Title: "A proposal to Develop Interactive Classification Technology"

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1.0 Background Information

Research for the first year was oriented towards:

1) the design of an interactive classification tool (ICT); and

2) the development of an appropriate theory of inference for use in ICT technology.

The general objective was to develop a theory of classification that could accommodate a diverse array of objects, including events and their constituent objects. Throughout this report, the term "object" is to be interpreted in a broad sense to cover any kind of object, including living beings, non-living physical things, events, even ideas and concepts. The idea was to produce a theory that could serve as the uniting fabric of a base technology capable of being implemented in a variety of automated systems. The decision was made to employ two technologies under development by the principal investigator, namely, **SMS** (Symbolic Manipulation System) and **SL** (Symbolic Language) [see deBessonet, 1991, for detailed descriptions of SMS and SL]. The plan was to enhance and modify these technologies for use in an ICT environment.

As a means of giving focus and direction to the proposed research, the investigators decided to design an interactive, classificatory tool for use in building accessible knowledge bases for selected domains. Accordingly, the proposed research was divisible into tasks that included:

1) the design of technology for classifying domain objects and for building knowledge bases from the results automatically;

2) the development of a scheme of inference capable of drawing upon previously processed classificatory schemes and knowledge bases; and

3) the design of a query/search module for accessing the knowledge bases built by the inclusive system.

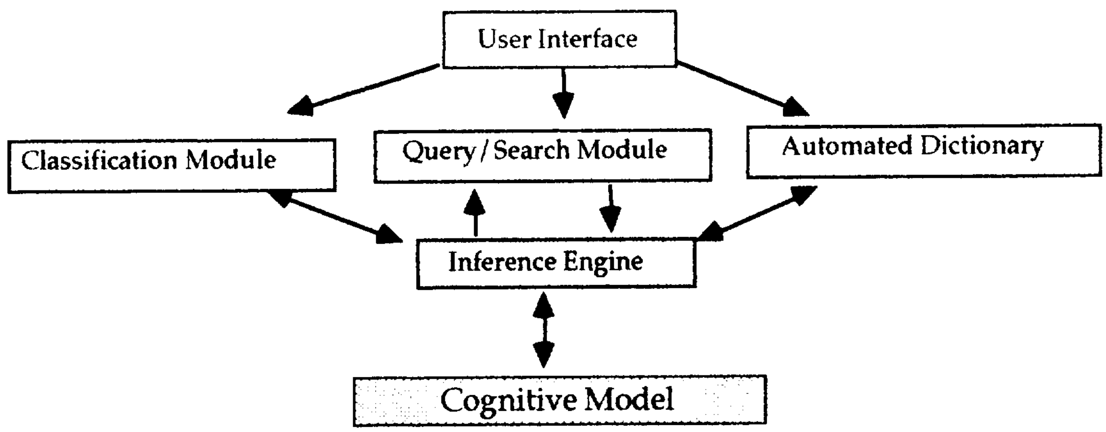
The interactive tool for classifying domain objects was to be designed initially for textual corpora with a view to having the technology eventually be used in robots to build sentential knowledge bases that would be supported by inference engines specially designed for the natural or man-made environments in which the robots would be called upon to operate.

3.0 Progress to Date

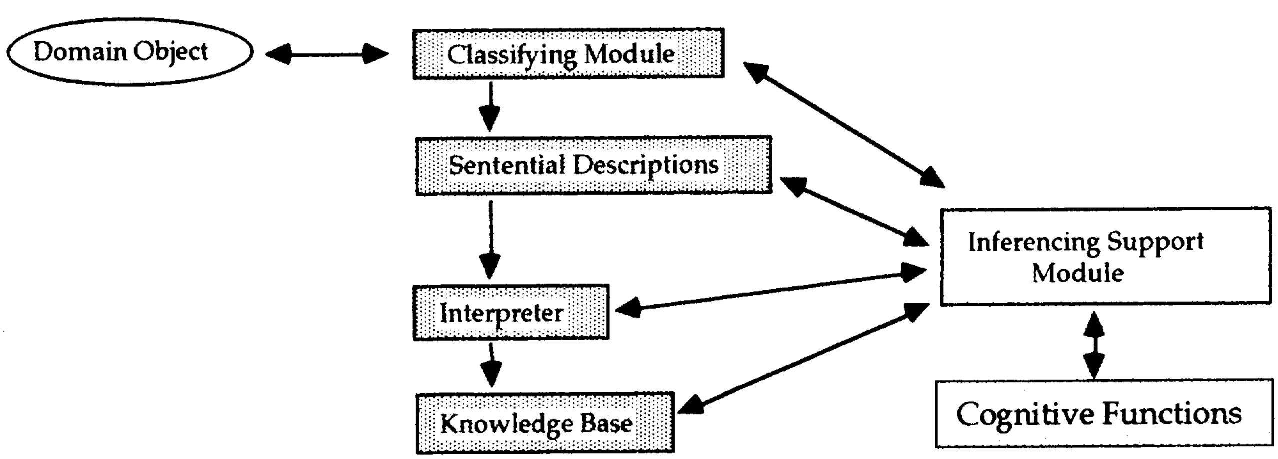
The results achieved thus far are very promising. As expected, the technology was found to be crucially dependent on theories of inference and classification that could be implemented over a complex of ontologically diverse objects. The investigators successfully developed a unified approach to knowledge representation and inferencing that is capable of accommodating a diverse range of objects. In addition, a plan was established for handling some of the more difficult cases, such as the representation of the cognitive processes of an android. The guiding principle is that the deeper the understanding of the object to be classified, the better and more useful the classification. The classification of a described cognitive act of remembrance, for example, can be contextually treated for classification purposes more effectively if the system has some defined notion of what it means to remember something.

One of the most significant results of the first year of research was the specification of a general, naively defined, cognitive model for use in classification technology (see section 6.0, *infra*). SMS vitally needs more developed theories in these areas to perform sophisticated tasks of interpretation that would be required of a classification system of the kind envisioned.

With respect to the development of ICT technology, work under the initial year of funding was successful. The proposed design was found to be adequate for the most part but needed one significant modification - the addition of a cognitive model and accompanying cognitive functions. A paradigm of cognition was needed to enable the investigators to address problems associated with interpreting sentences that describe cognitive processes of human beings and other cogitating objects. A diagram of the current ICT design is given below.



In the main interface, the user selects the module appropriate for the desired task. The classification module is used to build knowledge bases for selected domains, whereas the query/search module is employed to ask questions and retrieve information from whatever KBs have been built using the classification module. The automated dictionary is a by-product of the classification process and is used for quick look-up and graphical displays of relations between concepts. The classification process, which is the focus of attention in this proposal, is diagrammed below using arrows to indicate that the inferencing module would provide interactive support during the entire classification and interpretation process.



The investigators were successful in determining:

1) that ICT technology can be implemented incrementally for various kinds of information including examples, definitions, and normative dictates such as right/duty relationships;

2) that useful results can be achieved using a limited set of quantifiers and operators; and

3) that for best results, the system would require an interpreter capable of "understanding" selected epistemic operations as well as modal and emotional concepts.

With respect to the accompanying goal of developing an appropriate theory of inference to support an ICT environment, the investigators were successful in determining:

1) that for reasons of convenience and efficiency, the representation language used in ICT technology must accommodate the encoding of multiple perspective simultaneously;

2) that SL notation can be modified to encode multiple perspectives simultaneously; and

3) that with some modification and the availability of a compatible cognitive model, the problem of imprecise classification can be effectively addressed to a useful extent by employing a defeasible scheme of inference that employs multiple perspectives (see section 6.0, *infra*).

The components of the model of the classification process specified for SMS are:

1) classifier;
2) object to be classified;
3) bases of the classification (e.g. rules, criteria);
4) procedure
5) label, identifier, or marker for the classification; and
6) relation type (e.g. 'isa, 'is, and 'is=).

Classification in ICT includes the identification of objects; in addition, class identifiers include raw data headers, although for expository convenience only lexical labels are discussed herein. The *classifier* envisioned is assumed to be a cogitating object, which has important consequences for ICT technology. Since SMS is intended to serve as a classifier, and since some of the objects to be classified contain descriptions of cognitive acts that are themselves classificatory in nature, the inescapable result is that SMS must have some "understanding" of the cognitive processes in which the classificatory acts occur in order to be able to interpret them. In other words, the interpretive tasks require the availability of a paradigm of cognition that includes those processes.

The bases of a classification that would be made by a cogitating object of the SMS universe would in theory have to be accessed internally by that particular object. It was therefore necessary to develop a model of such a cognitive event, one that would fit the general epistemological theory specified for SMS (see deBessonet, 1995). The investigators made significant progress in modeling selected cognitive activities. The belief its that unless an interpreter has access to this kind of information, it will be seriously hampered in its ability to perform its crucial role in the classification process. An diagram of a simple, sensory component of the model as developed thus far is given in section 6.0, *infra*.

2.0 Submission of New Proposal; Goals

The investigators are submitting a new proposal to NASA requesting funding to continue the work performed under the first year of funding. The proposal contains much of the material of this report and describes the objectives of the proposed research accordingly. The proposed goals are:

1) the enhancement of the representation language SL to accommodate multiple perspectives and a wider range of meaning;

2) the development of a sufficient set of epistemic operators (cognitive functions) to handle basic cognitive acts performed by the SMS interpreter, including the storage and accessing of points of reference; and

3) the development of a default inference scheme to operate over SL notation as it is encoded.

3.0 Relevance of Proposed Work for NASA

The goals set for the proposed research have important relevance for NASA in technological areas related to:

1) knowledge engineering;
2) knowledge acquisition; and
3) automated systems designed for use in mechanical devices, including robots.

With respect to knowledge engineering, the proposed work would have direct application in addressing problems associated with handling large and moderately sized data bases. The interactive tool, for example, could be used to build conceptual retrieval systems for particular data bases. With respect to knowledge acquisition, the proposed technology could be used to assist in the elicitation of information from domain experts, thereby preserving it for future use even if the experts become unavailable. The interactive classification tool could be directly employed in this capacity in cases in which information been recorded by experts in forms in which particular items of information are not conveniently accessible. With respect to automated systems for use in mechanical devices, the proposed work would have relevance for devices that must automatically classify/identify objects in their domain.

Since the primary objective for the proposed work is to produce a uniform system of representation and inference specified within a well-defined theory of robot epistemology, progress along these lines would provide NASA with versatile technologies that could continue to be developed for a variety of specialized, automated tasks.

4.0 Findings

As mentioned previously, the research under the original proposal was directed towards the design of an interactive classification tool (ICT) and the development of an appropriate theory of inference to support ICT technology. Although described separately, the work tasks were interrelated and were performed simultaneously. An appreciation of the progress made and of the goals of the proposed research requires and understanding of the mutually supporting relationship between the two technologies. The interactive classification tool was designed to employ formalisms in an interactive mode in which information would be instantiated into the formalisms as text is processed. To maximize the power of the tool, an expansion process had to be designed that would operate recursively on instantiated formalisms to produce a result over which inferencing could be defined. Part of the expansion process is referred to a penumbral inferencing, a process by which nonstandard inferences are generated from given information (see deBessonet, 1991, 1995). A brief, formal illustration is given below.

One can conceive of a syntactical function Ω that would be capable of drawing relevant syntactical objects into association with a given object Φ using one or more relations defined for that purpose. Thus, $\Omega(\Phi, \Theta) = \{ \alpha_i \}$ where Φ ranges over sentential and nonsentential linguistic objects. Θ ranges over relations and $\{ \alpha_i \}$ is a set of objects, each of which bears the relation Θ to Φ. The function Ω can be used to produce penumbral inferences. Given that Θ_1 is a relation and that Φ_1 is a sentential object and that $\Phi_1 = < \beta_1\ \gamma_1\ \beta_2 >$, where β ranges over noun components and γ ranges over links (verbs), the function Ω can be applied to the internal noun components of Φ_1 to produce two sets of objects related to one another by the link γ_1. In other words,

$$< \Omega(\beta_1, \Theta_1)\gamma_1 \Omega(\beta_2, \Theta_1)> = <\{ \beta_{1-1}, \ldots, \beta_{1-\psi} \} \gamma_1 \{ \beta_{2-1}, \ldots, \beta_{2-\zeta}\}>$$

(where y ≥ 1 and z ≥ 1). Using the information to the right of the equal sign, one can relate each element of the first set to each element of the second set to produce a set of penumbral inferences, each inference bearing an assigned value indicative of its degree of presence. The inferences might take the form:

$$\{<<\beta_{1-1}\, \gamma_1\, \beta_{2-1}> \Delta_\iota>$$

$$\ldots$$

$$<<\beta_{1-1}\, \gamma_1\, \beta_{2-\zeta}> \Delta_\varphi>$$

$$<<\beta_{1-\psi}\, \gamma_1\, \beta_{2-1}> \Delta_\kappa>$$

$$\ldots$$

$$<<\beta_{1-\psi}\, \gamma_1\, \beta_{2-\zeta}> \Delta_\lambda>\}$$

(where Δ ranges over values indicative of full or penumbral presence in the system). This set of inferences would constitute part of the penumbral realm of the system. The effect of employing Ω on a given object Φ and a set of relations is that multiple objects become co-present with Φ and are themselves cast into penumbral relations with the objects to which Φ is related. If Φ is the object `grape',for instance, the object `wine' may be generated into presence in the penumbral realm by using an appropriate relation symbol as an argument to Ω.

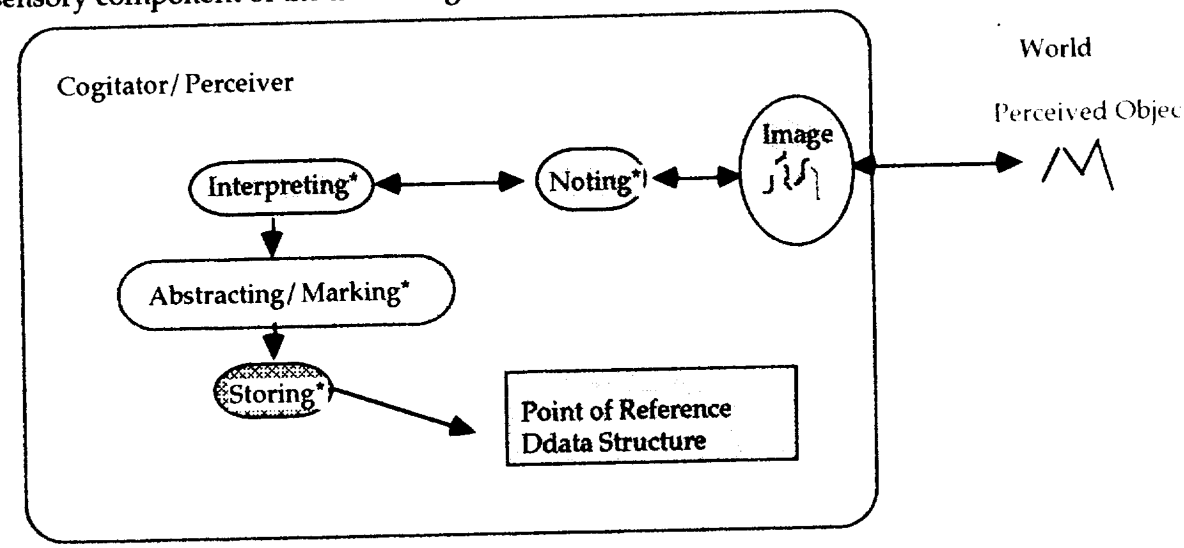
As predicted, the querying power of the system was found to be functionally dependent upon classificatory and interpretive capabilities. The constraining principle is that the retrieval capabilities of the system are measured by what had been classified and incorporated into the system through interpretation. The cognitive model was added to the design in an attempt to increase the system's interpretive capabilities. ICT technology is distinguished by its behind-the-scenes employment of a sententially oriented representation language and a specialized interpreter that reads the language and builds an optimized KB from input. ICT starts with a domain of objects and develops a KB for it over which an optimized search can be conducted. As objects are classified, the inferencing component prompts the human classifier for additional input in an attempt to maximize the semantic depth of the classificatory descriptions provided. The prompters, with the help of the inference engine, generate appropriate sentential descriptions and pass them to the interpreter. The representation language in which the descriptions are expressed are formally structured to enable the interpreter to cast descriptive content into a KB specially designed to accommodate analytical paths mapped out in query/search.

Significant progress was made in the first year towards addressing the problem of imprecision in expression. The plan is to employ a defeasible scheme of inference that accommodates multiple perspectives. The finding was that to capture the meaning of textual objects being classified, the system as currently designed would be required to perform some of its operations in the epistemic and modal realms. This is not to say that the system would be required to have fully developed epistemic and modal logics available to operate, only that these kinds of operations must be given interpretations within an SMS/ICT environment. The point can be illustrated by simple example using the assertions:

(1) An eagle is in the tree; and
(2) John saw an eagle in the tree.

The interpretation of the first assertion, say represented in SL as "<eagle v-l-in tree>" would differ significantly from the interpretation of "<john saw <eagle v-l-in tree>>," which is an SL representation of the second assertion. The second assertion contains the *perception* verb "saw" and must be given a special, epistemically oriented interpretation. For an ICT system to "understand" this assertion in depth, it must access a cognitive model in order to generate a base of information from which to respond to queries and perhaps do a bit of SMS-styled epistemic reasoning. The investigators have developed a preliminary version of a cognitive model that traces an act of perception from the initial sensory experience to its interpretation and storage in memory. The model is quite elaborate, but, for expository convenience, it will be given only a brief and partial description here. The reader should keep in mind that the SMS interpreter would be attempting to build internal representations of the meaning of sentences such as assertion (2) above. The investigators have defined a number of special operators (cognitive functions in SMS) to give the system this capability, among them **noting***, **interpreting***, **assigning***, **accepting***, **accessing***, **activating***, **applying***, **evaluating***, **abstracting***, **marking***, **associating***, **storing***, **comparing***, **recognizing***, and **remembering***.

The general scheme for acts of perception by sight is for the sensory image to be noted, interpreted, marked or copied, and then stored as a point of reference that is assigned an uncertain degree of accessibility, giving it a human-oriented limitation. A diagram of a simple, sensory component of the model is given below.



This represents the idea of a cogitator perceiving an object of the world, noting a less than perfect image of it in his or her horizon, interpreting it, and then entering it into memory as a point-of-reference data structure by means of defined processes of abstraction, marking and storage. The configuration represented is drawn from the sensory horizon of the general cognitive model. These processes, including the construction, storage and accessing of the point-of-reference data structure, are specially defined and related to enable them to be represented in SL, the representation language of the system.

Classification as defined in SMS enters the picture at the **noting*** phase when an object is noted as a "some-thing," to use SL terminology. Traditional classification occurs when a label is assigned to the object sensed or experienced. In SMS, the entire process is represented in accessible form. Much of the effort in the first year was spent on developing a theory of cognition for ICT technology. The development of a theory to cover perception and stored points of reference posed important representation issues. The investigators determined that perception statements, for instance, must be interpreted from multiple perspective, including:

a) the perspective of SMS; and
b) the perspective of the perceiver mentioned in the SL assertion.

In addition, the points of reference produced during the process of interpretation must be related to one another in a way that will enable the system to handle imprecise expression. The investigators developed an approach by which the KB of SMS can be treated as points of reference created by the SMS interpreter. In this respect, SMS itself is taken as a cognitive model (see deBessonet, 1995). Points of reference created in conformity with the special cognitive model defined for individual perceivers are represented in a special SL vocabulary that employs cognitive operators and terms, including the operators listed previously. Thus, two general perspectives become appreciable - that of SMS and those of individual, cogitating objects within SMS. Findings of the first year indicate that two perspectives can be kept distinct and that SL notation can be enhanced to handle the simultaneous encoding of both perspectives, at least to a large extent.

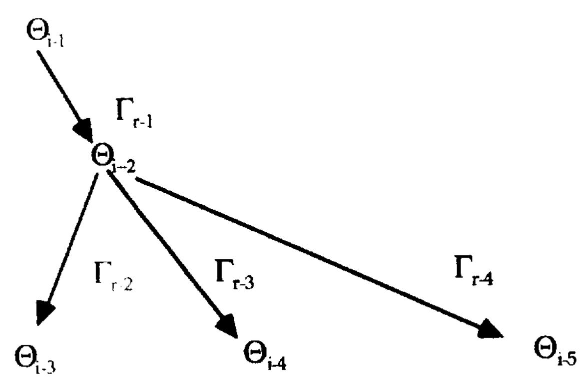
Returning to the example about John seeing the eagle, the multiple perspective approach would enable the codifier to assert that indeed John saw an 'eagle but would allow the encoder to avoid making a direct assertion about how 'john interpreted what he saw. If the system were to be queried about whether 'john saw an 'eagle, for instance, it would be in a position to give an unqualified, affirmative response, but if asked whether 'john believed it was an eagle,' the system could generate an appropriately qualified response (a penumbral response in SMS terminology). The findings were that this capability is contingent upon the detailed representation of the processes that take place within the cognitive model specified for individuals, including the creation, storing and accessing of points of reference, and upon an elaborate system of defaults especially designed for the environment in which multiple perspectives would be encoded simultaneously.

The system is being designed to operate in an object-oriented, CLOS-based programming environment. This environment was chosen because of the direct compatibility between Lisp functions and the cognitive functions being defined for the system. Readily understandable examples would be that EVAL and APPLY of Lisp correspond to the applying* and evaluating* functions of SMS. SMS interprets sentential input and builds a knowledge base (KB) from the results. The KB has a carefully specified structure that is optimized for accessibility and efficiency. Basically, the components of interpreted sentences are marked and cast into a massive configuration of objects related to one another through pointer/links, all of which may be likened to a detailed concept map.

Drawing upon techniques designed for SMS concept map interpretation, the system for relating concepts and points of reference can be diagrammed to highlight the defeasible nature of objects and relations that SMS considers to be tainted or uncertain. From a formal perspective, the general ideas can be abstractly described as follows. Let Q be the set of all quantifiers recognized by the system, let C be the set of terms/concepts (referred to herein as "nodes") used as noun-type components of SL sentences, let R be the set of all relational terms used to relate nodes, and let V be the set of all values used to describe the presence (cf. truth; see deBessonet, 1995) of objects and relations. The primary mapping would be defined as follows:

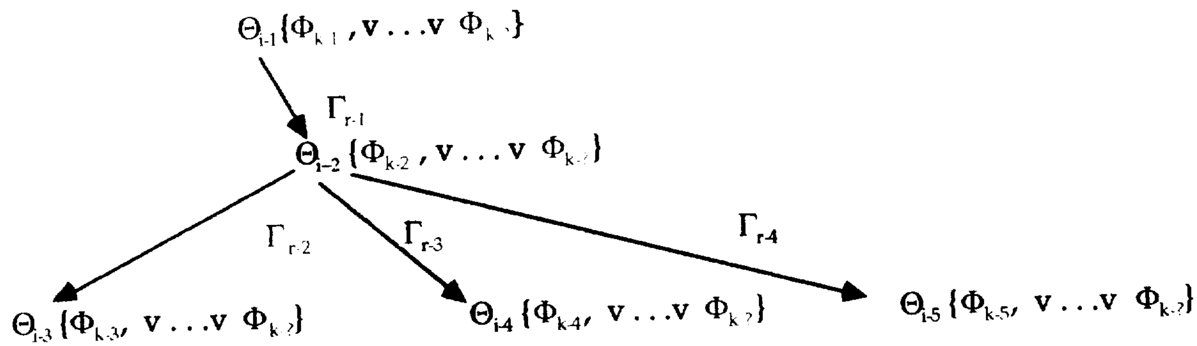
> Let A = {(c, q) I c e C, q e Q} and let B = A x A, the product set of A and A. Each member of B is then paired with a relation simply by letting D = {(b, r) I b e B, r e R}. The primary mapping would then be:
>
> *f*: D --> V

The general scheme can be explained diagrammatically using Greek letters as special variables. Numbers are attached to the letters to distinguish variables having the same range. Let Φ range over quantifiers, Γ over relations, and Θ over node concepts. The configuration below represents a segment of information encoded in SL.



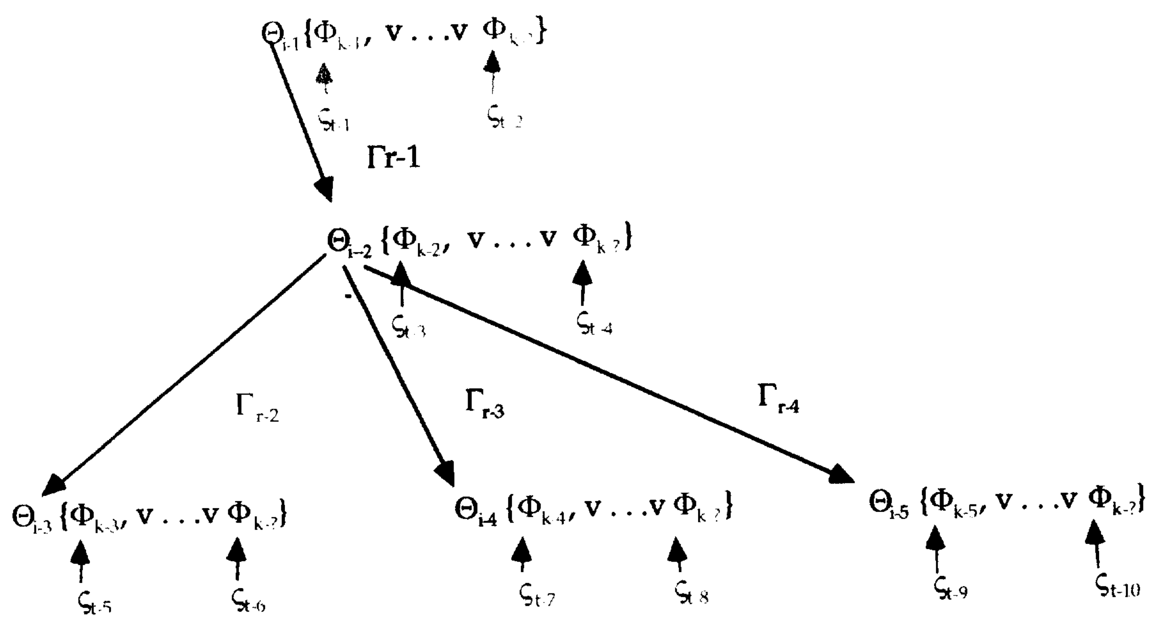
(where the arrows relate the nodes as described by the relation symbols to the right of the arrows and where varying color reflects diversity.)

Assuming that quantifiers would have been omitted from the encoded information, the first round of interpretation would add quantifiers to the nodes, supplying them on its own using default rules. The result can be schematically diagrammed as follows:



(where "v" represents disjunction and "?" represents unspecified numbers ranging over 1 through 12)

Each node is now accompanied by a disjunctive set of quantifiers that the system has generated as part of its nonstandard operations. Since the system must produce results from what is not explicitly given in the SL notation, the operations are clearly within what is called the penumbral realm in SMS, which means that the conclusions reached are by no means valid in the traditional truth-functional sense. The conclusions are nonetheless useful (see deBessonet, 1991). For the scheme to reflect this, values must be added to indicate that the conclusions are tainted in precisely defined ways. This means that every quantifier added in a conclusionary manner must be accompanied by a value that represents the nature of its taintedness. The result can be schematically diagrammed as follows:



(where ς ranges over values that indicate varying types of taintedness and the upward pointing arrows connect the values with quantifiers)

Any tainted relation or object generated is defeasible, and reasoning over the objects is specified with that in mind (see generally deBessonet, 1991). Conclusions are qualified accordingly, including those made with the scope of the cognitive model. The findings thus far are that points-of-reference data structures (PRDSs) can be understood to be configured and related as diagrammed above for nodes and relations. This is because the cognitive model is being represented directly in SL, which means that SL assertions about the creation and storage of points of reference are also encoded and processed like other SL statements. The proposed research would investigate the possibility of marking entire configurations of PRDSs and treating them as connecting mechanisms that are accessible at multiple points from multiple perspectives. The idea is to be able to handle concepts like "calling to mind" an event based on the thought of something similar to some aspect of the recalled event.

5.0 Relation to Present State of Knowledge and to Work in Progress Elsewhere

The work would significantly advance current interactive classification technologies. Perhaps the most demanding field in this area is the field of knowledge acquisition (KA). A fairly recent theoretical advance in KA proposed that an explicit model of human cognitive processes be used to guide the development of knowledge acquisition tools [Ford and Adams-Webber, 1991]. [Note: The proposed work would employ a cognitive model, but a naively constructed one specially tailored for determined tasks.] Despite advances in KA technology, a pressing need persists for an intermediate system into which information elicited from an expert could be mapped. The specific need is for a system that can communicate with the elicitation technology and perform inferencing operations on the information it receives, and then feed back the results to enable the elicitation component to react appropriately in its interaction with the domain expert. ICT technology is being designed with these specifications in mind.

As to knowledge representation and inferencing, there are perhaps as many systems of knowledge representation (KR) as there are KR researchers. Systems that use some derivative form of first-order logic notation or employ some scheme of inference based on the first-order predicate calculus have produced powerful results in limited domains in which modal and epistemic representation and reasoning is not required (see e.g. Genesereth and Nilsson, 1987; McDermott, 1987; and Wos *et al*, 1984). Although some progress has been made in the area of representation and reasoning involving incomplete domains, approximations, and fuzzy concepts (see generally Yager *et al*, 1987), there is still no adequate scheme to represent and reason about epistemic and modal concepts, and the problem of incomplete knowledge (see e.g. Levesque, 1984) continues to be quite formidable. Questions persist about the suitability of using fuzzy set theory and probabilistic theory on a broad scale to ground systems because of the unavailability of finely graded distributions, whether of probability or possibility, in many situations. SMS theory is being designed to address these issues on a broad scale by way of a unified approach to representation and inferencing, and ICT technology is being developed accordingly.

The proposed work is intended to complement a number of existing systems and technologies. The capabilities of standard logic as a knowledge representation and inferencing tool are well known and have widespread application in AI and related fields (see e.g. Genesereth and Nilsson, 1987). Systems based on fuzzy set theory have gained popularity is some circles in recent years and have been used effectively to address certain problems of uncertainty or imprecision (see e.g. Zadeh, 1986; Yager *et al*, 1987). Probability theory is, of course, also quite useful in this area (e.g. see generally Pearl, 1988; Rodder and Kern-Isberner, 1997). Schankian conceptual dependency (Schank,1975) continues to have its adherents and has been employed in a number of systems over the years. Like SL and SMS, conceptual graph notation, which was developed to bridge the gap between systems based on formal logic and systems that employ more informal methods (see e.g. Sowa, 1984), is still being employed in some applications (e.g. Dick, 1992). The importance of ontological considerations has also attracted some attention over the years (e.g. Hobbs, 1985), and recently, special attention has been given to ontological realms (e.g. Hirst, 1991). SMS theory supports the view that considerations pertaining to realms and their ontological status should not be ignored in system design. Schemes of nonmonotonic and default reasoning have been developed over the last couple of decades to deal with imprecision in the form of incomplete knowledge (e.g. McCarthy, 1980, 1986; McDermott and Doyle, 1980; Reiter, 1987), and researchers continue to strive to come up with adequate formal theories to deal with epistemic reasoning (Hintikka, 1962; Moore, 1985). Recently, an attempt has been made to specify a formal framework for reasoning about knowledge, particularly about knowledge requirements of tasks such as those performed in robotics (Brafman, et al, 1998). Statistical classifiers are being developed to use knowledge-based techniques, including topical context and local clues, to identify word senses (Leacock *et al*, 1998). Each of these approaches has its usefulness. SMS theory borrows features from these approaches and combines them, along with some new features, into a unified approach designed for effective use in an ICT environment. Hopefully, significant progress will be made by others in classifying word senses of machine-readable dictionaries (e.g. Chen and Chang, 1998) to enable the investigators to employ the results in an ICT environment.

Allowed space does not permit a discussion of the details about how SMS theory relates to each of the disciplines mentioned above, but a general statement can be made that describes the essence of the relationship between SMS and these other systems. Basically, SMS theory has its own way of approaching problems in the areas mentioned, but it draws upon these other disciplines. It extends and takes advantage of vivid database theory, for instance, by taking a different epistemological view of the world that allows multiple levels of varying vividness to be recognized in the system (see deBessonet, 1995). SMS theory leaves the door open for other systems to be properly adjusted or adapted for use in an SMS environment. It recognizes, for example, the power of truth-functional logic systems, such as the predicate calculus, and SMS is being specially designed so that a truth preserving capability can be demonstrated for it even though it is not specified as a truth-functional system (see deBessonet, 1991, Chapter 6). An elaborate proof process is being designed for the system to take advantage of certain features of the resolution principle (Robinson, 1965) that is so often used in first-order logic systems. The system can also be made to use probability distributions and finely graded fuzzy distributions if that kind of information is to be made available to the system (see deBessonet, 1991, section 4.10).

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