it encloses signification in an irreducible manner *i.e.* that the nature of the information it encapsulates cannot be recovered from the rest of the informational variety which makes up the three basic geni of information. Furthermore, this implies that not every medical speciality needs and uses all kinds of information in the same manner and to the same extent, and that the retrieval modalities are not similar; on the other hand, the precise content of a piece of information of a certain kind and its importance with respect to the general task depends on each medical speciality, the particular role it assumes in a certain phase of the clinical context (interpretation of clinical symptoms, identification of anatomical features, surgical planning, operation etc.) and the general coordinating finality. The last remark argues precisely for a cognitive informational approach, as

was briefly introduced in the first paragraph.

Now, it appears as if surgeons “navigate” between all species of information in order to arrive to at an operational decision. Such “navigational” schemata actually correspond to a meta-structural cognitive activity which consists of building up complex, integrated informational entities; even if separations between domains like anatomy, neurology, neurophysiology, neurochemistry etc. are quite traditional academically and even if oppositions in nature and content between the three informational geni mentioned above and their species are self-evident, they all make reference to classifications whose aim is to rationalize the study of the brain. In real dimensions and, in particular, in our context, the brain, as an informational domus, appears rather as a continuum; the notion of continuity is here, clearly, technical: it corresponds to actual infinite analysis taking into consideration every kind of information that is organized under an infinite number of structural principles. This is the main reason why doctors need to use reference informational structures that would correspond to what they have integrated during their medical studies and alongside their personal experience; this also makes obvious the need for systems that would allow integration of the relevant knowledge that has to be rich enough and simple enough in the sense that it should correspond naturally to the cognitive structures of doctors; or, at least, of systems that would help physicians, as naturally and as widely as possible, to integrate the pertinent information in a particular operational planning. Whatever it will be, a “human-like” approach is difficult to overestimate.

The last argument offers a major hint for the generic character of any approach to a knowledge representation model: aiming at helping physicians in a context like the one we have described, necessitates offering flexible capacities to organize every kind of knowledge material they work on; furthermore, from a point of view of the efficiency desired, any design of an associated computer system ought to offer powerful recovering capacities concerning multimodal information and rich “navigational” possibilities. One may naturally think of a model founded on basic hypermedia features. Of course; but clearly, it will not, alone, be sufficient.

We have conducted our presentation in order to make the general formal architecture of what we are working on intelligible. It consists of a knowledge base, a data base (including images and symbolic data), a base containing statistical data, relative image tools and a system of navigation between all these modules. We can represent such a design as follows (Fig. 1):

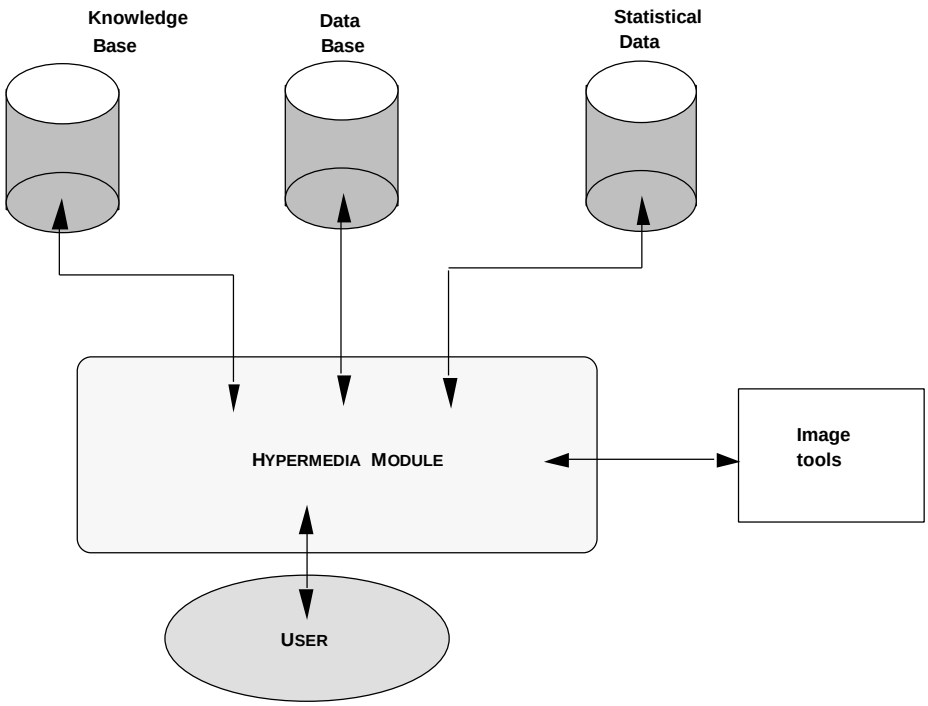

Fig. 1: The general architecture of the Atlas project

The knowledge base is actually the corner stone of the whole organization. The reason is that a domain like the one we are dealing with has essential empirical foundations and consequently, it refers to knowledge whose nature may not generally be given from necessary and sufficient criteria; this kind of knowledge is not peripheral nor exceptional but fairly abundant in every speciality concerned; thus one has to face it continuously. The knowledge base therefore naturally occupies the central place in the organizational scheme; it aims at handling such kinds of knowledge, full of exceptions (and not infrequently exceptions of exceptions...), uncertain qualifications, possible features, analogical extrapolations of facts observed on animals but never on humans, variability of inference modalities, in brief, empirical knowledge which reveals typical contents rather than logically founded definitional materials.

Let us describe in the following paragraph some basic elements required for the establishment of the very nature of such a knowledge base.

4. SOME TECHNICAL FEATURES OF THE KNOWLEDGE BASE

Setting up the technical part of the problem, and therefore, looking furthermore for formal issues, gives a rather classical schema. One can easily understand that most of the concepts and descriptions apply to many other problems within the context of decision making necessities. Bearing this in mind, one may construe the general conceptual problem as follows: how to select and structure a piece of information with the most human-like and decision oriented manner from an “informational multimodal magma” operating under selection schemata that are sensitive to contextual parameters? More formally, the knowledge base appears as a highly structured domain D on which selection functions F_1, ..., F_n operate, n being a natural number, such that $F_i(D)$, 1 = i = n, stands for a kind of informational integration; it corresponds, somehow, to what the cognitive process of a physician may relate during a subphase of the preparation of an operation as described in the previous paragraph. In set-theory notation, one could write D $F_i(D)$; but from a qualitative point of view this is very poor; actually, D stands for a pure structural potentiality whose actualization is achieved by the

F-functions: they point out specific structural aspects which correspond to the relevant organization of knowledge in real conditions. Of course, there are some standardized images of domain D, corresponding to traditional academic classifications such as Anatomy, Physiology, Neurobiology etc.; in a sense, they stand as general landmarks in the structuration process made explicit by the F_i functions. From a purely formal standpoint, there is no difference between, say, the $F_{anatomy}(D)$, $F_{physiology}(D)$ etc. and a general F_i; but such images are standardized, and anyway given and interiorized by physicians. One could talk here about typical, academically stabilized knowledge organizations.

The correct definition of such functions is maybe the hardest part of this project. Actually, their definition illustrates fundamental traits of the way one understands the initial requirement of mixing together human and machine capabilities. Indeed, such selection functions have to be founded on empirical knowledge extracted and structured according to models of the human expertise involved. Most of our investigation is devoted to such a task. On the other hand, they have to present a powerful operational character, since they are thought of as a concrete need of a working information system.

From a general technical point of view, the images formed by these functions may be seen as what one gets by the navigational facilities of the system; and, from a cognitive point of view, they should correspond to physicians' cognitive categories, both acquired from their experience and/or modeled under specific conditions related to a particular task. On the other hand, the general definition of the selection function allows one to point out some particular traits of an already selected part of the D potentiality or even to discern different aspects of it. Intuitively, one may understand the images one gets as “points of view” produced under particular contextual conditions, expressed by the parametric dependencies of the F-functions. We shall adopt this terminology in what follows and talk, in a technical sense, about the “F_i point of view” and sometimes, when no ambiguity is possible, about the F_i (cf. Fig. 2).

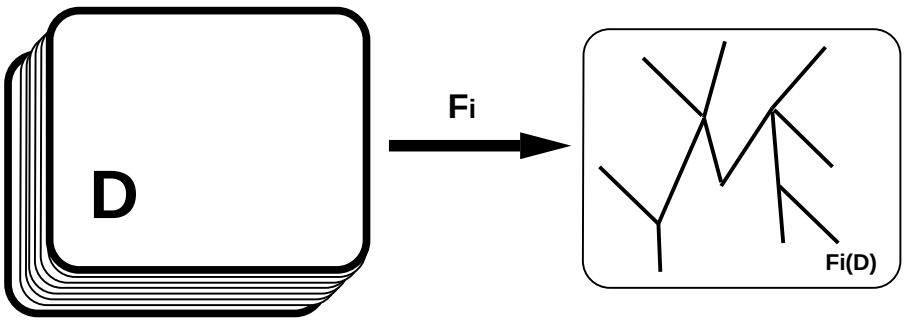

Fig. 2: Selection of a point of view from a potential global knowledge base

The greatest difficulty with the (potential) knowledge base D and, consequently the selected actual points of view generated by the F_i functions, 1 = i = n, is that one has not only to deal with traditional IS-A hierarchies (essentially studied in semantic networks, frame-based systems and object-oriented systems) even if the IS-A relation is still central to the whole modeling; there are many relations (anatomical, physiological, spatial, topological, morphological...) presenting proper properties which have to be considered as such in a particular structure. For instance there are relations of composition, ingredience, relative spatial identification, connectivity etc. proper to each analysis; thus, a composition relation is not necessarily the same in anatomical and neurochemical contexts. At the current state of the project we are still studing such relations and their properties and trying to understand the structural impact they imply.

On the other hand, each F_i point of view makes explicit symbolic entities of different abstraction levels: there are, of course, instances, "abstract" formal objects, playing the role of classes (or concepts seen extensionally) and enclosing universally valid properties and, finally, "typical" formal objects that are constellations of properties of empirical validity and so do not pretend to necessary universality; their existence, nature and function have been analysed in intensive cognitive research in the last twenty years, in particular in Cognitive Psychology; here again, one uses a class of techniques in order to extract such empirical knowledge from specialists; a main part of the project consists of continuous backward and forward protocols aiming at extracting, formalizing and validating collected information of cognitive agents. One of our first results is that the fundamental IS-A relation is clearly split into many species in the overall knowledge representation; it essentially conveys the senses of inclusion (class-class IS-A relation), membership (instance-class IS-A relation), typicality relation (instance (or typical object)-typical object IS-A relation), ingredience and sometimes existential judgement. Certainly, such a semantic distinction between objects lies before us from a structural point of view since such a split has significant repercussions on the class of relations of all F_i's; one ought to associate different semantics to a relation depending on the very abstractive nature of the related objects (instances, extensions or typical objects).

The formal distinction between instances, classes (or concepts) and typical objects appears as a considerable advance for the theory of knowledge representation systems; the intention is here clearly cognitively founded; it is crystallized by taking into account related theoretical developments ([Rosch Mervis 75], [Winston et al. 87], [Mervis Rosch 81], [Desclés Kanellos 90], [Kleiber 88, 90], [Dubois 91] etc.). From a purely formal standpoint, there is no difference in the way one describes such objects; the difference is to be looked for in the quality of knowledge associated with each of them; for instance, one may not associate the same inferential processes to a concept and to a typical object, the latter being rather the main focus of default inferential schemata. And indeed, one can hardly understand how empirical knowledge may elementarily be taken into consideration without any reference to the notion of typicality which is actually its theoretical counterpart. On the other hand, typical objects are supposed to be the reference points for similarity effects; in our domain the opposition typical *versus* atypical is intimately related to another opposition, that between normal and abnormal, even if the two oppositions are not assimilated; the latter is of capital importance in all health areas and therefore, any organization dealing with the former put some new light on the frontiers between the healthy and the pathological.

But let us turn back to the F_i points of view and discuss some general traits of their behavior. As a matter of fact, the space of the points of view is structured. One evident structure is the one formed by a sub-structure relation *i.e.* when $F_i(D)$ is a sub-structure of $F_j(D)$, i ? j (set of entities and respective relations of $F_i(D)$ being also in $F_j(D)$). This is a central case for navigational techniques; it expresses the enrichment of already available informational structures. One may reasonably construe that accessing new structures enriches previous knowledge material by an "incremental" process. Clearly, such a process has not only a cumulative effect; our expertise extraction techniques already seem to indicate that the general process is founded rather on family ressemblance coevolutions where logical problems (such as compatibiliy between old and new structures, general conflictual situations[2]...) relevance effects, complexity problems, focalization phenomena etc. may take place and necessitate solutions in more refined structures. So, if the partial

[2] See also below for some standard forms of such problems

structurations, expressed by the notion of point of view, seem to be completely static, one ought not to underevaluate the dynamic global aspect in which they take place. When physicians navigate in D "space" in order to obtain information, they do not deal with individual data but rather with large informational structures in which they search for the semiotic content with the best decisional impact. The navigational means of a system are not simplified ways of moving from an individual piece of information to another individual piece of information (of symbolic, pictorial or numerical nature) but rather from an $F_i(D)$ to an $F_j(D)$ (i ? j); and the decision process seems like a series of points of view $F_o(D)$, ..., $F_n(D)$ where the meaning is not only stored in an $F_i(D)$, 1 = i = n, taken individually, but also in the general succession of such structures. In other words, the decision process also takes into account "historical" aspects of the series of informational structures involved.

We have in fact progressed very little towards a general and exhausive characterization of such dynamical reorganizations in the Atlas project, even if the general schema seems to us fairly clear. Several well-identified local facts seem already of a great formal and cognitive interest. For example, a particular case emerges when one has the same entity x (instance, concept or typical object) such that x belongs in both $F_i(D)$ and $F_j(D)$, i ? j, but x is given with different properties in each of these structures (and, perhaps, it participates in different relations). For the symbolic paradigm in which the overall modeling is drawn, "x is the same" means that "x has the same name" in $F_i(D)$ and $F_j(D)$ respectively. What differs in each case is the so-called *intension* selected (by the functions F_i and F_j) for x in the knowledge sub-structures $F_i(D)$ and $F_j(D)$; to give a rough summary, it can be construed as a structure of properties (couples of the form (Attribute, Value)) and, possibly, a set of relations of determined semantics, with other entities. We commonly call the two occurrences of x (indiscernible from the sole viewpoint of their name) intentionally different. Much of our work concerns this aspect of equality between objects (cf. [Garlatti et al. 94]). The reason is that it is not so obvious to define an extensional equality in a classical knowledge representation system. On the other hand, we know from experience that there are many such cases: indeed, the same entity or the same circumscribed volume of a brain are generally seen differently by different specialists, using different diagnostic means, within the scope of different medical objectives etc.

But we also have the opposite case: it is possible to find two different entities y and z (in the sense that they are given different symbolic labels (names)) such that their intensions are equal. And such a phenomenon may appear not only in different points of view but also in a sole $F_i(D)$. Indeed, it is not impossible to find different names, for the same brain entity, given by doctors working in different (sub)specialities and, in any case, the scientific terminology is neither stabilized nor uni-lingual.

The notion of identity concerned is not always the same. For instance, two objects y and z may be intensionally different but extensionally equal. Generally, the notion of equality is also split into extensional and intensional versions. Moreover, the latter may present a plurality of different forms of an increasing fineness (for an extended discussion see [Kanellos 90]).

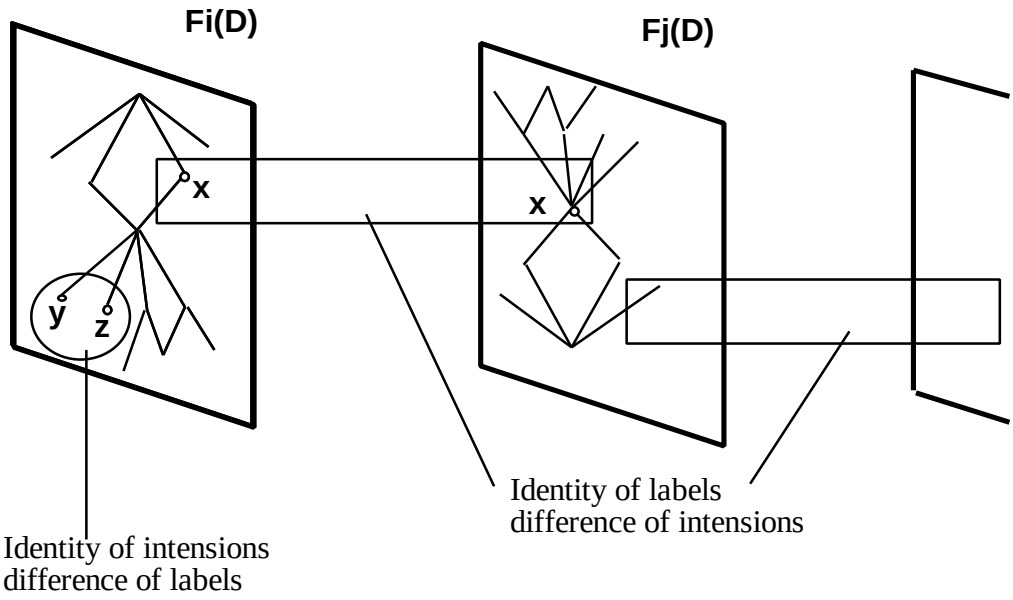

Fig. 3: Aspects of “noun” and intensional identity

It is useful to notice at this point that such phenomena are not exceptional; they rather consist of commonplace effects of any semiotic system. We thus meet again the initial demand of semiotically sensitive formal systems and the importance of a cognitive reflection when dealing with knowledge representation.

The importance of entities presenting such phenomena is in that they are the turning points in blending different points of view concerning a specified brain entity or volume. In particular, when the F_i are academically standardized (such as Anatomy, Physiology...), such relations allow intensional enrichments provided by the combined informational contribution of the analyses concerned (here anatomical, physiological...). But there are also structural constraints, especially (inheritance) conflicts; for instance, suppose that, for a given object x, we have x $F_i(D) \leftrightarrow F_j(D)$ and suppose that once the system has decided how to manage intra-point of view inheritance conflicts (*i.e.* conflicts occurring separately in $F_i(D)$ and $F_j(D)$) we find a conflictual state of affairs between the intensions selected respectively in $F_i(D)$ and $F_j(D)$ for x; unless we find an unambiguous inheritance global schema for x, the expected inferential capacity will be seriously affected.

Furthermore, it is worth noticing at this point that not all conflicts can be resolved; there are cases where, for a given i and j, i ? j, F_i and F_j are incompatible; this is, for instance, the case when an object x belongs to both F_i and F_j and possesses (but not inherits) properties p_1 and p_2, defined respectively in F_i and F_j which, once put together building up a new unique point of view, form a logically contradictory intension for x (in the sense that x cannot possess both p_1 and p_2). Observation of empirical situations confirms the existence of such situations. Moreover, a major problem appears with the identity status of the objects; indeed, the emergence of new points of view, derived from already existing ones, modifies some intensions and/or extensions of the objects involved so that intensionally or extensionally equal objects may be different in the new points of view. There are many subtleties in the correct formal definition of such a relative (actually, a point of view dependent) identity of an object; it is one of the themes of our current research.

5. SOME ELEMENTS OF THE CURRENT STATE OF THE YAKA SYSTEM[3]

We summarize in this paragraph some basic implementation issues, already carried out in the information system underlying our project. First of all, we have decided to consider only the traditionally typical anatomic and functional viewpoints. We have identified the structures concerned in these two approaches and have represented the relationships existing between each other. From the anatomical viewpoint we have considered structures like grey nuclei, ventricles, blood vessels and cortical structures such as gyri and sulci. These structures are organized in a hierarchy corresponding to the inclusion relation associating the anatomical features. The following relations have been considered:

- ingredience ("composed of"), applied to gyri, ventricles, sulci and grey nuclei; these relationships allow some properties to be propagated along the ingredience links;
- spatial relationships between gyri and sulci ("in front of", "behind", "above", "below" etc.);
- inclusion in a lobe ("in lobe").

These relations essentially aim at representing anatomical knowledge which helps the identification and the labelling of cortical features (gyri, sulci). For the moment, the functional viewpoint is reduced to the description of the Brodmann's areas and major connections between them and some grey nuclei; in particular, "afference" and "efference" relations between the thalamus and Brodmann's areas have been represented.

The knowledge base and navigation system are built on a frame-based object oriented system called Y3 ([Ducournau 90]). The latter uses the structure of the knowledge base. Three kinds of information can be reached: brain images (atlas plates), symbolic information (the objects, the relations between objects and the pairs (attribute, value) of objects in the knowledge base) and illustration documents (texts, images etc.); the system allows navigation between them. Once a structure is specified by the user (within a graph, a text or an image) the navigation process identifies the structure selected and relates it to the corresponding object of the knowledge base in order to allow access to the knowledge available in it.

The three following components of YAKA are already being implemented:

- The first version of the patient data base for angiology (sub-domain of anatomy).

- The navigation strategy for a particular task: the labelling of anatomical structures in MR images; 2D and 3D MR images, image tools, and warping models will be soon available as well.

- The new version of the knowledge base which will be composed of several independent academic classifications (or neuroanatomy, neurology and neurochemistry domains, which correspond to $F_{anatomy}(D)$, $F_{neurology}(D)$ and $F_{neurochemistry}(D)$ of paragraph 4) with extensional identity between objects of different domains (cf. [Garlatti et al. 94]).

6. PROGRESS MADE AND KEY RESULTS

Admittedly, we have been rather casual in presenting our work. But our aim was more descriptive and argumentative than purely formal or developmental; we were more concerned with showing in which direction and in what form our ongoing work on the Atlas project engages anthropocentric

[3] An essential part of the rest of this paragraph is borrowed from [Montabord et al. 93]

organization. Here is the place where we can review some aspects of the progress we have made and some key results we have obtained by working on this project. We can distinguish developmental, formal and conceptual results.

The last type revolves around what we broadly discussed in the fourth paragraph concerning the conceptual association when navigating between different information structures and the cognitive affinity of such a process with the notion of family resemblance. We are still working on a general description of such a fact as well as on its formal counterpart; so, at the current stage of evolution of our project, it looks wiser to keep to the general idea of our previous discussion and turn our attention to the first and second aspects.

We summarized the basic developmental issues in the fifth paragraph. For more details, one may refer to [Montabord et al. 93], and parts of [Garlatti et al. 94]. We judge more valuable for our conference to say something about the methodological interest of such developments. We are conscious that many such developments are rather poor from a cognitive point of view. One may invoke here the fundamental and general problem concerning the real capacities of a computer to effectively acquire central cognitive aspects (essentially those related to the acquisition and exploitation of empirical, common-sense knowledge); but this is a quite autonomous question of epistemological nature, exceeding the limits of our paper (and maybe of our conference itself). For our project the importance of such developmenets has to be looked for in their constructive role in properly investigating cognitive categories and working schemata of physicians revealed in real conditions. Indeed, we learn much by observing and analyzing the reactions of experts faced with the conceptual categories and organizing facilites implemented; the inadequation of the machine is a major source for understanding how doctors really work and so, how synergic collaboration between them and the machine can be improved. Anyway, at whatever level the demands of cognitive systems are formulated, such developments may very well justify their adequacy for practical requirements: they may still be seen as classical tools aiming at helping in well defined technical difficulties that physicians have to face.

As for the formal part of our progress, we may report two definite results concerning the definition and exploitation of the notion of extensional equality (cf. the discussion in the fourth paragraph for its importance in sense representation).

The first one concerns the elucidation of a partial aspect of this notion in the framework of a frame object-oriented knowledge representation system using multiple inheritance techniques (cf. [Ducournau Habib 93], [Ducournau et al. 93], [Marino et al. 90] etc.). The introduction of such a (necessary) notion leads to a plurality of local inheritance structures somehow representing “aspects” or “points of view”. Actually, once one tries to take into account a form of extensional equality in traditional knowledge representation systems, one has to face supplementary inheritance problems due, essentially, to the multiplication of conflict modalities. In [Garlatti et al. 94] we suggested a solution consisting in introducing a notion of “inheritance type” in order to characterize different inheritance schemata.

The second concerns a general formal model for the opposition between extensional and intensional equality based on set-theory constructions.[4] The major idea is that there is not one but many equalities both intensional and extensional which express different levels of semiotic identity; one

[4] A paper will soon appear founded on some basic ideas of [Kanellos 90].

may give a general definition and prove that they form a hierarchy of increasing granularity which expresses different levels of indiscernability of sense.

7. PERSPECTIVES AND CONCLUSION

Up to now, hypermedia have been seen as the administrative counterparts of multimedia applications. Their close relation to the very technological apparatus tends to assimilate them to the application itself; such an opinion is widespread and fairly resistant so that it systematically dissimulates a major cognitive aspect the hypermedia may be in charge of: that of being quite adequate for conceptual association modelling and, therefore, for category construction formalization. Unfortunately, very little work has been done from a theoretical point of view in this area; what one sees is rather well-known knowledge representation paradigms reformulated in terms of elementary hypermedia terminology in order to bring them into fashion. But the need for a proper hypermedia cognitive theory is not only real but becoming more urgent daily, since the multimedia area is already within our reach. And, clearly, we seem ready to reproduce the same errors as at the beginning of the artificial intelligence approach, undervaluing the necessity for an adequate formulation of the technological problem in terms of correct theoretical complexity.

The Atlas project is thought of in such a long-term perspective. It articulates two aspects, intimately correlated; the first refers to the specific character of the project itself and aims at developing its general theoretical framework and the related application; the second takes the Atlas project as the central paradigm and aims at acquiring both theoretical and practical skills in developing well founded finalized applications managing qualitative aspects of multimodal information.

The paradigmatic value of the project must not be underestimated. Indeed, once the need for novel computer systems (thought of to increase user information and control, and aimed at furnishing greater transparency in decision processes) is felt, the demand for new ways of thinking about synergic collaboration between informational systems and humans has already been formulated; with such a demand, human beings have to be seen as decisional agents in advanced production systems where the synergy between them and machines is necessarily asymmetric and rather anthropocentric; such forms of systems depend upon a balanced and cognitively subordinated integration between human skills, collaborative work organization and adapted technologies; the fundamental bridge between them may be reasonably looked for in unified formal issues. The general requisites beyond the Atlas project are not very different from a typical industrial task, at least as far as basic productive parameters are concerned; one can easily discern: i) a concrete need for shorter preparation cycles ii) greater and better-structured knowledge about the object concerned (the brain) iii) a requirement for new possibilities of interaction between participants in an operation *i.e.* more collaborative and participative forms of work iv) a necessity to detect probable faults earlier and increase the quality of post-operational results v) a continuous demand for a better consideration of inter-patient variability (regarding anatomy, physiology, pathology) requiring flexibility at all stages of patient care vi) an increased will to satisfy an increased social demand etc. In other words, one finds the same requirements for the integration of conceptual and executive functions with the least cost and risk. The challenge taken up by the Atlas project is that a renewed notion of hypermedia, supporting not only technological imperatives but rather, and more fundamentally, basic cognitive aspects, is a good candidate for taking into account industrial requirements to do with multimodal information and the relative decision problems. In this way, the cognitive approach may be seen as a prime strategic answer.

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