MRS and SNePS: A Comparison

Stuart C. Shapiro
Department of Computer Science and Engineering
and Center for Cognitive Science
201 Bell Hall
University at Buffalo, The State University of New York
Buffalo, NY 14260-2000
shapiro@cse.buffalo.edu

July 22, 2003

Abstract

We compare the formalism of minimal recursion semantics (MRS) with that of SNePS and conclude that scope-resolved MRS and SNePS are notational variants of each other.

1 Introduction

Minimal recursion semantics (MRS) is "a framework for computational semantics" [Copestake et al., 1999, p. 1]. SNePS "has been designed to be a system for representing the beliefs of a natural-language-using intelligent system (a 'cognitive agent')" [Shapiro and Rapaport, 1992, p. 243]. These different intended uses lead to several differences between MRS and SNePS, including the ability for MRS to express generalized quantifiers and ambiguous, but constrained, quantifier scopes, and the inclusion in SNePS of an implemented proof theory for reasoning. Nevertheless, except for these and a few other more minor differences, the conclusion of the comparison carried out in this paper is that scope-resolved MRS and SNePS are notational variants of each other, and that MRS may be viewed as a propositional semantic network.

2 MRS

MRS has been described informally by Copestake *et al.* as a modification of "a conventional predicate calculus representation with generalized quantifiers" [Copestake et al., 1999, p. 4]. I will summarize their exposition of the modification using their example, here shown as (1).

(1) *every big white horse sleeps*

The most conventional predicate calculus representation of (1) would be (2), which they do not show.

(2) $$\forall x[big(x) \land white(x) \land horse(x) \Rightarrow sleep(x)]$$

A version of (1) using restricted quantification would be (3).

(3) $$\forall x_{big(x) \land white(x) \land horse(x)} sleep(x)$$

A slight modification of (3), more suitable for typing, and using a functional notation for $\bigwedge$ instead of the infixed $\land$, is (4)[1], Copestake *et al.*'s first "conventional predicate calculus representation" of (1)

[1]Examples (4), (5), (6), (7), (8), (11), and (12) have been copied from [Copestake et al., 1999], examples (9b), (10a), (11), (12), (13), (23a), and (24) respectively.

$$
\begin{bmatrix} \text{RELN} & \textbf{\_every\_rel} \\ \text{HNDL} & \boxed{0}\ \textbf{handle} \\ \text{BV} & \boxed{3}\ \textbf{ref-ind} \\ \text{RESTR} & \boxed{1}\ \textbf{handle} \\ \text{BODY} & \boxed{2}\ \textbf{handle} \end{bmatrix},
\begin{bmatrix} \text{RELN} & \textbf{\_big\_rel} \\ \text{HNDL} & \boxed{1}\ \textbf{handle} \\ \text{ARG1} & \boxed{3} \end{bmatrix},
\begin{bmatrix} \text{RELN} & \textbf{\_white\_rel} \\ \text{HNDL} & \boxed{1}\ \textbf{handle} \\ \text{ARG1} & \boxed{3} \end{bmatrix},
\begin{bmatrix} \text{RELN} & \textbf{\_horse\_rel} \\ \text{HNDL} & \boxed{1}\ \textbf{handle} \\ \text{INST} & \boxed{3} \end{bmatrix},
\begin{bmatrix} \text{RELN} & \textbf{\_sleep\_rel} \\ \text{HNDL} & \boxed{2}\ \textbf{handle} \\ \text{ARG1} & \boxed{3} \end{bmatrix}
$$

Figure 1: An MRS feature structure for *every big white horse sleeps*

[Copestake et al., 1999, p. 4].

(4)
$$\text{every}(x, \bigwedge(\text{big}(x), \bigwedge(\text{white}(x), \text{horse}(x))), \text{sleep(x)})$$

As they point out, this uses a three-argument notation for generalized quantifiers. They refer to the second and third arguments as the *restriction* and the *body*, respectively. We may refer to the first argument as the *variable*.

Copestake *et al.*'s first modification of conventional predicate calculus is to let $\bigwedge$ be an n-ary predicate, thus yielding (5).

(5)
$$\text{every}(x, \bigwedge(\text{big}(x), \text{white}(x), \text{horse}(x)), \text{sleep(x)})$$

Their next modification can only be shown in the graphical tree version they showed for each version starting with (4) (but which I omitted). In this version, arguments that are themselves formulas rather than conventional terms are shown as children of the formula in which they are arguments. The modification is to omit the the $\bigwedge$ symbol, and allow a group of elementary predications (their term for what are conventionally called atomic formulas, but also including quantifier clauses such as every(x) or every$(x, h1, h2)$) to be conjoined implicitly. This version is shown as (6)

(6)

every(x)

/ \

big(x), white(x), horse(x) sleep(x)

The next step is "reifying the links in the tree, by using tags ... [referred] to as *handles*" [Copestake et al., 1999, p. 5], because "we want to be able to consider the nodes of a tree independently from any parent or daughters" [*Ibid.*]. This version is shown as (7), where elementary predications (EPs) with the same handle are considered to be conjoined.

(7)

h0 : every(x)

/ \

h1 h2

h1 : big(x), h1 : white(x), h1 : horse(x) h2 : sleep(x)

The last step to the "flat" MRS representation is to eliminate the graphical tree representation in favor of a bag[2] of labelled EPs, by moving the children of a node back to their original argument positions in the EP of the node, giving (8).

(8)
$$h0\colon \text{every}(x, h1, h2), h1\colon \text{big}(x), h1\colon \text{white}(x), h1\colon \text{horse}(x), h2\colon \text{sleep(x)}$$

Finally, Figure 1 shows an MRS feature structure for (8) (based on [Copestake et al., 1999, §5]). In the feature structure, every EP is shown as a frame, the argument positions of the EP are shown as slot names (features), the EP's own handle is shown as the value of the HANDL feature, and the other arguments are shown as values of the features, either directly or *via* their handles. Bound variables are indicated only as handle arguments.

[2] It is "a *bag* rather than a set, because there might be repeated elements" [Copestake et al., 1999, p. 5].

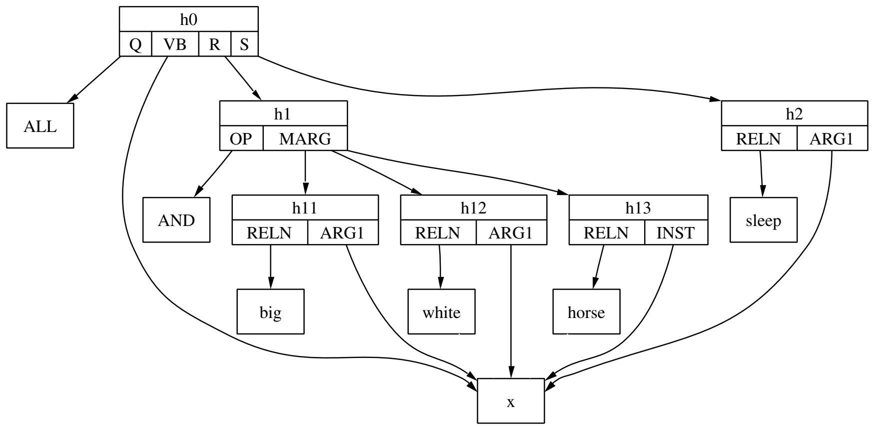

Figure 2: A MENS representation of *every big white horse sleeps*

3 SNePS

The SNePS formalism may be seen as a propositional semantic network, "a labeled directed graph in which nodes represent concepts and arcs represent nonconceptual binary relations between concepts" [Shapiro, 1979b, p. 180]. SNePS is a direct decendent of MENS [Shapiro, 1971b, Shapiro, 1971a] (See [Shapiro and Rapaport, 1992]), in which "We will refer to a conceptual entity or to the logical representation of a conceptual entity as an *item*... [Among other things,] every fact and event, every relationship that is to be a topic of discussion between the system and its human discussant will be represented by an item" [Shapiro, 1971b, p. 513]. The inclusion of facts and relationships among the conceptual entities is argued for and formalized in [Shapiro, 1993].

The choice of the nonconceptual relations to use to label the directed arcs is up to the user of MENS and SNePS, except for those that are interpreted by the system itself. Most of these interpreted relations are used to represent non-atomic formulas, and are interpreted by the SNePS inference package [Shapiro and The SNePS Implementation Group, 2002, Chapter 3]. In MENS, non-atomic formulas

> "are stored using two types of items ... We will call them quantifier clauses and connective clauses. A quantifier clause is the head of a quantified general statement and has four special system relations emanating from it. They are:
>
> (i). Q points to the quantifier
>
> (ii). VB points to the variable being bound
>
> (iii). R points to the restriction on the variable
>
> (iv). S points to the scope of the quantifier
>
> A connective clause ... has on OP system relation to the connective and one of the following sets of argument relations:
>
> (i). ...
>
> (ii). ...
>
> (iii). MARG to all the arguments if the connective is associative, commutative and idempotent (AND, OR, ...)" [Shapiro, 1971b, p. 519].

Figure 2 shows a MENS representation of (1). For clarity, the nodes are labeled as in (7), and arrows are used on the arcs instead of the original technique used to distinguish their two ends. Nodes `h0` and `h1` are quantifier and connective clauses, respectively, with relations emanating from them as specified above. Nodes `h1, h2, h11, h12`, and `h13` represent atomic propositions (EPs), and use as system relations features taken from Figure 1.

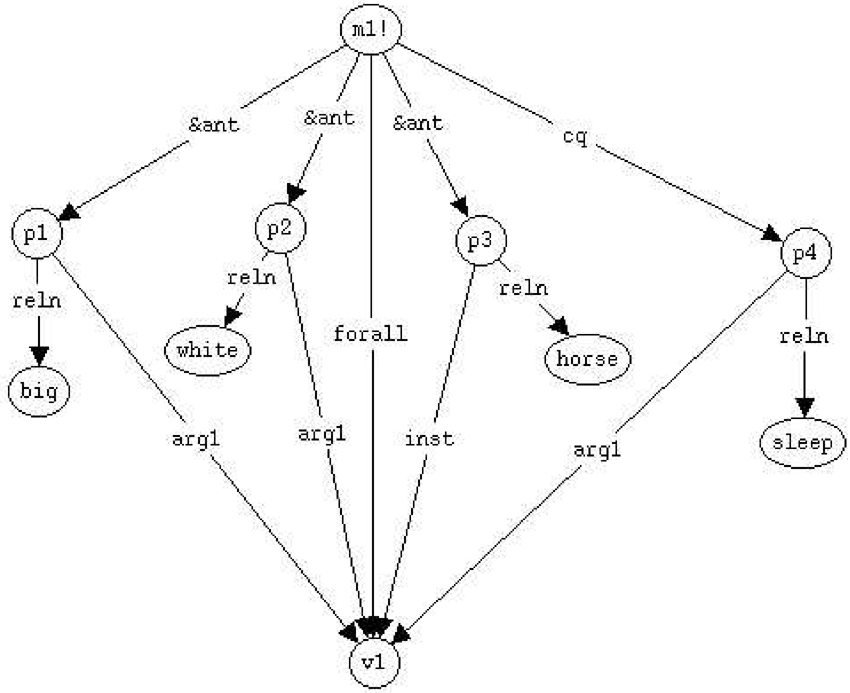

Figure 3: A SNePS 2.6 representation of *every big white horse sleeps*

Figure 3 shows a SNePS 2.6 [Shapiro and The SNePS Implementation Group, 2002] representation of sentence (1). The differences from the MENS representation are:

1. System relations are now shown as labels on arcs instead of fields inside the nodes.
2. A quantifier clause now has
    - `&ant` relations to the atomic propositions (EPs) that form the restriction, which are taken as a set;
    - a `forall` relation to the variable;
    - a `cq` relation to the body.
3. Nodes representing closed propositions are labeled m*i*, for some integer *i*, and the label may be followed by a "!" (for reasons irrelevant to this paper).
4. Nodes representing open propositions are labeled p*i*, for some integer *i*.

A SNePS node may also be shown in cableset notation [Morgado, 1986, Shapiro, 1991]:

- An atomic node (one with no arcs emanating from it) is shown as its label.
- A cable is shown as $\langle r, s \rangle$, where r is a relation and s is a set of nodes in cableset notation.
- A molecular node (one with arcs emanating from it) is shown as a set of cables optionally preceded by its label and ":", or the label may be used by itself if elsewhere specified.

The cableset notation for the nodes in Figure 3 is shown as (9).

(9)
$$\begin{array}{l}
\text{m1!:}\{\langle\text{forall}, \{\text{v1}\}\rangle \\
\quad\langle\text{\&ant}, \{\text{p1:}\{\langle\text{reln}, \{\text{big}\}\rangle\ \langle\text{arg1}, \{\text{v1}\}\rangle\} \\
\qquad\qquad \text{p2:}\{\langle\text{reln}, \{\text{white}\}\rangle\ \langle\text{arg1}, \{\text{v1}\}\rangle\} \\
\qquad\qquad \text{p3:}\{\langle\text{reln}, \{\text{horse}\}\rangle\ \langle\text{inst}, \{\text{v1}\}\rangle\}\}\rangle \\
\quad\langle\text{cq}, \{\text{p4:}\{\langle\text{reln}, \{\text{sleep}\}\rangle\ \langle\text{arg1}, \{\text{v1}\}\rangle\}\}\rangle\}
\end{array}$$

Using the fact that a molecular node may be shown as just its label as long as the node is specified elsewhere, (9) may be rewritten as (10).

(10) $m1! : \{\langle forall, \{v1\}\rangle\langle \&ant, \{p1, p2, p3\}\rangle\langle cq, \{p4\}\rangle\}$,
$p1 : \{\langle reln, \{big\}\rangle\langle arg1, \{v1\}\rangle\}, p2 : \{\langle reln, \{white\}\rangle\langle arg1, \{v1\}\rangle\}, p3 : \{\langle reln, \{horse\}\rangle\langle inst, \{v1\}\rangle\}$,
$p4 : \{\langle reln, \{sleep\}\rangle\langle arg1, \{v1\}\rangle\}$

4 Comparisons

In accord with its intended use as "a framework for computational semantics" [Copestake et al., 1999, p. 1], a significant aspect of MRS is that it can be used to represent the semantics of sentences with ambiguous quantifier scope. For example, (11)

(11) *every nephew of some fierce aunt runs*

might mean that there is one fierce aunt all of whose nephews run, or that every nephew of a fierce aunt, possibly a different fierce aunt for each nephew, runs. A single MRS representation, shown as (12), can represent (11) including the scope ambiguity.

(12) $\langle h1, \{h2\colon \text{every}(x, h3, h4), h5\colon \text{nephew}(x, y), h6\colon \text{some}(y, h7, h8), h9\colon \text{aunt}(y), h9\colon \text{fierce}(y), h10\colon \text{run}(x)\}$,
$\{h1 =_q h10, h7 =_q h9, h3 =_q h5\}\rangle$

Here, $hi =_q hj$ is a constraint saying that either $hi = hj$, or hi is the handle of some quantifier EP with an argument handle hk, and, in turn, $hk =_q hj$.

SNePS, however, in accord with its intended use "for representing the beliefs of a natural-language-using intelligent system" [Shapiro and Rapaport, 1992, p. 243], can only represent fully scoped sentences, since, at least arguably, an agent understands an ambiguous sentence as meaning one of its disambiguated readings.

An important feature of SNePS is the Uniqueness Principle, that "each concept represented in the network is represented by a unique node" [Maida and Shapiro, 1982, p. 291]. It follows that if some entity (concept) occupies several argument positions in some proposition, or any argument position in several propositions, the node representing that entity will have multiple arcs or paths of arcs to it from the proposition(s). The SNePS representation forms a network rather than a tree. For example in Figure 4, a SNePS 2.6 representation of (13), node `p2` is one of the propositions in the `&ant` argument position of `m1!` and also is in the `cq` argument position of `m1!`.

(13) *every big white horse is white*

MRS, however, is defined so that "the MRS structure forms a tree of EP conjunctions, ..., with a single root that dominates every other node, and no nodes having more than one parent" [Copestake et al., 1999, p. 8]. The problem is caused by representing conjunction by giving all conjuncts the same handle. To move *white(x)* to the body of (8) without duplicating it would lead either to (14), which says *every big white horse is big and white and a horse* or (15), which says *every big horse is white*.

(14) $h0\colon \text{every}(x, h1, h1), h1\colon \text{big}(x), h1\colon \text{white}(x), h1\colon \text{horse}(x)$

(15) $h0\colon \text{every}(x, h1, h2), h1\colon \text{big}(x), h2\colon \text{white(x)}, h1\colon \text{horse}(x)$

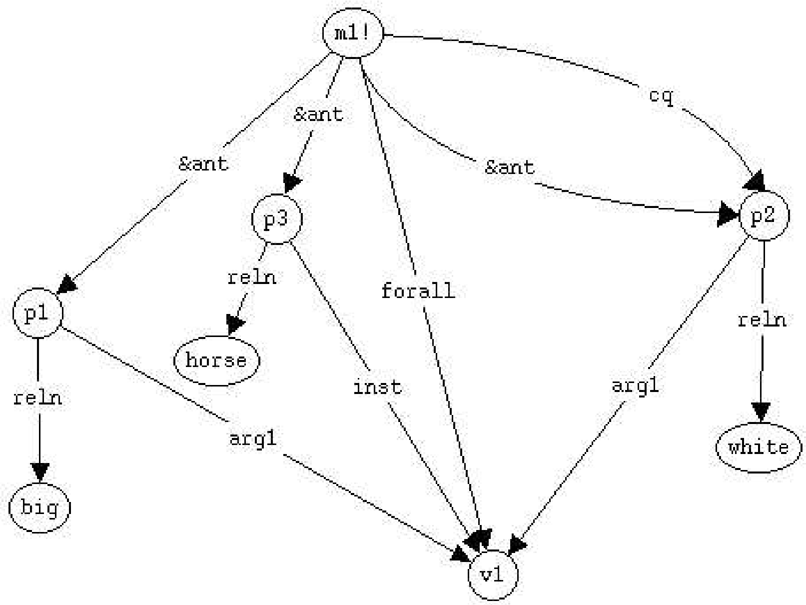

Figure 4: A SNePS 2.6 representation of *every big white horse is white*

Also in keeping with the different goals of MRS and SNePS, an MRS structure is to be seen as the semantics of a particular natural language sentence. However, regardless of the captions of Figures 2, 3 and 4, no SNePS network should be seen as representing the meaning of a sentence. Rather, an entire SNePS network represents the beliefs of an agent, and the results of that agent's understanding a new sentence is a possible modification of the network, with the new information from that sentence incorporated into the network with appropriate disambiguation and reference resolution (see [Shapiro and Rapaport, 1987, Shapiro, 1989]).

MRS does not yet have its own independent semantics (though see [Copestake et al., 2001]), but is a "meta-level language for describing semantic structures in ... predicate calculus with generalized quantifiers" [Copestake et al., 1999, p. 2]. It also does not have its own proof theory. SNePS, as a knowledge representation and reasoning system, has both a semantics and a proof theory [Shapiro, 2000].

MRS includes a notation for generalized quantifiers, although without a semantics or proof theory the import of that notation is not clear. SNePS 79 had representations and implementations of rules of inference for universal, existential, and numerical quantifiers, although the existential quantifier was never implemented in SNePS 2 [Shapiro, 1979a, Shapiro and Rapaport, 1992, Shapiro, 2000]. SNePS structures could certainly be built with translations of MRS generalized quantifiers, as discussed below, but, of course, they would also lack an implemented proof theory.

A difference between MRS and SNePS at the technical level, but whose theoretical importance is not clear[3] is that a group of EP's with the same handle, such as those with the handle of $h1$ in (8), forms a bag, while a group of SNePS nodes in the same argument position of a proposition, such as `p1, p2,` and `p3` in Figure 3, forms a set.

Except for the above differences, reified EPs in scope-resolved MRS structures may be seen as entirely equivalent to SNePS propositional nodes, with handles equivalent to the identifiers of the SNePS nodes. In the feature structure version of MRS, there is "one feature for each of the EP's argument positions" [Copestake et al., 1999, p. 15], and these correspond directly to the labels of the system relations of SNePS. Although Copestake *et al.* "assume that the EP's relation is encoded using the type of the feature structure" [Copestake et al., 1999, p.15], "we could have chosen to make the relation be the value of a feature (such as RELN) in the EP" [Copestake et al., 1999, p.16]. This relation of MRS and SNePS has been used in creating

[3]A. Copestake, personal communication

the SNePS networks shown in Figures 3 and 4.

5 Conclusion

The final conclusion of this paper, is that, again, except for the differences noted above, the significance of which should not be minimized, scope-resolved MRS and SNePS are notational variants of each other. The position of SNePS in this relationship, however, is not unique. One might say that scope-resolved MRS is a member of the class of propositional semantic networks, whose differences from each other are often subtle or technical. Besides SNePS, the class of propositional semantic networks include partioned semantic networks [Hendrix, 1979], extensional semantic networks [Janas and Schwind, 1979], conceptual graphs [Sowa, 1984], and ECO [Cercone et al., 1992].

Acknowledgments

I am grateful for the comments and help of Jean-Pierre A. Koenig and other members of the SNePS Research Group.

References

[Brachman and Levesque, 1985] Brachman, R. J. and Levesque, H. J., editors (1985). *Readings in Knowledge Representation*. Morgan Kaufmann, San Mateo, CA.

[Cercone et al., 1992] Cercone, N., Goebel, R., de Haan, J., and Schaeffer, S. (1992). The ECO family. *Computers & Mathematics with Applications*, 23(2–5):95–131. Reprinted in [**?**, pp. 95–131].

[Copestake et al., 1999] Copestake, A., Flickinger, D., Sag, I. A., and Pollard., C. (1999). Minimal recursion semantics: an introduction. Draft of September 1999. CSLI, Stanford University, Stanford, CA. Available as `http://www-csli.stanford.edu/~aac/papers/newmrs.pdf`.

[Copestake et al., 2001] Copestake, A., Lascarides, A., and Flickinger, D. (2001). An algebra for semantic construction in constraint-based grammars. In *Proceedings of the 39th Annual Meeting of the Association for Computational Linguistics*, pages 132–139.

[Hendrix, 1979] Hendrix, G. G. (1979). Encoding knowledge in partitioned networks. In Findler, N. V., editor, *Associative Networks: The Representation and Use of Knowledge by Computers*, pages 51–92. Academic Press, New York.

[Janas and Schwind, 1979] Janas, J. M. and Schwind, C. B. (1979). Extensional semantic networks: Their representation, application, and generation. In Findler, N. V., editor, *Associative Networks: The Representation and Use of Knowledge by Computers*, pages 267–302. Academic Press, New York.

[Lehmann, 1992] Lehmann, F., editor (1992). *Semantic Networks in Artificial Intelligence*. Pergamon Press, Oxford.

[Maida and Shapiro, 1982] Maida, A. S. and Shapiro, S. C. (1982). Intensional concepts in propositional semantic networks. *Cognitive Science*, 6(4):291–330. Reprinted in [**?**, pp. 170–189].

[Morgado, 1986] Morgado, E. J. M. (1986). *Semantic Networks as Abstract Data Types*. Ph.D. dissertation, Technical Report 96-19, Department of Computer Science, SUNY at Buffalo, Buffalo, NY.

[Shapiro, 1971a] Shapiro, S. C. (1971a). The MIND system: A data structure for semantic information processing. Technical Report R-837-PR, The Rand Corporation, Santa Monica, CA.

[Shapiro, 1971b] Shapiro, S. C. (1971b). A net structure for semantic information storage, deduction and retrieval. In *Proceedings of the Second International Joint Conference on Artificial Intelligence*, pages 512–523. Morgan Kaufmann, San Mateo, CA.

[Shapiro, 1979a] Shapiro, S. C. (1979a). Numerical quantifiers and their use in reasoning with negative information. In *Proceedings of the Sixth International Joint Conference on Artificial Intelligence*, pages 791–796. Morgan Kaufmann, San Mateo, CA.

[Shapiro, 1979b] Shapiro, S. C. (1979b). The SNePS semantic network processing system. In Findler, N. V., editor, *Associative Networks: The Representation and Use of Knowledge by Computers*, pages 179–203. Academic Press, New York.

[Shapiro, 1989] Shapiro, S. C. (1989). The CASSIE projects: An approach to natural language competence. In Martins, J. P. and Morgado, E. M., editors, *EPIA 89: 4th Portugese Conference on Artificial Intelligence Proceedings, Lecture Notes in Artificial Intelligence 390*, pages 362–380. Springer-Verlag, Berlin.

[Shapiro, 1991] Shapiro, S. C. (1991). Cables, paths and "subconscious" reasoning in propositional semantic networks. In Sowa, J., editor, *Principles of Semantic Networks: Explorations in the Representation of Knowledge*, pages 137–156. Morgan Kaufmann, Los Altos, CA.

[Shapiro, 1993] Shapiro, S. C. (1993). Belief spaces as sets of propositions. *Journal of Experimental and Theoretical Artificial Intelligence (JETAI)*, 5(2&3):225–235.

[Shapiro, 2000] Shapiro, S. C. (2000). SNePS: A logic for natural language understanding and commonsense reasoning. In Iwańska, Ł. and Shapiro, S. C., editors, *Natural Language Processing and Knowledge Representation: Language for Knowledge and Knowledge for Language*, pages 175–195. AAAI Press/The MIT Press, Menlo Park, CA.

[Shapiro and Rapaport, 1987] Shapiro, S. C. and Rapaport, W. J. (1987). SNePS considered as a fully intensional propositional semantic network. In Cercone, N. and McCalla, G., editors, *The Knowledge Frontier*, pages 263–315. Springer-Verlag, New York.

[Shapiro and Rapaport, 1992] Shapiro, S. C. and Rapaport, W. J. (1992). The SNePS family. *Computers & Mathematics with Applications*, 23(2–5):243–275. Reprinted in [**?**, pp. 243–275].

[Shapiro and The SNePS Implementation Group, 2002] Shapiro, S. C. and The SNePS Implementation Group (2002). *SNePS 2.6 User's Manual*. Department of Computer Science and Engineering, University at Buffalo, The State University of New York, Buffalo, NY.

[Sowa, 1984] Sowa, J. F. (1984). *Conceptual Structures: Information Processing in Mind and Machine*. Addison-Wesley, Reading, MA.