der the roof of
number of titles
our Lecture
nmediately vis-
over as Lecture
of the Lecture
an Editorial
iekmann, who
and proceed-

vell accepted
nce, and we
n outstanding
AI community.

Lecture Notes in Artificial Intelligence

Edited by J. Siekmann

Subseries of Lecture Notes in Computer Science

437

D. Kumar (Ed.)

Current Trends in SNePS – Semantic Network Processing System

First Annual SNePS Workshop
Buffalo, NY, November 13, 1989
Proceedings

Springer-Verlag
Berlin Heidelberg New York London Paris Tokyo Hong Kong

Preface

The First Annual SNePS Workshop was held on November 13, 1989, at the State University of New York at Buffalo. SNePS is a state-of-the-art knowledge representation and reasoning system used for Artificial Intelligence and Cognitive Science research. It is a semantic network based system designed by members of the SNePS Research Group in conjunction with and under the supervision of Dr. Stuart C. Shapiro and Dr. William J. Rapaport. SNePS 2.1, an implementation of SNePS in Common Lisp, runs on several computers and is distributed under license from the Research Foundation of the State University of New York. The aims of this workshop were to bring together Artificial Intelligence researchers working with (or interested in) SNePS. Twelve research papers were presented by people from seven different research sites in the United States and abroad. The papers were of top quality and covered several areas of ongoing AI research displaying the versatility of SNePS as an AI research tool. The presentations were interspersed with several discussion sessions concerning achievements of the participants as a collective SNePS community and were helpful in outlining future research directions. This volume contains all the papers presented at the workshop.

Attendance at the workshop was by invitation only. It was attended by 46 participants from 14 different organizations and three different countries. The group from Instituto Superior Téchnico, University of Lisbon, is actively developing SNePS and its environments, and they brought new implementations of several systems, including a SNePS based theorem prover and a knowledge debugger. These are currently being incorporated in SNePS 2.1 and will be included in future distributions.

This workshop was sponsored by the SNePS Research Group and the SUNY at Buffalo Center for Cognitive Science.

Many thanks to the authors and participants for making the workshop a great success. Thanks to Sy Ali and Hans Chalupsky for taking charge of the various organizational chores. Thanks also to Eloise Benzel, Sally Elder, Gloria Koontz, Leslie Russo, and Lynda Spahr for providing administrative support. And thanks to Dr. William Rapaport and the SUNY at Buffalo Center for Cognitive Science for providing funding for the printing of an early version of these proceedings as a Department of Computer Science, SUNY at Buffalo, technical report. This volume contains revised and updated versions of the papers in the technical report.

Deepak Kumar
Buffalo, March 1990

Contents

Order Dependence of Declarative Knowledge Representation

James Geller
Department of Computer and Information Sciences
New Jersey Institute of Technology
Newark, NJ 07102
geller@mars.njit.edu

Abstract

It has been a widely accepted assumption among knowledge representation researchers that declarative knowledge representation is in some sense order independent. In this paper we will argue that there are a number of different possible senses of the term "order independent" and that one needs at least one type of order dependence to develop a cognitively valid knowledge representation system that takes knowledge acquisition into account.

We will distinguish between spatial, temporal, and conceptual order dependence. We argue that any system dealing with a changing knowledge base should maintain the conceptual order implied by the chronological order of the concepts it is acquiring. It will be shown for the SNePS (Semantic Network Processing System) system that order dependence can be incorporated without any changes to the theory or interpreter of the system.

1 Introduction

Many researchers in the AI community hold that one of the attractive features of declarative knowledge representation for natural language processing [1] is its order independence. For instance Pitrat [13] writes that

> Using declarative knowledge is beneficial because of its convenience and efficiency. . . . The components of the knowledge are independent, so we can remove, add, or modify them independently of each other.

The idea of order-independence of declarative knowledge goes a long way back. In "the paper that started it all" (according to Brachman & Levesque, [3]) McCarthy [12]states that

[1] Our main interest in knowledge representation is for natural language processing.

The meaning of declaratives is much less dependent on their order than is the case with imperatives. This makes it easier to have afterthoughts.

The reader will notice that McCarthy's quote is much more conservative than Pitrat's. McCarthy does not make an absolute statement about the possibility to add or modify declarative structures independently from each other, only one that compares declarative structures to imperative ones.

One of the few exceptions to the order independence assumption has been presented by Shapiro and Maida [18]. In an elaborate argument, which we cannot reproduce here, the authors show that the semantic network structure representing a chain of natural language utterances might appear in two different formats, if extensionally identical objects are represented by intensionally different concepts.

In this paper we will distinguish between different meanings of the term "order independence" and present a few arguments why a cognitively valid model of declarative knowledge should *not* be order independent in one of these senses. We will show that such order dependencies occur in much simpler situations than the one described by Maida and Shapiro. We will also exhibit connections between our theory and Harnad's theory of "symbol grounding" [8]. Finally it will be pointed out that the SNePS [17, 19] system in its current implementation can deal with the changes that we are proposing.

2 Senses of Order Dependence

There are at least three different meanings that one can assign to the phrase "order independent."

1. It may mean that order independence denotes a strictly temporal phenomenon. Input to some system can be given in any desired temporal order, and the behavior of the system will not depend on this order.

2. Order independence could also mean that the knowledge base of the system is editable and one may add a new structure between any pair of existing structures. This type of independence is exhibited by systems like OPS-5 [4] and is a spatial phenomenon of the knowledge representation. The behavior of the system will be independent of this spatial order.

3. Finally, order independence could mean *conceptual order independence*. In this sense, more advanced (possibly abstract) concepts can be entered into a system, independently whether the simpler (probably concrete) concepts they are relying on are already known to the system or not. Note that although this sounds similar to temporal order independence, it is orthogonal to it, because it focuses on the acquisition behavior, not the "run time behavior" of a system.

We hold, that conceptual order independence precludes any cognitively valid system that can combine knowledge representation with knowledge acquisition.

3 Arguments for Conceptually Ordered Knowledge

The first observation to be made is that natural language and research in natural language processing are intimately connected with research in knowledge representation. Weischedel [22] reviews common issues of these two topics. With a few early exceptions like ELIZA [23] all major natural language processing systems incorporate some formalism of knowledge representation. On the other hand, the development of knowledge representation itself has received its major motivation by work in natural language processing.

If one takes a paragraph of English text and reorders the sentences in it, this will usually result in a severe reduction of understandability. Some part of this effect is due to anaphora that refer back to earlier sentences, but replacing them by the terms they refer to would not eliminate the problem. A paragraph is simply more than a set of sentences, as has been shown in research on paragraph sized text [9].

Given the ordering constraints in text and the intimate relation between text and knowledge it seems somewhat surprising that declarative knowledge representation should be completely order independent.

Our second argument is as follows. Looking at the logical structure of connected text or speech, one often finds sentences that define a new term. This is especially true in scientific, legal, and mathematical language. One would expect that the definition of a new term occurs before or shortly after its use. This constraint on language structure should be mirrored in the knowledge representation of the corresponding text. [2]

This dependence goes to the point that a knowledge representation system that attempts to be cognitively valid should be permitted to reject a sentence if it detects an abundance of undefined terms. After definition and use of a new term have been added to a knowledge base, the knowledge structures should reflect that one of these concepts relies on one or more of the others.

A third argument for order dependence of knowledge representations can be based on the knowledge acquisition behavior of children. Although every child experiences its own distinct development, there are certain stages common to them [5]. In the beginning one word statements abound, and only after some time children will form sentence-like structures. In their utterances concrete expressions will precede abstract ones.

It seems counterintuitive that we should assume that a child will understand the sentence "Lucy padded a yellow dog," if the child does not know what a dog is, and does not know what "padding" means. Even if it derives and stores some information from this sentence, it seems unlikely that its internal representation will be complete and identical to the one that we would attribute to an adult who is familiar with the concepts of dog and padding.

Although we do not want to jump to any conclusions, it seems that one needs to have a certain selection of concrete knowledge before abstract knowledge can be built. Again, this means that one cannot add concrete and abstract knowledge in any random order, at least not during early

[2]Terry Nutter has pointed out to me that the teaching style of Russian mathematicians is diametrically opposed to this statement. They start with a theorem and develop all the necessary background for it. It seems that they must rely on some naive grounding of the used terms, and that they could not explain a theorem using artificial terms like xykryk. In any event, this phenomenon requires more study.

development.

So far we have looked at knowledge representation as a repository for natural language, knowledge representation as expressing the internal structure of paragraph sized pieces of text, and children's acquisition of knowledge structures.

For our fourth argument we will add the perspective of reasoning. Knowledge structures are not necessarily acquired, but in many cases they are derived from previous knowledge by the use of reasoning rules. If a structure A that is the premise for another structure B is withdrawn, it might become necessary to eliminate structure B also. This type of reasoning maintenance has been initiated by Doyle [6] and has led to the active field of research and development of truth maintenance systems (TMS). It demonstrates another example of knowledge structures for which an explicit order has to be maintained. While the previous three arguments involve problems with "independently adding", knowledge structures, this argument shows that one cannot "independently remove" knowledge structures. This stands in visible contrast to Pitrat's previously cited strong statement.

We will now present two more arguments that deal with adding knowledge. Lenat [11] presents several statements to the nature that one cannot learn something unless one almost knows it. He quotes personal communication with Porter saying that, "nothing new is learned except with respect to what's already known." We have developed a metaphor based on this statement.

Adding a single structure to a knowledge base seems like adding a piece to a jigsaw puzzle. This is an activity which is best done in an orderly fashion, starting at some corner, and growing along the edges, and finally into the middle. Staying with the same metaphor, one can start from different corners at the same time, or even grow small islands, but one cannot randomly plant pieces into free space and expect that they will grow together.

In our paradigm of conceptual ordering of knowledge structures that means that one cannot add a knowledge structure if it does not "touch" one or more already existing knowledge structures. In the context of a semantic network, touching means to "share a concept." One may create temporary "islands" but not too many of them, and they have to grow together at some point in time.

The last argument appeals to the (presumed) teaching experience of the reader. In introducing a new subject, one usually makes an assumption as a teacher that students know certain underlying facts. Often it turns out that this is not true for some students. By listening to a question a teacher can often derive what the missing link between the students knowledge and the teachers new item of information is. This indicates that some sort of ordering information is maintained between the structures of the subject which is sufficient to pin down a specific missing element.

On the other hand, it is easy to realize for a teacher if a student is at a knowledge level that is too low to bridge the existing gap with a simple explanation.

4 Arguments against Order Dependence

Our previous arguments raise a number of questions some of which we will address in this section.

4.1 Acquisition Versus Representation

The first question is whether we are confusing issues of knowledge acquisition with issues of knowledge representation. The definition of conceptual order dependence and most of the arguments given in favor of this order dependence make reference to the addition of knowledge to a knowledge base.

As mentioned in passing in a previous section we are mostly interested in knowledge representation for purposes of natural language processing. One can divide the tasks involved in natural language understanding into two different groups of subtasks, depending whether a parsed discourse introduces new concepts or not. If new concepts are introduced, then we would like to call this type of natural language processing *learning by being told.* [3]

Obviously, learning by being told involves the acquisition of new concepts. Therefore we think that our arguments for the order dependence of concepts are relevant to knowledge representation, as soon as one advances from "simple" natural language understanding to learning by being told. It is agreed that a research program that explicitly excludes learning by being told is not in need of the conceptual order dependence advocated here.

4.2 Order Dependence and Predicate Logic

In this section we will refute an argument that runs approximately as follows: formulas in predicate logic are order independent, predicate logic is the best understood way to do knowledge representation, this paper claims there should be order dependence, therefore this paper must be wrong.

The order independence that predicate logic is talking about is the independence of the result of a theorem prover from the order in which axioms and theorems are stored internally. In other words, this is a spatial order independence. We are not interested in this order independence, but in the conceptual order dependence between the objects and predicates used in these theorems and in constraints in acquiring these theorems if they involve several concepts which are previously unknown to the system.

A theorem prover does not try to understand individual concepts. This is exactly the power of logic, that one can construct programs that operate based on the form of well formed formulas, but not on their meaning. We are trying to make these formulas a better model of human intelligence by imposing additional constraints on their acquisition, which seem to agree with human behavior.

4.3 Order Dependence and Production Rules

A similar argument as for logic might be used for production rules. Production rules have been introduced originally as a cognitive model. This paper claims that a cognitive model of knowledge representation should permit to express order dependence. Production rules do not maintain an order dependence. Therefore this paper must be wrong.

Production rules, although interesting as a cognitive model, certainly do not capture all aspects of human information processing. To mention only one phenomenon that they are not addressing, it

[3] This term it due to Shapiro, personal communication.

is now widely agreed that short term memory and long term memory are not sufficient to model all the human cognitive abilities [21]. Conceptual order dependence of knowledge structures is simply another issue that is not addressed in rule-based (production) systems.

Frustrations with limitations of the production rule methodology have also lead to the development of deep-model based [20] expert systems. This indicates that the limitations of production systems are not limited to cognitive aspects, but extend to very practical performance issues.

4.4 Which Knowledge Needs Order Most?

Given that knowledge representation formalisms currently in use do not maintain conceptual order information the question arises whether domains differ in their need to maintain this knowledge.

Looking back at our arguments we find that we have used "definitions," "logical reasoning," and "teaching" as three indications for the need to maintain knowledge about the order of ones concepts. Defined terms should "point back" to their definitions. Results of a reasoning process should point back to the facts and rules used in their derivation, and more complicated scientific concepts should clearly refer back to the simpler concepts they are derived from. The one domain where these three types of knowledge occur most commonly together is science education.

5 Conceptual Order Dependence and Representational Primitives

Researchers in knowledge representation have covered a wide spectrum concerning the issue of "primitives." Quillian's [14] ground breaking work on semantic networks explicitly excluded the use of primitives. At the other extreme are Schank's well known [16] primitive actions. Semantic networks and representation languages of the KL-ONE family [1] are based on "epistemic primitives" [2] that control the inheritance mechanisms but are not primitives of the representation domain. In the SNePS system [17, 19] predefined primitives are limited to a small set of arcs that are the building blocks for rules, while primitives of the representation domain exist only as non conceptual relations expressed as user defined arcs.

Requiring a partial order for concepts in declarative knowledge representation raises the question whether one must have a set of primitives. We think that the answer is yes. We are not arguing for any minimal, specific, or limited set of primitives. This frees us from trying to identify such a set. Nevertheless, there are three classes of concepts that seem not to be defined in terms of other concepts. These three classes are (1) perceptual concepts, (2) emotional concepts, and (3) motoric concepts. In our representational theory these three classes of concepts function as primitives for all other concepts.

A perceptual concept is a concept which (has instances that) we can recognize without being able to explain what features permit us to recognize it. An emotional concept is a concept that describes a mental state which we cannot explain but which we can recognize. A motoric concept is a concept that describes an action that we can perform, often without being able to explain in detail how we are doing it.

The best understood of these three classes of concepts are the perceptual ones. For natural kinds, perceptual concepts have been analyzed in categorization research [15]. It is from here that we derive an argument against a limited set of primitives. People can recognize members of an unlimited number of increasingly complex categories. The fact that we cannot explain how we recognize them shows that their definition is not grounded in a declarative knowledge representation formalism, which makes it possible to think of them as primitives from the point of view of the knowledge representation system. (From the point of view of the perceptual system the recognition of complicated categories might very well be based upon procedures for recognizing instances of simple categories.)

In terms of our previously introduced metaphor, a jigsaw puzzle, the primitives correspond to the pieces at the edges of the puzzle. If we assume that the puzzle can grow unlimited to the right and up, then the left edge (the y-axis) may grow unlimited upwards, and the lower edge (the x-axis) may grow unlimited to the right. Therefore, there are primitives of the declarative knowledge representation system, but there is an unlimited number of them.[4]

5.1 Representational Primitives and Symbol Grounding

Harnad [8] has argued that AI systems that only manipulate symbols will not be able to pass the Total Turing Test, [5] and to expose real human-like intelligence. As a solution to this problem he suggests to ground symbols by a system of transducers and neural networks in observations of the real world.

What he refers to as perceptually grounded symbols corresponds to our understanding of perceptual concepts. Our assumption in this paper is that every concept must be grounded. Many concepts will be grounded perceptually, motorically, or emotionally, but many other concepts will be grounded by definitions using already grounded concepts. We refer to this process as *propositional grounding*. Concepts that are grounded by a definition containing already grounded concepts are propositionally grounded concepts.

This paper does not represent research in symbol grounding. We take it as a given fact that symbols must be grounded [6] Our question is how to represent the grounding of concepts which are not primitive (according to our definition) in a knowledge representation framework.

6 Pragmatic Reasons for other Order Dependencies

As a side note we want to point out that it has already been stated in the literature that when working with a knowledge based system there are *pragmatic* reasons **not** to insist on spatial order independence of individual knowledge structures. This is not obvious when one works with a problem that fits onto a single page, but it becomes obvious with larger problem sizes. One place where difficulties have been noticed are rule based systems like OPS-5 [4], where production rules in

[4]If we extend our metaphor to a 3-dimensional open ended puzzle it seems attractive to associate the directions of growth with perceptual, emotional, and motoric primitives.

[5]An extension of the Turing Test that requires interaction with the world.

[6]This fact is still the subject of heated discussions between AI researchers.

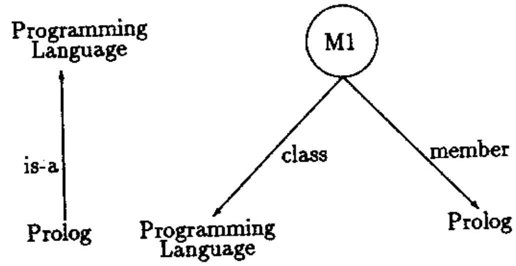

Figure 1: IS-A in KL-ONE and SNePS

principle may be given in any order. However, in practice things are more difficult, as Jackson [10] states, "Even in cases where the rules do make true categorical statements about the domain, there is no guarantee that your program will perform in the way that you expect. . . . As mentioned earlier, this is often a critical consideration when adding a new rule to the system."

When debugging an OPS-5 program, the complete independence of rules forces the programmer to potentially consider every rule in the system. The debugging task becomes considerably easier if rules that deal with closely related situations or are likely to be fired in close succession are spatially organized together.

7 An Example: IS-A Hierarchies

For an example we will use one of the best investigated phenomena in the whole field of knowledge representation, namely the is-a relation. Fig.1 shows a graphical representation for the is-a relation in two different styles. The left part shows a representation that corresponds to the members of the KL-ONE family, while the right part shows an equivalent representation for the SNePS system.

Both parts show a representation for the fact that Prolog is a programming language. The major difference is that SNePS also represents the proposition of this fact as a node, m1, while the proposition is implicit in the KL-ONE form.

Both representations, however, do not record the temporal order of acquiring the two involved concepts. It is not clear from the internal representation or the diagram, whether the concept of programming language was known before or after the concept of Prolog. Clearly one would like to maintain this information, for the reasons explained in the previous sections.

In addition, a person will often be able to remember that s/he knew the concept of programming language before learning about Prolog. If knowledge representation is trying to be cognitively valid, as we think it should, then it must be possible in principle to maintain the distinction between

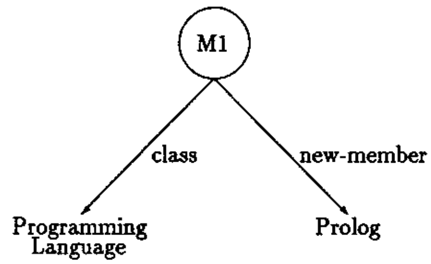

Figure 2: Distinguishing a new member.

heaving heard first about Prolog or having heard first about programming languages.

This distinction also comes out clearly from natural language utterances which could result in building the structures in Fig. 1. A sentence like "Prolog is a programming language" assumes that the hearer is already familiar with the concept of a programming language. On the other hand, a sentence like "Prolog is an example for what has been called a relational programming language" clearly introduces the class of relational programming languages and assumes that Prolog is an already known concept.

In Fig. 2 we show an alternative representation that distinguishes the new member relative to the existing class. In Fig. 3 we show another variant of Fig. 1, this time a preexisting object is associated with a new class.

This new representation raises one obvious question. Have we created unnecessary complications? Do we have to do three tests from now on to decide whether something is a member of a class, or at least two tests, to distinguish between Fig. 2 and Fig. 3? Fortunately, this is not the case, at least not if we limit ourselves to the use of the SNePS system.

The SNePS interpreter combines two systems of reasoning, a rule based reasoning facility and a path-based reasoning facility. The path-based facility permits one to describe arbitrary combinations of arcs using operators like "AND", "OR", and "KLEENE-STAR". It is similar to the original reasoning mechanism that Quillian [14] had in mind when he introduced semantic networks. Any defined path may then be used in the system for retrieval operations, as if it were just a simple arc. We will show an example run that demonstrates how this facility permits us to keep the added knowledge in the system, without complicating the retrieval operations.

```
*(define member class new-member new-class)

(MEMBER CLASS NEW-MEMBER NEW-CLASS)
```

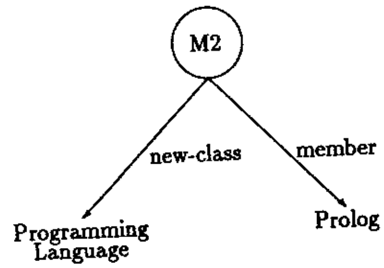

Figure 3: Distinguishing a new class.

```
*(build new-member prolog class language)

(M1)

*(build new-class programming-language member prolog)

(M2)

*(define-path member (or member new-member))

MEMBER implied by the path (OR MEMBER NEW-MEMBER)
MEMBER- implied by the path (OR MEMBER- NEW-MEMBER-)

*(define-path class (or class new-class))

CLASS implied by the path (OR CLASS NEW-CLASS)
CLASS- implied by the path (OR CLASS- NEW-CLASS-)

*(find member ?x class ?y)

(M1 M2)

*(find new-member ?z class ?a)
```

```
(M1)

*(find member ?b new-class ?c)

(M2)
```

Above test run shows an interaction with the SNePS system. Lines starting with a "*" are user input, and the "*" is the system prompt. All other lines show system replies. Timing information has been edited out for clarity. The line (define member class new-member new-class) introduces the names of all user defined arcs to the system. The line (build new-member prolog class language) creates a structure as shown in Fig.2. The command (build new-class programming-language member prolog) creates a SNePS structure as shown in Fig. 3. The line (define-path member (or member new-member)) introduces a path "member" that consists either of an arc "member" or of an arc "new-member". A similar definition is given for the path "class" in the next user input.

The last three structures show retrieval operations from the network. (find member ?x class ?y) finds any node with a member and a class arc or path emanating from it. ?x and ?y are, as usual, variables (more precisely variable nodes). The system responds with (M1 M2), in other words it has found both previously built structures, independently whether they denote a new member or a new class. On the other hand, (find new-member ?x class ?y) looks specifically for new members of an existing class.

With this example we have hopefully demonstrated what we mean by conceptual order dependence of knowledge structures, and we have also shown that a well designed system like SNePS can implement this new theory without introducing new features.

8 Part Hierarchies

Part hierarchies are another very popular representation system in AI [7]. Clearly there is no problem to carry above representational ideas over to them. Instead of building a network structure with two arcs "member class" we can build a network structure with two arcs "part whole". We can then introduce alternative arcs "new-part" and "new-whole" and use them to maintain order dependence in the network. Finally, using two disjunctive path definitions that combine part and new-part into one path, and whole and new-whole into another path, we can retrieve any part assertion, independently of the conceptual order in which part and whole are maintained. Still, the knowledge of the order is in the system and may be accessed.

The other question is whether people actually remember in which order they acquire part relations. According to our intuition this is often the case. For technical devices we can usually tell that we first knew the device and later on learned about its parts. For clusters of objects we often know the parts before we acquire the term for the whole. In this sense we know about books before we learn about libraries, and about cows before we learn about cattle herds.

9 Open Problems

A large number of open problems is left to deal with. For instance, it is not clear whether our formalism represents a real gain in representational power, or whether it could be simulated with other known representational tools. Similarly it is not clear for which relations order dependence is represented, and how the cognitive system decides when to maintain it, and when to ignore it.

Also, a number of possible counter arguments have not been dealt with yet. For instance, a teacher can reorganize the material in his lecture. Our representation so far does not account for this phenomenon. This problem and related questions, such as similarities between our formalism and "temporal logics," will have to be dealt with in future work.

10 Conclusions

In this paper we have distinguished between three different senses of the term "order independence of declarative knowledge." We have argued that people are able to remember to some degree the order in which they acquire concepts. We refer to this order as conceptual order. A cognitively valid knowledge representation formalism that can deal with knowledge acquisition needs the ability to maintain this order.

We have collected arguments to support the need for ordered knowledge. For instance, the ability of a teacher to organize his knowledge in an order such that certain items are dependent on specific other items is an indication that some order is maintained in the human knowledge representation system. We have also argued, that natural language processing, if it advances to the level of learning by being told, needs to maintain conceptual order information.

Connections between our theory and the symbol grounding problem were discussed. The best way to view this work from the symbol grounding paradigm is to consider it as an approach to propositional grounding which relies that primitive concepts are grounded perceptually.

Two widely investigated relations, the part-of and the is-a relation, have been used as examples how to formulate class membership and part relation in a way such that the conceptual order is maintained in the semantic knowledge of the system. Finally we have shown that the SNePS semantic network processing system can support the distinctions imposed by conceptual order, without complicating the retrieval of the basic facts and without changing the SNePS theory or interpreter.

Acknowledgements

Many thanks to Deepak Kumar, for organizing the first SNePS workshop, Stuart Shapiro, Terry Nutter, Bill Rapaport, and Ernesto Morgado for commenting on the presentation of an earlier version of this paper, Stevan Harnad for personal help with the symbol grounding theory, and Yehoshua Perl, for paying my trip to the workshop from his grant.

tance, it is not clear whether our
vhether it could be simulated with
vhich relations order dependence is
ntain it, and when to ignore it.
en dealt with yet. For instance, a
ntation so far does not account for
similarities between our formalism
c.

es of the term "order independence
le to remember to some degree the
onceptual order. A cognitively valid
dge acquisition needs the ability to

ered knowledge. For instance, the
h that certain items are dependent
aintained in the human knowledge
age processing, if it advances to the
rder information.
g problem were discussed. The best
is to consider it as an approach to
re grounded perceptually.
relation, have been used as examples
way such that the conceptual order
ally we have shown that the SNePS
tions imposed by conceptual order,
hout changing the SNePS theory or

ePS workshop, Stuart Shapiro, Terry
ng on the presentation of an earlier
n the symbol grounding theory, and
grant.

References

[1] R. J. Brachman and J. Schmolze. An overview of the KL-ONE knowledge representation system. *Cognitive Science*, 9(2):171–216, 1985.

[2] Ronald J. Brachman. On the epistemological status of semantic networks. In Nicholas Findler, editor, *Associative Networks*. Academic Press, New York, 1979.

[3] Ronald J. Brachman and Hector J. Levesque. *Readings in Knowledge Representation*. Morgan Kaufmann Publishers Inc., Los Altos, California, 1985.

[4] L. Brownston, R. Farrell, E. Kant, and N. Martin. *Programming Expert Systems in OPS5*. Addison-Wesley, Reading, MA, 1985.

[5] Herbert H. Clark and Eve V. Clark. *Psychology and Language*. Harcourt Brace Jovanovic, New York, 1977.

[6] J. Doyle. A glimpse of truth-maintenance. In P. H. Winston and R. H. Brown, editors, *Artificial Intelligence: An MIT Perspective*, pages 119–135. The MIT Press, Cambridge, MA, 1982.

[7] James Geller. *A Knowledge Representation Theory for Natural Language Graphics*. PhD thesis, SUNY at Buffalo, CS Department, 1988.

[8] Stevan Harnad. The symbol grounding problem. *Physica D*, forthcoming.

[9] Eduard H. Hovy. Planning coherent multisentential text. In *26th Annual Meeting of the Association for Computational Lingusitics*, pages 163–169. ACL, 1988.

[10] Peter Jackson. *Introduction to Expert Systems*. Addison-Wesley, Reading, MA, 1986.

[11] Douglas B. Lenat and Edward A. Feigenbaum. On the threesholds of knowledge. In *Proceedings of the tenth International Joint Conference on Artificial Intelligence*, pages 1173–1182, Los Altos, CA, 1987. Morgan Kaufman Publishers.

[12] John McCarthy. Programs with common sense. In M. Minsky, editor, *Semantic Information Processing*, pages 403–418. The MIT Press, Cambridge, MA, 1968.

[13] J. Pitrat. Declarative knowledge representation. In L. Bolc, editor, *Natural Language Processing*, pages 93–135. Springer Verlag, New York, 1987.

[14] M. Ross Quillian. Semantic memory. In Marvin L. Minsky, editor, *Semantic Information Processing*, pages 227–270. The MIT Press, 1968.

[15] Eleanor Rosch. Principles of categorization. In Eleanor Rosch and Barbara Lloyd, editors, *Cognition and Categorization*, pages 27–48. Lawrence Erlbaum, 1978.

[16] R. C. Schank. *Conceptual Information Processing*. North-Holland Publishing Company, 1975.

[17] Stuart C. Shapiro. The sneps semantic network processing system. In Nicholas V. Findler, editor, *Associative Networks: The Representation and use of Knowledge by Computers*, pages 179–203. Academic Press, New York, 1979.

[18] Stuart C. Shapiro and Anthony S. Maida. Intensional concepts in propositional semantic networks. *Cognitive Science*, 6:170–189, 1982.

[19] Stuart C. Shapiro and William J. Rapaport. Sneps considered as a fully intensional propositional semantic network. In Nick Cercone and Gordon McCalla, editors, *The Knowledge Frontier*, pages 262–315. Springer Verlag, New York, 1987.

[20] Stuart C. Shapiro, Sargur N. Srihari, Ming-Ruey Taie, and James Geller. Vmes: A network based versatile maintenance expert system. In *Proc. of 1st International Conference on Applications of AI to Engineering Problems*, pages 925–936, New York, April 1986. Springer Verlag.

[21] E. Tulving. *Elements of Episodic Memory*. Clarendon, Oxford, UK, 1983.

[22] R. M. Weischedel. Knowledge representation and natural language processing. *Proceedings of the IEEE*, 74(7):905–920, 1986.

[23] Joseph Weizenbaum. Eliza-a computer program for the study of natural language communication between man and machine. *Communications of the ACM*, 9(1):36–45, 1966.