SNePS 2.8 USER'S MANUAL¹

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Contents

Li	List of Figures vii		
1	Intro	oduction	1
	1.1	General	1
	1.2	What's New	2
	1.3	System Portability	5
	1.4	Commands and Environments	6
	1.5	Types of Nodes	7
	1.6	Contexts	7
	1.7	SNePSUL Variables	8
2	SNel	PSUL Commands	9
	2.1	Context Specifiers	9
	2.2	Loading SNePS	9
	2.3	Entering and Leaving SNePS	9
	2.4	Using Auxiliary Files	10
		2.4.1 Reading/Writing Files	10
		2.4.2 Writing/Altering Source Files For Use With SNePS 2.6 and ACL 6	11
	2.5	Relations	12
		2.5.1 Reduction Inference	12
		2.5.2 Path-Based Inference	13
	2.6	Operating on Contexts	15
	2.7	Building Networks	15
	2.8	Deleting Information	16
	2.9	Functions Returning Sets of Nodes or of Unitpaths	17
	2.10	Displaying the Network	18
		Retrieving Information	19
3	SNII	P: The SNePS Inference Package	21
	3.1	Representing and Using Rules	21
		3.1.1 Connectives	21
		3.1.2 Quantifiers	23
		3.1.3 Recursion	24
	3.2	Tracing Inference	25
4	SNel	RE: The SNePS Rational Engine	27
	4.1	Acting	27
	4.2	Primitive Acts	28
	4.3	Associating Primitive Action Nodes with Their Functions	35
	4.4	Defined Acts	36

iv CONTENTS

	4.5 4.6	Goals	39 40
5	Pro	gram Interface	47
	5.1	Transformers	47
	5.2	With-SNePSUL Reader Macro	47
		5.2.1 Controlling the Evaluation of SNePSUL Forms Generated by #!	48
		5.2.2 Example Use of #!	49
	5.3	Defining New Commands	51
6	SNe	PSLOG	55
	6.1	SNePSLOG Basics	55
	6.2	SNePSLOG Syntax	55
	6.3	SNePSLOG Semantics	58
	0.0	6.3.1 Semantics of SNePSLOG Commands	58
		6.3.2 Semantics of wffNameCommands	62
		6.3.3 Semantics of wff commands	63
		6.3.4 Semantics of SNePSLOG Wffs	64
	6.4	Inference in SNePSLOG	65
	0.4	6.4.1 Rules of Inference	65
		6.4.2 Recursion	67
	6.5	SNeRE in SNePSLOG	68
	0.5	6.5.1 SNePSLOG Versions of SNeRE Constructs	68
		6.5.2 Restrictions	69
	6.6		
	6.7	The Tell-Ask Interface	70
	0.7	The Java-SNePS API	71
7	Pro	cedural Attachment	73
8	SNe	BR: The SNePS Belief Revision System	75
	8.1	Hypotheses, Contexts, and Belief Spaces	75
	8.2	Responsibilities of SNeBR	75
	8.3	Recognizing a Contradiction	75
	8.4	Identifying Possible Culprits	76
	8.5	Choosing a Culprit	76
			70
		8.5.1 Manual (Assisted) Culprit Choosing	76
		8.5.1 Manual (Assisted) Culprit Choosing	77
		8.5.2 Automatic Culprit Choosing	
	8.6	8.5.2 Automatic Culprit Choosing	77
	8.6 8.7	8.5.2 Automatic Culprit Choosing	77 79
9	8.7	8.5.2 Automatic Culprit Choosing	77 79 79
9	8.7	8.5.2 Automatic Culprit Choosing	77 79 79 79
9	8.7 SNa	8.5.2 Automatic Culprit Choosing	77 79 79 79 81 81
9	8.7 SNa 9.1	8.5.2 Automatic Culprit Choosing . 8.5.3 Prioritized Belief Revision . Disbelief Propagation . Warning About a Belief Space Known to be Contradictory. ILPS: The SNePS Natural Language Processing System Top-Level SNaLPS Functions . The Top-Level SNaLPS Loop .	77 79 79 79 81 81 82
9	8.7 SNa 9.1	8.5.2 Automatic Culprit Choosing 8.5.3 Prioritized Belief Revision Disbelief Propagation Warning About a Belief Space Known to be Contradictory. LPS: The SNePS Natural Language Processing System Top-Level SNaLPS Functions The Top-Level SNaLPS Loop 9.2.1 Input to the SNaLPS Loop	777 79 79 79 81 81 82 82
9	8.7 SNa 9.1 9.2	8.5.2 Automatic Culprit Choosing 8.5.3 Prioritized Belief Revision Disbelief Propagation Warning About a Belief Space Known to be Contradictory. LPS: The SNePS Natural Language Processing System Top-Level SNaLPS Functions The Top-Level SNaLPS Loop 9.2.1 Input to the SNaLPS Loop 9.2.2 SNaLPS Variables	777 79 79 79 81 81 82 82 82
9	8.7 SNa 9.1	8.5.2 Automatic Culprit Choosing 8.5.3 Prioritized Belief Revision Disbelief Propagation Warning About a Belief Space Known to be Contradictory. LPS: The SNePS Natural Language Processing System Top-Level SNaLPS Functions The Top-Level SNaLPS Loop 9.2.1 Input to the SNaLPS Loop 9.2.2 SNaLPS Variables Syntax and Semantics of GATN Grammars	77 79 79 79 81 81 82 82 82 82 83
9	8.7 SNa 9.1 9.2	8.5.2 Automatic Culprit Choosing 8.5.3 Prioritized Belief Revision Disbelief Propagation Warning About a Belief Space Known to be Contradictory. ILPS: The SNePS Natural Language Processing System Top-Level SNaLPS Functions The Top-Level SNaLPS Loop 9.2.1 Input to the SNaLPS Loop 9.2.2 SNaLPS Variables Syntax and Semantics of GATN Grammars 9.3.1 Arcs	77 79 79 79 81 81 82 82 82 83 84
9	8.7 SNa 9.1 9.2	8.5.2 Automatic Culprit Choosing 8.5.3 Prioritized Belief Revision Disbelief Propagation Warning About a Belief Space Known to be Contradictory. ILPS: The SNePS Natural Language Processing System Top-Level SNaLPS Functions The Top-Level SNaLPS Loop 9.2.1 Input to the SNaLPS Loop 9.2.2 SNaLPS Variables Syntax and Semantics of GATN Grammars 9.3.1 Arcs 9.3.2 Actions	777 799 799 799 811 822 822 823 844 855
9	8.7 SNa 9.1 9.2	8.5.2 Automatic Culprit Choosing 8.5.3 Prioritized Belief Revision Disbelief Propagation Warning About a Belief Space Known to be Contradictory. ILPS: The SNePS Natural Language Processing System Top-Level SNaLPS Functions The Top-Level SNaLPS Loop 9.2.1 Input to the SNaLPS Loop 9.2.2 SNaLPS Variables Syntax and Semantics of GATN Grammars 9.3.1 Arcs 9.3.2 Actions 9.3.3 Preactions	777 79 79 79 81 81 82 82 83 84 85 86
9	8.7 SNa 9.1 9.2	8.5.2 Automatic Culprit Choosing 8.5.3 Prioritized Belief Revision Disbelief Propagation Warning About a Belief Space Known to be Contradictory. ILPS: The SNePS Natural Language Processing System Top-Level SNaLPS Functions The Top-Level SNaLPS Loop 9.2.1 Input to the SNaLPS Loop 9.2.2 SNaLPS Variables Syntax and Semantics of GATN Grammars 9.3.1 Arcs 9.3.2 Actions	777 799 799 799 811 822 822 823 844 855

CONTENTS

		9.3.6	Tests	37
		9.3.7	Terminal Symbols	37
	9.4	Morpho	ological Analysis and Synthesis	38
		9.4.1	Syntax of Lexicon Files	38
		9.4.2		39
				90
	9.5			91
		_		91
				97
10	SNoI	DS oc o I	Database Management System 10	03
10			as a Relational Database	
	10.1			
			S Commence of the commence of)3
)6
	10.0)6
)7
	10.3	Databas	se Functions	98
Un	iversi)9
	1.	Definiti	ons)9
	2.	Source	Code License	10
		2.1.	The Initial Developer Grant	10
		2.2.	Contributor Grant	11
	3.		ition Obligations	11
		3.1.		11
				11
			Description of Modifications	
				12
			1 🗸	12
				12
				13
	4.			13
	5.		, 13	13
				13
	6.			
				13
			Effect of New Versions	
			Derivative Works	
	_			14
	7.		AIMER OF WARRANTY	
	8.			14
	9.			15
	10.			15
	11.			15
	12.		·	16
	13.	Multipl	e-licensed code	16
	Exhi	bit A - U	Iniversity at Buffalo Public License	17
Ind	lex		11	18

vi CONTENTS

List of Figures

4.1	Three ways of associating action nodes with action functions. M3, M4, and M5 are act nodes, with action nodes SAY, M1, and B1 respectively	37
9.1	Graphical version of the example GATN	92
9.2	SNePS network after running the example	102
10.1	Fragment of SNePS network for the Supplier-Part-Project Database	104

viii LIST OF FIGURES

Chapter 1

Introduction

1.1 General

SNePS is a logic-, frame- and network-based knowledge representation, reasoning and acting system. The name "SNePS" originally was an acronym of "The Semantic Network Processing System,".

A semantic network, roughly speaking, is a labeled directed graph in which nodes represent entities, are labels represent binary relations, and an arc labeled R going from node n to node m represents the fact that the entity represented by n bears the relation represented by R to the entity represented by m. The set of nodes in the network-based view of SNePS is coextensive with the set of terms in the logic-based view of SNePS.

SNePS is called a *propositional* semantic network because every proposition represented in the network is represented by a node, not by an arc. Relations represented by arcs may be thought of as part of the syntactic structure of the node they emanate from. In the frame-based view of SNePS, every non-atomic term is a frame whose slots are the arcs of the network-based view, and the fillers of the slots are the nodes those arcs point to. Whenever information is added to the network, it is added in the form of a frame—a node with arcs (slots) emanating from it to other nodes (the slot fillers).

Each entity represented in the network is represented by a unique node/term. This is enforced by SNePS 2 in that whenever the user specifies a node to be added to the network that would look exactly like one already there, in the sense of having the same set of arcs (slots) going from it to the same set of other nodes (fillers), SNePS 2 retrieves the old one instead of building the new one.

SNePSUL, the SNePS User Language, is the lowest-level command language for using SNePS. It is a Lispish language, usually entered by the user at the top-level SNePSUL read-eval-print loop, but it can also be called from Lisp code or from GATN arcs. The SNePSUL chapters of this manual follow the style of Guy Steele's COMMON LISP book, and assume that the reader is familiar with that book and with COMMON LISP. The organization of this manual has been retained from the time when SNePSUL was the standard way to interact with SNePS. However, the use of SNePSLOG is now recommended.

SNIP (Chapter 3), the SNePS Inference Package, interprets certain nodes as representing reasoning rules, called *deduction rules*. SNIP supports a variety of specially designed propositional connectives and quantifiers, and performs a kind of combined forward/backward inference called *bi-directional* inference.

SNePSLOG (Chapter 6) is a logic programming interface to SNePS, and provides direct access in a predicate logic notation to almost all the facilities provided by SNePSUL. It is now the recommended way to interact with SNePS.

SNeBR (Chapter 8), the SNePS Belief Revision system, recognizes when a contradiction exists in the network, identifies possible culprits, and performs disbelief propagation. It eliminates contradictions automatically in some cases, and helps the user to do so in the general case.

SNaLPS (Chapter 9), the SNePS Natural Language Processing System, consists of a morphological analyzer, a morphological synthesizer, and a Generalized Augmented Transition Network (GATN) Grammar

interpreter/compiler. Using these facilities, one can write natural language (and other) interfaces for SNePS.

1.2 What's New

- **SNePS 2** differs in several respects from its predecessor, now called SNePS-79, mostly because of theoretical decisions that were made since SNePS-79 was implemented.
- **SNePS 2.1** differs from SNePS 2.0 by including belief revision as a standard feature.
- **SNePS 2.3** includes some techniques for making node-based inference faster, and includes SNeRE (Chapter 4).
- **SNePS 2.4** includes: a change in how contexts and sets of contexts are implemented that should improve the speed of the system; deducetrue, deducefalse, deducewh, and deducewhnot (Section 2.11); the Tell-Ask interface (Section 6.6); and SNePSLOG Mode 3, which allows SNePSLOG syntax to be used to build SNePS networks using as flexible a choice of relations as may be done using SNePSUL syntax (Section 6.3.1).
- SNePS 2.5 includes: a change in how nodes are implemented and how sets of nodes are ordered that should improve the speed of the system; activate (Section 2.7); the SNePSLOG perform command (Section 6.3.1); a revised semantics for when-do, with the old when-do now renamed whenever-do (Section 4.1).
- SNePS 2.6 code has been modified so that it can be loaded into Allegro CL version 6.X and used with its default case mode of "case-sensitive-lower" (all predefined COMMON LISP symbols have lower-case names, and the case of characters typed into the LISP listener is left as originally typed) or loaded into earlier versions of Allegro CL, or other versions of COMMON LISP that use "case-insensitive-upper" mode (all predefined COMMON LISP symbols have upper-case names, and the case of characters typed into the LISP listener is changed to upper case). Some SNePS symbols may look different in the two different modes, such as M1 vs. m1. The output for the examples in this manual was generated from earlier versions of SNePS, so it is typically in uppercase (except where special formatting was used to generate the output).
- SNePS 2.6.1 Previously, the functions + and & took only two arguments. Now they can take zero or more. The function show has been added. The SNeRE mental action believe now checks for and disbelieves more contradictory beliefs than before. The SNePSLOG commands activate, activate!, ask, askifnot, askwh, and askwhnot have been added. There have been several other bug fixes. Documentation of the SNePSLOG command list-wffs has been added to the manual; it was previously available. Section 6.5, "SNeRE in SNePSLOG," has been added to this manual, some material describing features that were never implemented in SNePS 2 has been deleted from the manual, and there have been other editorial changes. A complete description of what's new in SNePS 2.6.1 is at http://www.cse.buffalo.edu/sneps/Downloads/releaseNotes261.html.
- SNePS 2.7 The SNePSLOG parser has been completely rewritten, improved, and made more robust. The chapter on SNePSLOG has been completely rewritten. SNePSLOG is now the preferred interface to SNePS. Normal output from SNePSLOG now shows the wffName. The SNePSLOG command define-terms has been added, and define-frame given an optional string argument, which, when used together, provide a facility for giving a natural language gloss of SNePS terms. The tell-ask interface has been improved, and its documentation has been moved to §6.6. Previously askwh and askwhnot would return a simple list of terms, even if the query had more than one free variable. Now, they return a list of substitutions even if the query has only one free variable. (Similarly for the SNePSUL commands deducewh and deducewhnot). A Java-SNePS API has been added

1.2. WHAT'S NEW

to give Java programs access to SNePS via the tell-ask interface, see §6.7. The final cases in which the inference system could get into infinite recursion have been eliminated—see §3.1.3 and §6.4.2. The SNePSUL intext command and the new SNePSLOG load command silently load files. Previously, one could not have a node named with a string the Lisp reader could not handle, such as "#", and node-to-lisp-object did not handle nodes with names like "5 pounds". Both these problems are now fixed. A node's name can now be any Lisp number, string, or symbol, and node-to-lisp-object is able to handle it. Previously, inference and acting tracing was on by default, now they are off by default. Previously, in add-to-context, only the wffs in termSet that had already been introduced to the KB as hypotheses were added as hypotheses of the context. Now, all the wffs listed as to be added are asserted into the context. An procedural attachment facility has been added. It is described in Chapter 7. The guarded acts in snif and sniterate can now take sets of conditions and sets of acts. snif and each loop of sniterate still performs one act one of whose guards holds. The mental acts adopt and unadopt are now available for adopting and unadopting policies, and should be used for those purposes instead of believe and disbelieve. A chapter on SNeBR (Chapter 8) has been added. XGinseng has been eliminated because it was implemented in Garnet, which has not been maintained, and was difficult to use. SNePS networks may now be displayed by show, either via: dot; or JUNG and JIMI, depending on the installers choice (both require separate downloading). If both versions are installed, the user may choose which one to use by setting the value of the global variable cl-user: *use-gui-show*.

There have been other bug fixes, improvements to speed, and improvements to user messages. A complete description of what's new in SNePS 2.7 is at http://www.cse.buffalo.edu/sneps/Downloads/releaseNotes262.html.

SNePS 2.7.1

SNePS

The command (beliefs-about $\{nodeset\}$ * context-specifier) has been added. It returns a set of all the nodes, asserted in the given context, that dominate the nodes described by the nodesets.

SNePSLOG

- 1. In SNePS 2.7.0, an attempt to use the &=>-Introduction rule caused a Lisp error. That has been fixed, and &=>-Introduction works in SNePS 2.7.1.
- 2. In SNePS 2.7.0, the v=>-Introduction rule did not work. Moreover, the v=>-Introduction rule, as documented in the *SNePS 2.7 User's Manual* is incorrect. In SnePS 2.7.1, the v=>-Introduction rule works as long as there is only a single antecedent. The v=>-Introduction rule for multiple antecedents is not yet implemented.
- 3. In certain circumstances, activate and activate! caused an error. That has been fixed.
- 4. The snepslogCommand beliefs—about pTermSet [.] has been added. It returns a set of all the asserted wffs that dominate the terms described by pTermSet.
- 5. The function (nl-tell *string*) has been added. It may be called from the top-level Lisp listener in the snepslog package. Assuming that a lexicon and GATN grammar have been loaded, nl-tell passes *string* to the parser, and returns a string containing whatever the parser returns.
- 6. Linebreaks may occur in input to the SNePSLOG reader, but if the input looks like it might end prematurely, the character "\" (without the quotation marks) may be placed before the end-of-line to indicate that the input continues on the next line. For example, the wff p() => q(). may end just before the => if and only if the line with p() ends with a "\". This is also very useful in a define-frame command if you want to put the documentation string on the next line. Previously, this was an undocumented feature, but "-" was used instead of "\", which caused problems if a linebreak occurred in a path just after a converse relation, like subclass-.

7. SNePSLOG now allows the use of and, or, nand, nor, xor, and iff, each followed by a termSet. For example, all (x) (Entity (x) \Rightarrow xor{Animal (x), Vegetable (x), Mineral(x)).

SNIP

- 1. In certain circumstances, activate caused an error. That has been fixed.
- 2. See the note about &=>-Introduction under SNePSLOG, above.
- 3. See the note about v=>-Introduction under SNePSLOG, above.

SNeBR

Restriction sets in node supports and in contexts have been eliminated in favor of a global set of minimal nogoods. A minimal nogood is a set of hypotheses that is known to be inconsistent, such that no subset of it is known to be inconsistent.

SNeRE

1. Consider the following knowledge base:

```
: andor(1,1){aheadIs(wall), aheadIs(corridor)}.
 wff3!: andor(1,1){aheadIs(corridor),aheadIs(wall)}
: andor(1,1) {holding(person), holding(noOne)}.
 wff6!: andor(1,1) {holding(noOne),holding(person)}
: holding(noOne).
 wff5!: holding(noOne)
: aheadIs(corridor).
 wff2!: aheadIs(corridor)
```

Now, ask a question whose answer looks like a state constraint.

```
: (holding(noOne) and aheadIs(wall))?
 wff9!: andor(0,1){holding(noOne),aheadIs(wall)}
             {<der, {wff2, wff3}, {}>}
```

If we now do

: perform believe(aheadIs(wall))

In SNePS 2.7.0, holding (noone) would no longer be asserted, even though wff9 will no longer be asserted once wff2 is disbelieved. This is fixed in SNePS 2.7.1.

SNePS 2.7.1 also includes some additional improvements.

SNePS 2.8

SNePS

- 1. SNePS can now be compiled by Armed Bear Common Lisp (ABCL), which produces Java bytecode.
- 2. Nodes whose identifiers are not readable by Lisp as symbols (e.g. numbers and identifiers with spaces in them) are now printed with escape brackets.
- 3. When typing nodes, a user may use the escape character and escape brackets.

SNePSLOG

1. In version 2.7.1, if an atomic symbol (individual constant, function symbol, etc.) began with a substring that matched any of the following: and, or, nand, nor, xor, iff, andor, thresh, or nexists it would be misparsed, or an error would result. For example, instanceOf (north, direction) would be parsed as

instanceOf (~th, direction). That has now been fixed. However, now none of these connectives may immediately be followed by a blank, but must immediately be followed either by "{" or "(", whichever is appropriate.

2. tell has been given optional format arguments. So instead of evaluating

```
(tell (format nil "\simA(\simA)." 'Dog 'Fido)) you may now do (tell "\simA(\simA)." 'Dog 'Fido)
```

- 3. The character "!" is now optional at the end of a wffname. If the "!" is not the terminal character of the wffNameCommand (that is, is not the final character of the SNePSLOG command), it will be ignored.
- 4. The macro (foreachsub *variables subs* &body *forms*) has been added to the tell/ask interface. For each substitution in *subs*, foreachsub evaluates the forms in *forms* with the variables in *variables* taking on the values specified by that substitution. This is particularly useful for processing the values returned by (askwh ...) or by (tell "askwh...").
- 5. Individual constants whose identifiers are not readable by Lisp as symbols (e.g. numbers and strings with spaces in them) are now printed with escape brackets.
- 6. The SNePSLOG parser can read individual constants containing the escape character and escape brackets.
- 7. The show command now displays molecular nodes using their wff names.
- 8. The attempt to assert a negated, universally quantified andor or thresh, such as ~ (all(x)(B(a,x) <=> x)) previously caused an error. This has been fixed.

SNIP

1. Before if p (a) were an hypothesis of the current context, and p (a) |-r (a), then p (a) =>r (a) would not be inferred because SNIP didn't think that p (a) was introduced in the hypothetical context. That has now been fixed.

SNePS 2.8 also includes some additional improvements.

1.3 System Portability

SNePS 2 is written in ANSI COMMON LISP (two exceptions are noted in the following paragraph). Hence, every proper implementation of ANSI COMMON LISP should be sufficient to run SNePS 2. In particular, SNePS 2 should run successfully using the following:

- UNIX operating system
- LINUX operating system
- Apple/Macintosh operating system
- Microsoft Windows operating system
- Allegro Common Lisp (Franz Inc.)
- Lucid (or Sun) Common Lisp
- GNU CLISP
- CMU Common Lisp
- Macintosh Common Lisp

- Harlequin LispWorks
- Armed Bear Common Lisp (ABCL)

The JUNG/JIMI version of show, and the Java-SNePS API require some facilities peculiar to Franz's ACL. For installations that do not have that compiler, an executable file is available for downloading from http://www.cse.buffalo.edu/sneps/Downloads/. That executable provides all the features of SNePS 2.8. Every other feature of SNePS 2.8 is written in ANSI Common Lisp.

1.4 Commands and Environments

A SNePSUL *command* is classified according to its role either as a *procedure* or as a *function*. A *procedure* is a command that performs some action but returns nothing, using the COMMON LISP (values) function. A *function* is a command that always returns some value, possibly after having performed some action as a side effect. A function is implemented directly as a Lisp function.

A command is also classified according to the environment(s) in which it may legally appear. A procedure can be entered only at the top level of SNePSUL. A function, however, may appear in many different environments. The five environments are:

- 1. The top level of SNePS 2
- 2. A relation-set position embedded in a command
- 3. A node-set position in build
- 4. A node-set position in find or findassert
- 5. A *node-set* position in any of the other commands

Finally, a command can be classified according to the relation between its position and the position of its arguments in the input line.

Most commands have an arbitrary number of arguments. They are called *prefix commands*, because they can only be entered using Cambridge prefix notation:

(prefix-command argument . . . argument).

Some two-argument commands can be entered in infix position, and so are called *infix commands*. When an infix command is used in infix position, SNePS rearranges the input line to transform the form into a prefix form. Precedence is always from left to right. An infix command can be used as

(infix-command argument argument)

or as

argument infix-command argument

with no parentheses.

Since SNePS always remembers the result of the last top-level function, an infix command can also be used as

infix-command argument

in which case SNePS recalls the result of the last function and makes it the first argument for the infix command before rearranging the form to the prefix notation.

Similarly, some one-argument commands can be entered in postfix position and therefore are called *postfix commands*. A postfix command can be used as

1.5. TYPES OF NODES 7

(postfix-command argument)

or as

argument postfix-command

with no parentheses, or just as

postfix-command

in which case the result of the last function is used as argument.

Another kind of one-argument command, called *macro commands*, have one-character names and are used as

macro-command argument

with no parentheses, and preferably with no space between the command and the argument. Before passing it to the evaluator, the SNePS reader expands this form to a standard Cambridge prefix form.

1.5 Types of Nodes

There are four types of nodes in the SNePS network: base, variable, molecular, and pattern.

Base nodes are distinguished by having no arcs emanating from them. A base node may be created by the user's referring to it by name in the proper context. In such a case, the name of a base node can be any Lisp symbol. If a number is used, the node's name is a symbol whose symbol-name is a string of the characters that makes up the number. If a string is used, the node's name is the symbol whose symbol-name is that string. A base node may also be created using the # macro command, in which case the node's name is $\mathbb{B}x$, where x is some integer. A base node is assumed to represent some entity—individual, object, class, property, etc. It is assumed that no two base nodes represent the same, identical entity. One may, of course, introduce an equality or equivalence relation and the rules for using them. In that case the introduced equality or equivalence relation is weaker than the identity relation just referred to. This is the most basic way that SNePS assumes an intensional representation—no two nodes are intensionally identical even though they might be extensionally equivalent.

Variable nodes also have no arcs emanating from them, but represent arbitrary individuals or propositions, in much the same way that logical variables do. Variable nodes are created using the \$ macro command. The name of a variable node is $\forall x$, where x is some number.

Molecular nodes and pattern nodes have arcs emanating from them. Molecular nodes may represent propositions, including rules, or "structured individuals." A molecular node that represents a proposition may be *asserted* or *unasserted*. Pattern nodes represent arbitrary propositions or arbitrary structured individuals, and are similar to open sentences in predicate logic. Pattern nodes and unasserted molecular nodes are created by the build function. Asserted molecular nodes are created by the assert function. An unasserted molecular node may be asserted by using the ! postfix command. The name of a pattern node is Px, where x is a number. The name of an asserted molecular node is Px, where x is a number. The name of an asserted molecular node is Px, where x is a number. The name of an asserted molecular node is Px, where x is a number. The name of an asserted molecular node is Px, where x is a number. The name of an asserted molecular node is Px.

Once any node is created, it may be referred to by its name. It is not necessary to include the! suffix to refer to an asserted molecular node. In fact, its use is always interpreted as a call to the! command, which will assert the node even if it wasn't previously asserted.

1.6 Contexts

A *context* is a structure with three components: 1) a set of hypotheses; 2) a set of names; 3) a kinconsistent flag. The set of hypotheses is a set of nodes which are the assumptions of the context. The set of hypotheses

is the determining component of the context in the sense that no two contexts will have the same set of hypotheses. The set of names is a set of symbols each of which functions as a name of this context. The kinconsistent flag is True if this set of hypotheses is known to be inconsistent.

A context name intensionally defines a context, which is extensionally defined by its set of hypotheses. The SNePSUL user always refers to contexts by name, and may add assertions to, or remove assertions from a context. Actually, such changes do not change contexts (extensionally defined), but change the context that the name refers to. The system takes care of such details, and the SNePSUL user may normally think of a context name as always referring to the same context.

The user is always working in a particular context, called the *current context*. The current context for a particular SNePSUL command may be specified by an optional argument to the command. Otherwise, all commands are carried out with the *default context* as current context. By default, this context is named default-defaultct.

In SNePS 2.3 and later versions, a proposition node is not simply asserted or unasserted—it is either asserted or unasserted in each context. The ! suffix will be printed with a node's name when that node is asserted in the current context. An *hypothesis* is a node that was asserted by the user using assert or !, rather than being asserted only because it was derived during inference. An hypothesis is always an hypothesis of one or more context; it may also be asserted in other contexts, and might be unasserted in still other contexts.

Every node is said to be in zero or more contexts. A node n is in a context c in any of the following cases:

- n is one of the hypotheses that define c.
- n has been derived from a set of assumptions that is a subset of the set of hypotheses of c.
- n is dominated by a node in c.

1.7 SNePSUL Variables

SNePSUL, the SNePS User Language, has variables which are entirely distinct from SNePS variable nodes. The value of a SNePSUL variable is always a set of objects, nil if nothing else. A SNePSUL variable may be given a value with the ?, #, or \$ macro commands, or with the = infix command. The value of a SNePSUL variable is obtained by using the * macro command. SNePSUL variables created and maintained by SNePS are:

nodes assertions patterns varnodes relations variables	The set of all nodes in the network. The set of all nodes in the network that were asserted by the user. The set of all pattern nodes in the network. The set of variable nodes in the network. The set of defined arc labels. The set of SNePSUL variables.
defaultct	The name of the default context.
commands	The set of SNePSUL commands.
topcommands	The set of commands valid at SNePS top-level.
bnscommands	The set of commands valid at node-set positions in build-type commands.
fnscommands	The set of commands valid at node-set positions in find-type commands.
rscommands	The set of commands valid at relation-set positions in commands.
nscommands	The set of commands valid at at node-set positions in other commands.

Chapter 2

SNePSUL Commands

2.1 Context Specifiers

In a number of commands described in this chapter, part of the syntax is *context-specifier*, and the semantics mentions the context specified by *context-specifier*. In every such case, the possible syntax of *context-specifier*, and what context is specified by each possibility is:

omit If the context-specifier is omitted, the specified context is the default context (the value of *defaultct).

:context The context specified is the default context (the value of *defaultct).

:context context-name The context specified is that named context-name, which must be a symbol.

: context nodeset context-name The context specified is that named context-name, which is initialized to be the context whose set of hypotheses is the value of nodeset, which must be a SNePSUL expression that evaluates to a set of proposition nodes.

: context all-hyps The context specified is the one whose set of hypotheses is the set of all hypotheses—all assertions entered by the user.

2.2 Loading SNePS

Ask whoever maintains SNePS at your site how to load SNePS. Typically, this involves running COMMON LISP, and then loading SNePS.

2.3 Entering and Leaving SNePS

The commands in this section move the user between the SNePSUL evaluator and the COMMON LISP evaluator. Although every SNePSUL function is a COMMON LISP function, the SNePSUL loop provides certain special facilities, so it is best to be in the proper top-level loop for extended work.

(sneps)

Lisp function that brings the user into the SNePS read-eval-print loop.

(lisp)

SNePSUL function that returns the user to the Lisp evaluator.

^

SNePSUL command that causes the next form to be evaluated by Lisp.

^ ^

SNePSUL command that puts the user into an embedded Lisp read-eval-print loop until the next occurrence of the form ^^, whereupon the user is returned to the SNePSUL loop.

2.4 Using Auxiliary Files

2.4.1 Reading/Writing Files

The commands in this section provide for the use of auxiliary files for the storage of networks or of sequences of commands.

```
(outnet file)
```

Stores the current network on the *file* in a special SNePS format. The syntax for the file specification is machine dependent.

```
(innet file)
```

If *file* was created by a call to outnet, the current network will be initialized to the one stored on *file*. **Note:** innet rewrites the entire network and several SNePSUL variables, so it cannot be used to combine several networks. An error message is issued if *file* is not in the appropriate format.

```
(intext file)
```

Reads a sequence of SNePSUL commands from the *file* and executes them, without doing any printing. All assertions specified by the file are done as one batch at the end of the loading process, and they are all asserted into the current context.

```
(demo &optional file pause)
```

Reads from the *file*, echoes it, and behaves as if that stream had been typed directly into SNePS. (You can even call demo recursively.) If *file* is a string of length 1 that does not name a file or is a symbol whose name is a string of length 1, then a menu of possible demonstrations is printed, and the user may pick one of them. If *file* is an integer, and the menu lists at least that many demonstrations, the one with that number will be run. If *pause* is given, its value may be any of t, b, bv, a, av, or n. If *pause* is t, b, or bv, SNePS will pause before each input command is read. If *pause* is a, or av, SNePS will pause just after each input is read, but before it is executed. If *pause* is omitted or is n, SNePS will not pause at all. If *pause* is av or bv, a pause message will be printed when the pause occurs; otherwise the message will not be printed. If both arguments are omitted, the menu will be shown, and *pause* defaults to av. When SNePS pauses, the following commands are available:

h,?	Print this help message
1,^	Enter Lisp read/eval/print loop
s,%	Enter SNePS toplevel loop,
0,:	Enter SNePSLOG
С	Continue without pausing
р	Set pause control
q	Quit this demo
a	Quit all demos
any other key	Continue the demo

All these commands are also available inside demo files. This enables you, for example, to turn on pausing at some interesting point in your demo and to run quickly through all the setup stuff, or turn pausing off, or enter a Lisp top-level somewhere or whatever. Here are the commands that allow you to do that. (These are not SNePSUL commands, but they are specially interpreted demo control commands. The DC stands for demo control):

```
dc-pause-help
dc-lisp
dc-sneps
dc-snepslog
dc-no-pause
dc-set-pause ...takes an argument, e.g., (dc-set-pause av)
dc-read-pause
dc-quit
dc-quit-all
```

All commands except dc-set-pause are atomic. They can be given in upper or lower case, and they are available in SNePSLOG and the parser as well. However, the way the parser reads input they have to be followed by a "." if sentences are terminated that way, and dc-set-pause has to be given as DC-SET-PAUSE bv. because the function parser::atn-read-sentence collects tokens into a list automatically.

2.4.2 Writing/Altering Source Files For Use With SNePS 2.6 and ACL 6

ACL 6 vs. Other Versions of Lisp

In any LISP other than ACL 6, SNePS 2.6 should run like SNePS 2.5, with no noticable differences. As described in Section 1.2, ACL 6 differs in the case of its pre-defined symbols and input. This means that some source files that ran successfully in SNePS 2.5 might not run successfully in SNePS 2.6 using ACL 6.

To insure portability across LISP systems, any new source files should be written per the advice in the SNeRG Technical Note 30, "Notes on Converting to ACL 6", by Stuart C. Shapiro, which can be found as Reference Number 2001-5 at:

```
http://www.cse.buffalo.edu/sneps/Bibliography/
```

This will be referred to from now on as SNeRG TN 30.

If a programmer wishes to load a *pre-existing* SNePS input file using SNePS 2.6 running in ACL 6, they have two options¹:

- Make sure the file (and any other files involved) are ACL 6 compatible refer to the SNeRG TN 30 described above
- 2. Wrap the main file (i.e. the single file which contains SNePS input and/or loads any other input files) in the code shown below.

Code Wrap For ACL 6 and SNePS 2.6 Compatibility

If a pre-existing source file does not run successfully using ACL 6 and SNePS 2.6 and altering *all* the files involved is not desirable, the following code can be wrapped around the main input file — this should result in a successful run. Some minor code changes might be necessary (per SNeRG TN 30), but any inconsistency of case (e.g. NIL vs. nil) in SNePS code or in the input lines will be adjusted by the wrap. The code wrap is intended to be read at the top LISP level.

Insert the following code at the **beginning** of the main source file:

¹NOTE: These suggestions work if the pre-existing file runs successfully using SNePS 2.5. They are especially important if the run includes loading altered SNePS code. Older files might need further adjusting.

```
;;; adjustment for ACL6
#+(and allegro-version>= (version>= 6 0))
(sneps:adjust-for-acl6 :before)
```

Insert the following code at the **end** of the main source file:

```
;;; adjustment for ACL6
#+(and allegro-version>= (version>= 6 0))
(sneps:adjust-for-acl6 :after)
```

2.5 Relations

By relation in this manual, we mean any relation used to label network arcs. Therefore "relation" and "arc label" are used interchangeably. Whenever an arc labelled R goes from node x to node y, SNePS considers an arc labelled R— to go from y to x. Relation names ending in the character $\# \setminus -$ are reserved for this "reverse arc" or "converse relation" labelling. Therefore no relation name may end with a $\# \setminus -$. The term relation always refers to a normal, "forward" arc label. We will use the term unitpath to mean either a relation name or the name of its converse relation.

```
(define \{relation\}^*)
```

Defines each *relation* to be an arc label. The name of a relation must not end in the character #\-. Each *relation* is added to the SNePSUL variable relations. An informative message is given if a relation has previously been defined. Initially, SNePS has a set of relations defined as if the following had been executed:

```
(define forall exists pevb
    min max thresh threshmax emin emax etot
    ant &ant cq dcq arg default
    if when vars suchthat do
    condition then else
    action act plan goal precondition effect
    object1 object2)
```

For uses of the predefined relations, see Sections 3.1.1, "Connectives," 3.1.2, "Quantifiers," and Chapter 4, "SNeRE."

```
(undefine {relation}*)
```

Undefines each *relation*. If any *relation* is being used in the current network, the arcs are not removed from the network structure, but they do become undefined. undefine is most useful in correcting typographical errors in calls to define.

2.5.1 Reduction Inference

An asserted node with a certain set of arcs emanating from it implies another node with a subset of those arcs. Using this implication to derive new nodes is called "reduction inference," and is implemented and used by deduce. For example,

```
* (describe (assert member (snoopy rover) class (dog animal)))
(M1! (CLASS ANIMAL DOG) (MEMBER ROVER SNOOPY))
(M1!)
   CPU time : 0.08
* (describe (deduce member snoopy class dog))
```

2.5. RELATIONS

```
(M2! (CLASS DOG) (MEMBER SNOOPY))
(M2!)
CPU time : 0.05

* (describe (assert agent john act gives object book-1 recipient mary))
(M3! (ACT GIVES) (AGENT JOHN) (OBJECT BOOK-1) (RECIPIENT MARY))
(M3!)
CPU time : 0.08

* (describe (deduce agent john act gives object book-1))
(M4! (ACT GIVES) (AGENT JOHN) (OBJECT BOOK-1))
(M4!)
CPU time : 0.05
```

Warning: According to Shapiro, 1991,² if you build a node that is implied via reduction inference by an already asserted node, the new node will automatically be asserted. This is not implemented in the current version of SNePS 2.

2.5.2 Path-Based Inference

Path-based inference allows an arc between two nodes to be inferred from the presence of a path of arcs between them. The various versions of find as well as deduce will use any path-based inference rules that have been declared.

```
(define-path {relation path}*)
Declares the path-based inference rule,
```

```
\forall (n_1, n_2) path(n_1, n_2) \Rightarrow relation(n_1, n_2).
```

I.e., if a path of arcs specified by path is in the network going from node n_1 to node n_2 , then the single arc labelled by relation is inferred as going from node n_1 to node n_2 . See the following subsection for the syntax of path. No relation may have more than one path-based inference rule for it at any time. This is not a restriction, since a disjunction of paths is also a path. Warning: A path-based inference rule will not be expanded recursively. I.e., no relation (or converse relation) in the path will be expanded even if a path-based inference rule has been declared for it. A subtle implication of this is that it is almost always proper to do (define-path relation (or relation new-path)), so that explicit occurrences of relation will be recognized.

```
(undefine-path \{relation path\}^*)
Deletes the given path-based inference rules.
```

Syntax and Semantics of Paths

A *unitpath* is simply a single arc followed in the forward or the reverse direction. A *path* can be a sequence of unitpaths, or a more complicated way of getting from one node to another. Keep in mind the distinctions between *relation*, *unitpath*, and *path*, since there are places where it matters.

```
unitpath ::= relation
Any single arc relation is also a unitpath.
```

²S. C. Shapiro, Cables, paths and "subconscious" reasoning in propositional semantic networks. In J. Sowa, Ed. *Principles of Semantic Networks: Explorations in the Representation of Knowledge*. Morgan Kaufmann, San Mateo, CA, 1991, 137–156.

unitpath ::= relation-If R is a relation from node x to node y, then R- is a unitpath from y to x. *path* ::= unitpath Any single arc, either forward or backward, is a path. path ::= (converse path) If P is a path from node x to node y, then (converse P) is a path from y to x. $path ::= (compose \{path \mid !\}^*)$ If x_1, \ldots, x_n are nodes and P_i is a path from x_i to x_{i+1} , then (compose P_1 ... P_{n-1}) is a path from x_1 to x_n . Note: If the symbol! appears between P_{i-1} and P_i , then x_i must be asserted in the current context. Examples: 1) After doing (build member socrates class man), the path (compose member- class) goes from socrates to man, but the path (compose member- ! class) doesn't. However, after doing (assert member socrates class man), both paths exist. 2) (find (compose!) *nodes) is a way to find all nodes that are asserted in the current context. path ::= (kstar path)If path P composed with itself zero or more times is a path from node x to node y, then (kstar P) is a path from x to y. path ::= (kplus path) If path P composed with itself one or more times is a path from node x to node y, then (kplus P) is a path from x to y. $path ::= (or {path})^*$ If P_1 is a path from node x to node y or P_2 is a path from x to y or ... or P_n is a path from x to y, then (or P_1 P_2 ... P_n) is a path from x to y. $path ::= (and \{path\}^*)$ If P_1 is a path from node x to node y and P_2 is a path from x to y and ... and P_n is a path from x to y, then (and P_1 P_2 ... P_n) is a path from x to y. path ::= (not path)If there is no path P from node x to node y, then (not P) is a path from x to y. Warning: Belief revision will not work for nodes that were inferred via path-based inference that used not arcs. path ::= (relative-complement path path) If P is a path from node x to node y and there is no path Q from x to y, then (relative-complement P(Q) is a path from x to y. Warning: Belief revision will not work for nodes that were inferred via path-based inference that used relative-complement arcs. path ::= (irreflexive-restrict path) If P is a path from node x to node y, and $x \neq y$, then (irreflexive-restrict P) is a path from x

path ::= (exception path path)

If P is a path from node x to node y and there is no path Q from x to y with length less than or equal to the length of P, then (exception P Q) is a path from x to y.

```
path ::= (domain-restrict (path node) path)
If P is a path from node x to node y and Q is a path from x to node z, then (domain-restrict (Q z) P) is a path from x to y.

path ::= (range-restrict path (path node))
If P is a path from node x to node y and Q is a path from y to node z, then (range-restrict P (Q z)) is a path from x to y.

path ::= (path^*)
If P_1 is not one of the symbols and, converse, compose, exception, kstar, kplus, not, or, relative-complement, irreflexive-restrict, domain-restrict, or range-restrict, then (P_1 \ldots P_{n-1}) is equivalent to (compose P_1 \ldots P_{n-1}).
```

2.6 Operating on Contexts

```
(set-context nodeset[symbol])
```

Creates a context whose hypothesis set is *nodeset* (which cannot contain pattern nodes). If symbol is given, that is made the name of the context; otherwise *defaultct becomes the name of the context.

```
(set-default-context context-name)
```

Changes the default context (the value of *defaultct) to be *context-name*.

```
(add-to-context nodeset[context-name])
```

Adds the nodes of *nodeset* into the hypothesis set of the context, *context-name*. If *context-name* is omitted, adds the hypotheses to *defaultct.

```
(remove-from-context nodeset[context-name])
```

Removes the nodes of *nodeset* from the hypothesis set of the context, *context-name*. If *context-name* is omitted, removes the hypotheses from *defaultct.

```
(list-context-names )
```

Prints a list of all valid context names.

```
(describe-context [context-name])
```

Prints the hypothesis set, all names, and the value of the kinconsistent flag of the context named *context-name*. If *context-name* is omitted, prints the information on *defaultct.

```
(list-hypotheses [context-name])
```

Returns the hypothesis set of the context named *context-name*. If *context-name* is omitted, returns the hypothesis set of *defaultct.

2.7 Building Networks

The commands of this section add information to the network, either in the form of a node, a node and some arcs, or an assertion tag. It is not possible to add just an arc to the network. Isolated nodes cannot be added to the network, so the commands # and \$ can only be used within the lexical context of a build, assert, or add.

We will use the term *wire* to mean a labelled arc and the node it points to. So a molecular node has a set of wires coming out of it.

```
(adopt {relation nodeset}*)
```

Builds and adopts the specified policy. (See Chapter 4.) As of SNePS 2.7.1 the SNePSUL command adopt is just a synonym of assert (see below).

```
(build {relation nodeset}*)
(assert {relation nodeset}* context-specifier)
(add {relation nodeset}* context-specifier)
```

Puts a node in the network with an arc labelled *relation* to each node in the following *nodeset*, and returns a singleton set containing the built node. The new node is added to the value of the SNePSUL variable nodes. If this new node would look exactly like an already existing node, i.e., would have exactly the same set of wires emanating from it, then no node is built, but a singleton set containing the extant node is returned. build creates an unasserted node. assert is just like build, but creates the node as an asserted node (an hypothesis), and adds it to the hypothesis set of the context specified by *context-specifier*. add is just like assert, but, in addition, triggers forward inference. **Note:** where *relation* is specified in the syntax, neither a converse relation nor a non-unit path is allowed. build is not a top-level SNePSUL command in SNePS 2.

```
(activate {nodeset}* context-specifier)
```

Finds all the nodes that dominate the nodes in *nodeset* (including the nodes in *nodeset* themselves), and that are asserted in the context specified by *context-specifier*, and triggers forward inference on them.

```
(!node context-specifier)
```

A postfix command that asserts *node* in the context specified by *context-specifier*, and returns a singleton set containing *node*.

```
(assert ... context-specifier) is equivalent to (! (build ...) context-specifier). (build ...)! is equivalent to (assert ...).
```

#symbol

A macro command that creates a new base node, assigns a singleton set containing the new node as the value of the SNePSUL variable *symbol*, and returns that set. This may not be used at the top-level SNePSUL loop, since that would create an isolated node. (Note: The # macro is smart enough to guess whether you want to create a base node or whether the standard COMMON LISP dispatching macro is intended. This means that the #! "with-snepsul" syntax is available at the SNePS top level, as well as in GATN grammars, etc., and that other common uses, such as #' for functions, are available too.)

\$symbol

A macro command that creates a new variable node, assigns a singleton set containing the new node as the value of the SNePSUL variable *symbol*, and returns that set. This may not be used at the top-level SNePSUL loop, since that would create an isolated node.

2.8 Deleting Information

The commands of this section delete information from the network, and are mainly intended for use after mistakes or when debugging.

```
(erase {nodeset}*)
(silent-erase{nodeset}*)
```

Removes all nodes in all *nodesets* from the network along with any nodes that become isolated in the process (that is, all nodes which no longer have any arcs connected to them), and all nodes that were dominated by nodes it erases that are not also dominated by other nodes. Refuses to delete nodes that have arcs coming into them. silent-erase is like erase, but does no printing.

```
(resetnet [reset-relations?])
```

Reinitializes the network to the state in which no nodes have been built. If *reset-relations?* is t, the set of SNePS relations is reset to the pre-defined ones; If *reset-relations?* is nil (default), the defines relations and declared path-based inference rules remain as is.

```
(clear-infer-all )
```

Deletes any information placed in the "active connection graph" version of the network by SNIP. I.e., all deduction rules are returned to their unactivated state as if no inference had yet been performed. It is recommended that clear-infer be used instead. See below.

```
(clear-infer )
```

Like clear-infer-all, but retains some pointers from rules to their instances that makes node-based inference faster. clear-infer is recommended over clear-infer-all unless there is a specific reason to use the latter.

2.9 Functions Returning Sets of Nodes or of Unitpaths

The functions described in this section neither add to nor delete from the network. Rather, they compute and return sets either of nodes or of unitpaths.

```
(\{node\}^*)
```

A list of nodes at the top level of the SNePSUL loop, or in a context where a node set is required, is treated as an expression whose value is a set of the nodes in the list.

```
(★ symbol)
```

A macro command function which returns the set of nodes in the value of the SNePSUL variable symbol.

```
(list-nodes [context-name])
```

Returns the set of all nodes that are in the context named *context-name*. If *context-name* is omitted, returns the set of all nodes that are in *defaultct.

```
( S-expression)
```

The set of nodes obtained by evaluating the Lisp *S-expression*.

```
(& nodeset*)
```

Infix function that returns the intersection of the *nodesets*.

```
(+ nodeset*)
```

Infix function that returns the union of the *nodesets*.

```
(- nodeset nodeset)
```

Infix function that returns the set of nodes in the first *nodeset* but not in the second *nodeset*.

```
(= nodeset symbol)
```

Infix function that assigns the *nodeset* to be the value of the SNePSUL variable *symbol*.

```
(_ nodeset unitpathset)
```

Infix function that returns the set of those nodes in the *nodeset* which do not have any of the unitpaths in the *unitpathset* emanating from them.

```
(> unitpathset symbol)
```

Infix function that assigns the *unitpathset* to be the value of the SNePSUL variable *symbol*.

```
(\{unitpath\}^*)
```

A list of unitpaths in a context where a unitpathset is required, is treated as an expression whose value is a set of the unitpaths in the list.

2.10 Displaying the Network

The commands in this section are various ways of printing, or otherwise displaying, the information in the network.

```
(dump {nodeset}* context-specifier)
```

Prints the name of each node in the *nodeset* that is in the context specified by *context-specifier*, along with all arcs going from it or into it, and the nodes that each arc points to or from. For a complete dump of the network, execute (dump *nodes :context all-hyps).

```
(describe {nodeset}* context-specifier)
```

Similar to dump, but: describes only the molecular and pattern nodes in the *nodesets*; describes all molecular and pattern nodes dominated by nodes it describes; describes any node at most once—the second and later times, only the node's name is printed.

```
(full-describe {nodeset}* context-specifier)
```

Similar to describe, but also shows the context(s) each node is asserted in. Unlike dump and describe, full-describe can describe nodes that are not in any context.

```
(show nodeset*)
(show nodeset* &key :file :format)
```

Displays the network connected to the nodes in the <code>nodesets</code> in a graphical form. The first version uses <code>JUNG</code> and <code>JIMI</code>, and produces a graph that can be manipulated by hand. The second version saves a specification of the network in the DOT language to a file, from which an output file is produced via the <code>dot</code> compiler. The <code>file</code> keyword argument specifies the base name of the <code>.dot</code> and output files (by default a temporary file). The <code>format</code> keyword specifies the format of the output file, which must be either <code>:gif</code> (default) or <code>:ps</code>. The output file is displayed via either <code>xv</code> or <code>gv</code>. <code>dot</code> produces a static figure. Only one of these versions of <code>show</code> is available; which one, depends on the SNePS installer. Neither <code>dot</code>, <code>JUNG</code>, nor <code>JIMI</code> are part of the SNePS distribution. <code>dot</code> is part of the Graphviz package which can be downloaded from <code>http://graphviz.org/</code>). <code>JUNG</code> and it's associated packages, <code>Xerxes</code>, <code>Colt</code>, and <code>JakartaCommon Collections</code>, can be downloaded from <code>http://jung.sourceforge.net/</code>. <code>JIMI</code> can be downloaded from <code>http://java.sun.com/products/jimi/</code>. The <code>JUNG/JIMI</code> version of <code>show</code> requires either that <code>SNePS</code> is being run under <code>Franz</code>'s <code>ACL</code>, or that one of the executable packages of <code>SNePS</code> is being used. The <code>SNePS</code> installer may install either the <code>dot</code> version or the <code>JUNG/JIMI</code> version, both, or neither. If both are installed, the user can dynamically pick the version to be used by setting the global variable <code>cl-user:*use-gui-show*/indexuse-gui-show*/indexuse-gui-show* to t for the</code>

JUNG/JIMI version, or to nil for the dot version.

```
(surface {nodeset}*)
```

Generates a description of each node in each *nodeset* using the currently loaded GATN grammar starting in state σ .

2.11 Retrieving Information

The functions in this section find nodes in the network, and return them.

```
(find {path nodeset}* context-specifier)
(findassert {path nodeset}* context-specifier)
(findconstant {path nodeset}* context-specifier)
(findbase {path nodeset}* context-specifier)
(findvariable {path nodeset}* context-specifier)
(findpattern {path nodeset}* context-specifier)
```

Returns the set of nodes in the specified context such that each node in the set has every specified *path* going from it to at least one node in the accompanying *nodeset*. (find class (man greek)) will find nodes with a class arc to either man or greek, whereas (find class man class greek) will find nodes with class arcs to both man and greek. find returns all appropriate nodes in the specified context; findassert returns only asserted nodes; findconstant returns only base or molecular nodes; findbase returns only base nodes; findvariable returns only variable nodes; findpattern returns only pattern nodes.

```
(beliefs-about nodeset* context-specifier)
```

Returns a set of all the nodes, asserted in the given context, that dominate the nodes described by the nodesets.

?symbol

May be used in any find function in place of a *nodeset*, to stand for "any node." The scope of these symbols is the outermost find function and all embedded find functions. After return of the outermost find function, *symbol* will be a SNePSUL variable whose value will be the set of nodes it matched.

```
(deduce [numb] {relation nodeset}* context-specifier)
(deducetrue [numb] {relation nodeset}* context-specifier)
(deducefalse [numb] {relation nodeset}* context-specifier)
(deducewh [numb] {relation nodeset}* context-specifier)
(deducewhnot [numb] {relation nodeset}* context-specifier)
```

Like findassert, but uses SNIP to back-chain on any deduction rules in the specified context. deducetrue returns all inferred nodes that satisfy the specification. deducefalse returns all inferred nodes that satisfy the negation of the specification. deducer nodes that satisfy the specification, and inferred nodes that satisfy the negation of the specification. deducewh returns a list of substitutions for the free variables in the specification indicating the set of nodes that would be returned by deducetrue. deducewhnot returns a list of substitutions for the free variables in the specification indicating the set of nodes that would be returned by deducefalse. Note that only relations may appear in the specification, not any other unitpaths or paths. Neither may ?symbol variables appear in the specification. The numb argument is optional. If numb is omitted, then deduce continues until no more answers can be derived. If numb is a single integer, it specifies the total number of answers requested. If numb is zero, no inference is done—only answers already in the network are returned. Otherwise, numb must be a list of two numbers, (npos nneg), and deduction terminates after at least npos positive and nneg negative instances are derived.

Chapter 3

SNIP: The SNePS Inference Package

Automatic inference may be triggered using the function deduce (see Section 2.11), a generalization of find, or the function add (see Section 2.7), a generalization of assert. In order for these to accomplish anything, deduction rules must exist in the network. A deduction rule is a network structure dominated by a rule node. A rule node represents a logical formula of molecular nodes, using connectives and quantifiers.

3.1 Representing and Using Rules

Rules are placed in the network with the assert and add commands (see Section 2.7). The arcs needed to build rules are predefined by SNePS.

3.1.1 Connectives

Connectives are the means by which simple propositions are compounded to make more complicated ones. In classical logic, this compounding is accomplished by use of standard connectives such as & (AND) and \vee (OR). A number of disadvantages exist in using standard connectives in SNePS, primarily because of their binary nature and the size of the network needed to store representations with standard connectives. To avoid these problems, SNePS uses non-standard connectives. These non-standard connectives are as adequate as standard connectives, but they take arbitrarily large sets of arguments and express common modes of human reason simply. The non-standard connectives are: and-entailment, or-entailment, numerical entailment, andor, and thresh. An explanation of each connective follows.

And-Entailment

 $\{A_1, \ldots, A_n\} \Leftrightarrow \{C_1, \ldots, C_m\}$ means that the conjunction of the antecedents implies the conjunction of the consequents. An and-entailment rule is built with the SNePSUL command:

(assert & ant
$$(A_1, \ldots, A_n)$$

cq (C_1, \ldots, C_m))

Use An asserted and-entailment may be used in forward or backward inference to conclude that one or more of its consequents is to be asserted.

Or-Entailment

 $\{A_1, \ldots, A_n\} \lor \Rightarrow \{C_1, \ldots, C_m\}$ means that the disjunction of the antecedents implies the conjunction of the consequents. An or-entailment rule is built with the SNePSUL command:

(assert ant
$$(A_1, \ldots, A_n)$$

 $\operatorname{cq} (C_1, \ldots, C_m)$)

Note: or-entailment is more efficient than and-entailment, so if there is only one antecedent, use ant rather than &ant.

Use An asserted or-entailment may be used in forward or backward inference to conclude that one or more of its consequents is to be asserted.

Numerical Entailment

 $\{A_1, \ldots, A_n\}$ $i \Rightarrow \{C_1, \ldots, C_m\}$ means that the conjunction of any i of the antecedents implies the conjunction of the consequents. In other words, if i or more of the antecedents are true, then all of the consequents are true. A numerical-entailment rule is built with the SNePSUL command:

```
(assert thresh i &ant (A_1, \ldots, A_n) cq (C_1, \ldots, C_m))
```

Use An asserted numerical-entailment may be used in forward or backward inference to conclude that one or more of its consequents is to be asserted.

AndOr

 $\bigvee_{i=1}^{j} \{P_1, \dots, P_n\}$ means that at least i and at most j of the n propositions are true. An andor rule is built with the SNePSUL command:

```
(assert min i max j arg (P_1, \ldots, P_n))
```

The following special cases of andor are representations of standard connectives: i = j = n is AND; i = j = 0 is a generalization of NOR; and i = j = 1 is a generalization of EXCLUSIVE OR.

Use An asserted and-or may be used in forward or backward inference to conclude that one or more of its arguments is to be asserted, or that the negation of one or more of its arguments is to be asserted. An unasserted and-or for which i = j =number of arguments will be asserted during backward inference if all its arguments are asserted.

Thresh

 $\Theta_i^j\{P_1,\ldots,P_n\}$ means that either fewer than i or more than j of the n propositions are true. j may be omitted, in which case it defaults to n-1. A thresh rule is built with the SNePSUL command:

(assert thresh
$$i$$
 threshmax j arg (P_1, \ldots, P_n))

If i = 1 and j is omitted, the thresh is a generalization of equivalence.

Use An asserted thresh may be used in forward or backward inference to conclude that one or more of its arguments is to be asserted, or that the negation of one or more of its arguments is to be asserted.

3.1.2 Quantifiers

Quantifiers permit the use of variables in deduction rules. The relations forall and exists, are predefined quantifier relations. They are used to point to variable nodes, indicating for which values of the variable node the rule holds. forall and exists represent universal and existential quantifiers, respectively. SNePS 2 uses restricted quantification, which means that every quantified expression must have a restriction as well as a scope.

The Universal Quantifier

 $\forall (x_1,\ldots,x_n)\{R_1(x_1),\ldots,R_n(x_n)\}:\{P_1(x_1,\ldots,x_n),\ldots,P_m(x_1,\ldots,x_n)\}$ means that for every substitution, $\sigma=\{t_1/x_1,\ldots,t_n/x_n\}$ for which the following conditions hold

- t_i satisfies the restriction $R_i, 1 \le i \le n$
- $t_i \neq t_j$ whenever $i \neq j$
- t_i does not already occur in the rule, $1 \le i \le n$

 $P_i(x_1, \ldots, x_n)\sigma$, $1 \le i \le m$ is true. There may be fewer restrictions than variables if some restriction contains more than one variable free, as long as every variable occurs in at least one restriction. A universally quantified rule is built with the SNePSUL command:

```
(assert forall (x_1, ..., x_n)
& ant (R_1(x_1), ..., R_n(x_n))
cq (P_1(x_1, ..., x_n), ..., P_m(x_1, ..., x_n)))
```

The first occurrence of a variable must be preceded by the \$ macro, and subsequent occurrences must be preceded by the * macro.

If there is only one restriction, ant should be used instead of &ant.

Use Universal instantiation has been implemented, but not universal generalization.

The Existential Quantifier

The existential quantifier has not yet been implemented in SNePS 2. However, it is not needed, because Skolem functions can be used instead.

Whenever an existentially quantified variable y is bound within the scope of universally quantified variables x_1, \ldots, x_n, y can be replaced by the Skolem function $f(x_1, \ldots, x_n)$, as long as f is used nowhere else. The existential quantifier that binds y can then be eliminated.

For example to represent the formula

```
\forall x (Man(x) \Rightarrow \exists y (Woman(y) \land Loves(x,y)))
```

you might do

The Numerical Quantifier

 $_k \exists_i^j(x_1,\ldots,x_n) \{R_1(x_1),\ldots,R_n(x_n)\} P(x_1,\ldots,x_n)$ means that of the k substitutions, $\sigma = \{t_1/x_1,\ldots,t_n/x_n\}$ for which the following conditions hold

- t_i satisfies the restriction R_i , $1 \le i \le n$
- $t_i \neq t_j$ whenever $i \neq j$
- t_i does not already occur in the rule, $1 \le i \le n$

between i and j of them also make $P(x_1, \ldots, x_n)\sigma$ true. There may be fewer restrictions than variables if some restriction contains more than one variable free, as long as every variable occurs in at least one restriction.

A numerically quantified rule is built with the SNePSUL command:

```
(assert emin i emax j etot k pevb (x_1, \ldots, x_n) &ant (R_1(x_1), \ldots, R_n(x_n)) cq P(x_1, \ldots, x_n)
```

The first occurrence of a variable must be preceded by the \$ macro, and subsequent occurrences must be preceded by the * macro.

The Uniqueness Principle for Variables

Currently, the Uniqueness Principle, that every entity represented in the network is represented by a unique node, is not enforced by SNePS for variables. Therefore, it is advised that the Uniqueness Principle for variables be followed by the SNePSUL user as a matter of style. This should be done as follows. Every restriction R used in a restricted quantifier should have a series of variables, x_1^R, x_2^R, \ldots Every rule that uses R once should use x_1^R as its variable. A rule that uses the restriction R more than once should use x_1^R in the first use of R, x_2^R in the second use of R, etc. This can be done by using the \$ macro to create each variable node the first time the restriction occurs, and the * macro on all subsequent occasions, including subsequent rules. For example, the two rules "Every dog is a pet" and "Every dog hates every cat" might be entered as follows, assuming that the restrictions Dog(x) and Cat(y) have not previously been used in the network:

3.1.3 Recursion

Recursive rules such as

may be used without causing an infinite loop.

Infinite loops caused by backward chaining on rules such as

are terminated under the control of the global parameters *depthCutoffBack* and *depthCutoffForward*, respectively. If a subgoal is generated during backward chaining whose depth, in terms of arc paths, exceeds *depthCutoffBack*, it is not pursued. Also, if a result is generated during forward chaining whose depth, in terms of arc paths, exceeds *depthCutoffForward*, it is not pursued. *depthCutoffBack* and *depthCutoffForward* are each set by default to 10, and can be changed independently via setf.

3.2 Tracing Inference

The variable and functions described in this section let you turn on and off various ways of tracing SNIP's activities. Following these traces requires various degrees of knowledge of how SNIP is implemented. Implementation details, however, are beyond the scope of this manual.

```
*infertrace*
```

This variable controls an inference trace that is readily understandable by the SNePSUL user. When this inference tracing is enabled, a message is printed whenever: a deduce is done; a sub-goal is generated during backward inference; a sub-goal matches a stored assertion; a rule fires. The message indicates which of these is happening, and prints one or more proposition nodes or instantiated pattern nodes. The possible values of *infertrace* are:

nil This inference tracing is disabled.

t Default. Nodes are printed using describe.

surface Nodes are printed using surface. (See Section 2.10.)

```
(ev-trace process-name*)
```

A SNePSUL top-level command for tracing MULTI processes. If called with one or more arguments (unquoted), it turns on event tracing of those named processes. If called with no arguments, and some processes are being traced, it returns a list of processes being traced. If called with no arguments, and no processes are being traced, it turns on event tracing of all processes. Following these traces requires a knowledge of how SNIP is implemented. They are intended for implementing and debugging new features of SNIP.

```
(unev-trace process-name*)
```

A SNePSUL top-level command for turning off event tracing of MULTI processes. If called with one or more arguments (unquoted), it turns off event tracing of those named processes. If called with no arguments, it turns off all event tracing.

```
(in-trace process-name*)
```

A SNePSUL top-level command for tracing MULTI processes. If called with one or more arguments (unquoted), it turns on initiation tracing of those named processes. If called with no arguments, and some

processes are being traced, it returns a list of processes being traced. If called with no arguments, and no processes are being traced, it turns on initiation tracing of all processes. Following these traces requires a knowledge of how SNIP is implemented. They are intended for implementing and debugging new features of SNIP.

```
(unin-trace process-name*)
```

A SNePSUL top-level command for turning off initiation tracing of MULTI processes. If called with one or more arguments (unquoted), it turns off initiation tracing of those named processes. If called with no arguments, it turns off all initiation tracing.

```
(multi::print-regs process)
```

Function that prints the registers of the individual *process* and their current values. Assumes a knowledge of how SNIP is implemented. Intended for implementing and debugging new features of SNIP.

```
snip::send-request
snip::send-reports
```

These two functions may profitably be traced by someone familiar with how SNIP is implemented. Tracing snip::send-request will show the requests being sent, the nodes they are sent to, and the queue of pending processes. Tracing snip::send-reports will show the reports being sent, the channels they are being sent through, and the reports coming out of the channels.

Chapter 4

SNeRE: The SNePS Rational Engine

4.1 Acting

SNeRE, The SNePS Rational Engine, is a package that allows for the smooth incorporation of acting into SNePS-based agents. SNeRE recognizes a node with an action arc to be a special kind of node called an *act node*. Since an act usually consists of an action and one or more objects of the action, an act node usually has additional arcs pointing to the nodes that represent the objects of the action. These additional arcs are generally labelled object1...objectn, where n is the number of objects the action is performed on. The relations object1 and object2 are pre-defined. If more objecti are needed, the user must define them.

There are three ways to initiate acting. The first is by use of the SNePSUL command perform.

```
(perform actnode context-specifier)
```

Causes the *actnode* to be performed. Deductions and assertions triggered during the performance will be made in the specified context.

```
* (perform (build action say object1 "Hello" object2 "there")) Hello there CPU time : 0.15
```

(How the say action is defined will be explained below.)

The other two ways to initiate action are during inference:

1. If a node of the form $M: \{\langle whenever, p \rangle, \langle do, a \rangle \}$ or of the form $M: \{\langle when, p \rangle, \langle do, a \rangle \}$, where p is a proposition node and a is an act node, is in the network, and forward inference causes M to be adopted and p to be asserted, then a is performed.

The difference between when and whenever is that if the proposition p is disbelieved (see below) and readded, the act controlled by whenever will be performed again, but the act controlled by when won't.

2. If an adopted node of the form M!: $\{\langle if, p \rangle, \langle do, a \rangle\}$, where p is a proposition node and a is an act node, is in the network, and SNIP back-chains into p, then a will be performed.

4.2 Primitive Acts

The only acts that can actually be performed are *primitive acts*—those whose actions are *primitive actions*, which, themselves, are associated with *primitive action functions*. Several primitive action functions are predefined. The user may define additional ones by using the function define-primaction:

```
(define-primaction action (relation_1 ... relation_n) \{form\}^*)
This defines action to be a LISP function of arity n, whose list of lambda variables is (relation_1 ... relation_n), and whose body is \{form\}^*. When the function is called, each lambda variable will be bound to a node set. For example the action function for say, used in the examples above, was defined by:
```

4.2. PRIMITIVE ACTS 29

The predefined primitive action functions, and what they do are:

Functions for Mental acts

```
(believe object1), where object1 must be a proposition node. object1 is asserted, and forward inference is done with it, but if a contradiction results, then prioritized belief revision is performed (see §8.5.3).
```

```
* (assert min 0 max 0
              arg (build agent Stu state is location here))
   (M2!)
    CPU time : 0.09
   * (describe (deduce agent $who state is location here))
   (M2! (MIN 0) (MAX 0) (ARG (M1 (AGENT STU) (LOCATION HERE) (STATE IS))))
   (M2!)
    CPU time : 0.18
   * (perform (build action believe
                      object1 (build agent Stu state is location here)))
    CPU time : 0.06
   * (describe (deduce agent $who state is location here))
   (M1! (AGENT STU) (LOCATION HERE) (STATE IS))
   (M1!)
    CPU time : 0.06
(disbelieve object1), where object1 must be a proposition node.
   object1 is removed-from-context.
   * (describe (deduce agent $who state is location here))
   (M1! (AGENT STU) (LOCATION HERE) (STATE IS))
   (M1!)
    CPU time : 0.07
   * (perform (build action disbelieve
                      object1 (build agent Stu state is location here)))
    CPU time : 0.03
   * (describe (deduce agent $who state is location here))
    CPU time : 0.07
(adopt object1), where object1 must be a policy node (when-do, whenever-do, or if-do).
   The policy is adopted, and an attempt is made to use it.
```

(unadopt object1), where object1 must be a policy node (when-do, whenever-do, or

Functions for Control acts

if-do). The policy is no longer adopted.

(do-all *object1*), where *object1* is a set of one or more act nodes, causes all of the act nodes to be performed in some arbitrary order.

```
* (perform
       (build action do-all
               object1 ((build action say object1 "Hello" object2 "Bill")
                         (build action say object1 "Hello" object2 "Stu"))))
   Hello Stu
   Hello Bill
    CPU time : 0.32
(do-one object1), where object1 is a set of one or more act nodes, causes an arbitrary one
   of the act nodes to be performed. If the variable snip::*choose-randomly* is T (default),
   do-one will choose its act randomly; if it is NIL, it will choose deterministicly, which might be
   desirable during debugging. (See page 45 for clarification.)
   * (perform
       (build action do-one
               object1 ((build action say object1 "Hello" object2 "Bill")
                         (build action say object1 "Hello" object2 "Stu"))))
   Hello Bill
     CPU time : 0.15
(snsequence object1 ...objectn), where object1 ...objectn are act nodes, causes
   object1 ...objectn to be performed in that order.
   * (perform
       (build action snsequence
               object1 (build action say object1 "Hello" object2 "Bill")
               object2 (build action say object1 "Hello" object2 "Stu")
               object3 (build action say object1 "Hello" object2 "Oscar")))
   Hello Bill
   Hello Stu
   Hello Oscar
    CPU time : 0.31
   Warning: In the current version of SNePS, if two objects of snsequence are the same act,
   it will only be done once, so instead of
    (build action snsequence
           object1 a1 ...
           objecti ai objecti+1 ai+1 ...
           objectj ai ... objectn an)
   one should use
    (build action snsequence
           object1 a1 ...
           objecti ai
           objecti+1 (build action snsequence object1 ai+1 ...
                                                   objectj-i ai ... objectn-i an)
```

(snif object1), where object1 is a set of guarded acts, and a guarded act is either of the form $\{\langle condition, p \rangle, \langle then, a \rangle\}$, or of the form $\{\langle clse, elseact \rangle\}$, where p is a proposition node and a and elseact are act nodes. snif chooses at random one of the guarded acts whose condition is asserted, and performs its act. If none of the conditions is asserted and the else clause is present, the elseact is performed.

4.2. PRIMITIVE ACTS 31

```
* (describe (assert agent "Stu" state is location here))
(M6! (AGENT Stu) (LOCATION HERE) (STATE IS))
(M6!)
CPU time : 0.02
* (describe (deduce agent $who state is location here))
(M6! (AGENT Stu) (LOCATION HERE) (STATE IS))
(M6!)
CPU time : 0.17
* (perform
    (build action snif
           object1
           ((build condition
                   (build agent "Bill" state is location here)
                    (build action say object1 "Hello" object2 "Bill"))
            (build condition
                   (build agent "Stu" state is location here)
                   (build action say object1 "Hello" object2 "Stu"))
            (build else
                   (build action say
                          object1 "No one's" object2 "here!")))))
Hello Stu
CPU time : 0.50
* (perform (build action disbelieve object1 M6))
CPU time : 0.02
* (perform
   (build action snif
          object1
          ((build condition
                  (build agent "Bill" state is location here)
                  (build action say object1 "Hello" object2 "Bill"))
           (build condition
                  (build agent "Stu" state is location here)
                  then
                  (build action say object1 "Hello" object2 "Stu"))
           (build else
                  (build action say
                         object1 "No one's" object2 "here!")))))
No one's here!
 CPU time : 0.27
```

(sniterate *object1*), where *object1* is a set of guarded acts. If at least one of the guard's conditions is asserted, sniterate performs the act of a random one of the guards whose condition is asserted, and then performs the entire sniterate again. When none of the guards has an asserted condition, if there is an *elseact* it is performed, and the sniterate terminates.

```
* (describe (deduce agent $who state is location here))
(M1! (AGENT Bill) (LOCATION HERE) (STATE IS))
(M2! (AGENT Stu) (LOCATION HERE) (STATE IS))
(M1! M2!)
CPU time : 0.10
* (perform
   (build
     action sniterate
     object1 ((build
                condition (build agent "Bill" state is location here)
                (build action snsequence
                       object1
                        (build action say object1 "Hello" object2 "Bill")
                       object2
                        (build
                         action disbelieve
                         object1
                          (build agent "Bill" state is location here))))
              (build
                condition (build agent "Stu" state is location here)
                (build action snsequence
                       object1
                        (build action say object1 "Hello" object2 "Stu")
                       object2
                       (build
                         action disbelieve
                         object1
                          (build agent "Stu" state is location here))))
              (build
                else (build action say
                            object1 "That's" object2 "all")))))
Hello Stu
Hello Bill
That's all
CPU time : 0.83
```

(withall vars suchthat do [else]), where vars is a set of variable nodes, suchthat is a proposition with vars free, do is an act node with vars free, and else is an act node with no free variables. withall finds all substitutions for vars for which suchthat is asserted, and performs all those instances of do. If there are no such substitutions and else is present, it is done.

4.2. PRIMITIVE ACTS 33

```
(describe (deduce agent $who state is location here))
    CPU time : 0.08
   * (perform
       (build action withall
              suchthat (build agent *x state is location here)
                        (build action say object1 "Hello" object2 *x)
                        (build action say object1 "No one's" object2 "here")))
              else
   No one's here.
    CPU time : 0.34
   * (describe (assert agent "Stu" state is location here))
   (M3! (AGENT Stu) (LOCATION HERE) (STATE IS))
   (M3!)
    CPU time : 0.08
   * (describe (assert agent "Bill" state is location here))
   (M4! (AGENT Bill) (LOCATION HERE) (STATE IS))
   (M4!)
    CPU time : 0.07
   * (perform
       (build action
                      withall
              suchthat (build agent *x state is location here)
                       (build action say object1 "Hello" object2 *x)
                        (build action say object1 "No one's" object2 "here")))
              else
   Hello Bill.
   Hello Stu.
    CPU time : 0.54
(withsome vars suchthat do [else]), where vars is a set of variable nodes, suchthat
   is a proposition with vars free, do is an act node with vars free, and else is an act node with
   no free variables. with some finds some substitution for vars for which suchthat is as-
   serted, and performs that instance of do. If there is no such substitution, and else is present, it
   is performed.
   * (describe (deduce agent $who state is location here))
   (M3! (AGENT Stu) (LOCATION HERE) (STATE IS))
   (M4! (AGENT Bill) (LOCATION HERE) (STATE IS))
   (M3! M4!)
    CPU time : 0.19
   * (perform
       (build action
                        withsome
              vars
                        $x
              suchthat (build agent *x state is location here)
                        (build action say object1 "Hello" object2 *x)
              else
                        (build action say object1 "No one's" object2 "here")))
   Hello Stu.
    CPU time: 0.43
```

```
* (perform
   (build action disbelieve
          object1 (build agent "Stu" state is location here)))
 CPU time : 0.03
* (perform
   (build action disbelieve
          object1 (build agent "Bill" state is location here)))
 CPU time : 0.03
* (perform
   (build action withsome
          vars
                   $x
          suchthat (build agent *x state is location here)
                  (build action say object1 "Hello" object2 *x)
                  (build action say object1 "No one's" object2 "here")))
          else
No one's here.
 CPU time : 0.42
```

Notice that withall and withsome only operate on entities already believed to satisfy the *suchthat* criterion. If you want to operate on entities discovered in the future to satisfy the *suchthat* criterion, use when-do or whenever-do, and note that they only perform on new beliefs:

```
* (describe (assert member ("Stu" "Bill") class person))
(M1! (CLASS PERSON) (MEMBER Bill Stu))
(M1!)
CPU time : 0.07
* (describe (assert agent "Stu" state is location here))
(M2! (AGENT Stu) (LOCATION HERE) (STATE IS))
(M2!)
CPU time : 0.06
* (describe
   (assert forall $p
          ant (build member *p class person)
           cq (build when (build agent *p state is location here)
                      do
                           (build action say
                                  object1 "Hello new"
                                  object2 *p))))
(M3! (FORALL V1) (ANT (P1 (CLASS PERSON) (MEMBER V1)))
  (P4 (DO (P3 (ACTION SAY) (OBJECT1 Hello new) (OBJECT2 V1)))
   (WHEN (P2 (AGENT V1) (LOCATION HERE) (STATE IS))))))
(M3!)
CPU time : 0.19
```

```
* (perform
   (build action withall
          vars $x
          suchthat (build min 2 max 2
                           arg ((build member *x class person)
                                 (build agent *x state is location here)))
          do (build action say object1 "Hello old" object2 *x)))
Hello old Stu
CPU time : 0.60
* (clear-infer)
(Node activation cleared. Some register information retained.)
CPU time : 0.01
* (add agent "Bill" state is location here)
Hello new Bill
CPU time : 0.31
(The (clear-infer) was needed to mark the change in time and discourse context.)
```

4.3 Associating Primitive Action Nodes with Their Functions

SNeRE will recognize an act node by its action arc to another node. However, if that latter node represents a primitive action, it must be associated with a primitive action function. To provide flexibility in the representation of primitive actions, the user is obliged to explicitly associate primitive action nodes with their functions.

```
(attach-primaction \{action-node-form\ action-function-name\}^*) action-node-form\ must\ be\ a\ SNePSUL\ form\ that\ evaluates\ to\ a\ node\ n\ or\ a\ singleton\ nodeset\ (n)\ , and action-function-name\ must\ be\ a\ symbol\ that\ was\ defined\ to\ name\ a\ primitive\ action\ function\ f. These are associated with each other so that when an act node whose action node is n is performed, f is applied to the nodesets at the end of the arcs whose relations are the lambda variables of f.
```

As an example, we will establish three primitive actions using a variety of representation schemes.

```
--> (define-primaction sayfun (object1 object2)
      "Print the the argument nodes in order followed by a period."
      (format t "~&~A ~A.~%"
              (first (ns-to-lisp-list object1))
              (first (ns-to-lisp-list object2))))
SAYFUN
--> (define-primaction exclaimfun (object1 object2)
      "Print the the argument nodes in order followed by an exclamation mark."
      (format t "~&~A ~A!~%"
              (first (ns-to-lisp-list object1))
              (first (ns-to-lisp-list object2))))
EXCLAIMFUN
--> (define-primaction questionfun (np vp)
      "Print the the argument nodes in order followed by a question mark."
      (format t "~&~A ~A?~%"
              (first (ns-to-lisp-list np))
```

```
(first (ns-to-lisp-list vp))))
QUESTIONFUN
--> (attach-primaction
      say sayfun
      (= (build lex "exclaim") exclaim) exclaimfun
      (find entity- (assert entity (\# 'question) expression "question"))
      questionfun)
--> ^^
CPU time : 0.17
* (perform (build action say object1 "Hello" object2 "Stu"))
Hello Stu.
CPU time : 0.18
* (perform (build action *exclaim object1 "Hello" object2 "Bill"))
Hello Bill!
CPU time : 0.14
* (perform
 (build action *question np "Who's" vp "there"))
Who's there?
CPU time : 0.16
```

Figure 4.1 shows the three act nodes that were performed. The attach-primaction call shown above associated action node SAY with the primitive action function sayfun, action node M1 with the primitive action function exclaimfun, and action node B1 with the primitive action function questionfun.

The user must remember to use attach-primaction to associate action nodes even with the built-in primitive action functions she intends to use. As a reminder, the built in action functions are listed in Table 4.1. The achieve primitive action function will be described below.

Table 4.1: Built-in Primitive Action Functions

```
believe disbelieve adopt unadopt
achieve do-one do-all snsequence
snif sniterate withsome withall
```

4.4 Defined Acts

An act that is not a primitive act is called a *defined act*. If SNeRE is asked to perform a defined act, it will try to infer a *plan* to carry out the act. A *plan* in the SNeRE formalism is represented by any act node, but especially one whose action is a control action. A node of the form $M: \{\langle plan, p \rangle, \langle act, a \rangle\}$, where a is a defined act node, and p is a plan node, represents the proposition that the plan represented by p is the way to perform the defined act represented by a. Having inferred some plans for carrying out a defined act, SNeRE will perform do-one on them.

4.4. DEFINED ACTS 37

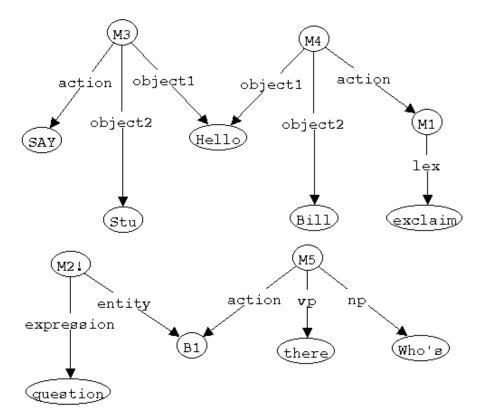


Figure 4.1: Three ways of associating action nodes with action functions. M3, M4, and M5 are act nodes, with action nodes SAY, M1, and B1 respectively.

CPU time : 0.06

To illustrate the use of defined acts, we will first define say as a one object action function, and associate action nodes with the functions say, and snsequence.

```
--> (define-primaction say (object1)
      "Print the object."
      (format t "~&~A" (sneps:choose.ns object1)))
SAY
--> (attach-primaction
      say say
      snsequence snsequence)
Т
--> ^^
CPU time : 0.05
Then, we will give a rule that says the way to greet a person is to sayHi, then say the person's name (and
assert that Stu and Bill are people).
* (describe (assert forall $person
                     ant
                             (build member *person class person)
                             (build act (build action greet object1 *person)
                      cq
                                    plan (build action snsequence
                                                 object1 sayHi
                                                 object2 (build action say
                                                                  object1 *person)))))
(M1! (FORALL V1) (ANT (P1 (CLASS PERSON) (MEMBER V1)))
 (CO
  (P5 (ACT (P2 (ACTION GREET) (OBJECT1 V1)))
   (PLAN
    (P4 (ACTION SNSEQUENCE) (OBJECT1 SAYHI)
     (OBJECT2 (P3 (ACTION SAY) (OBJECT1 V1)))))))
(M1!)
CPU time : 0.18
* (describe (assert member (Stu Bill) class person))
(M2! (CLASS PERSON) (MEMBER BILL STU))
(M2!)
CPU time : 0.06
We will give three plans for sayHi.
* (describe (assert act sayHi
                     plan (build action say object1 "Hello")))
(M4! (ACT SAYHI) (PLAN (M3 (ACTION SAY) (OBJECT1 Hello))))
(M4!)
CPU time : 0.09
* (describe (assert act sayHi
                     plan (build action say object1 "Hi")))
(M6! (ACT SAYHI) (PLAN (M5 (ACTION SAY) (OBJECT1 Hi))))
(M6!)
```

4.5. GOALS 39

A defined act node may be represented by a node with no action arc emanating from it, as long as a plan can be derived for it.

4.5 Goals

In the SNeRE formalism, a *goal* is a proposition that the SNeRE agent is trying to bring about. The action of trying to bring about a goal is called "achieve":

(achieve *object1*), where *object1* must be a proposition node, is performed by finding plans for achieving *object1*, and performing a do-one on them.

The plans for achieving goals are given by assertions of the form $M! : \{\langle goal, g \rangle, \langle plan, p \rangle\}$, which says that p is a plan for achieving the goal g.

```
* (describe (assert forall $person
                    ant
                           (build member *person class person)
                           (build act (build action call object1 *person)
                                  plan (build action snsequence
                                              object1 (build action say
                                                              object1 "Come here")
                                              object2 (build action say
                                                              object1 *person)))))
(M24! (FORALL V6) (ANT (P27 (CLASS PERSON) (MEMBER V6)))
  (P31 (ACT (P28 (ACTION CALL) (OBJECT1 V6)))
   (PLAN
    (P30 (ACTION SNSEQUENCE) (OBJECT1 (M23 (ACTION SAY) (OBJECT1 Come here)))
     (OBJECT2 (P29 (ACTION SAY) (OBJECT1 V6)))))))
(M24!)
CPU time : 0.19
* (perform (build action achieve
                  object1 (build agent Bill state is location here)))
Come here
BILL
CPU time : 1.76
```

4.6 The Execution Cycle: Preconditions and Effects

SNeRE acting may be understood by the following pseudo-definition of perform, although the actual implemention is different.

Notes and comments:

- A trace of the acting system is printed when the global variable *plantrace* is set to T. If *plantrace* is set to 'surface, then nodes are sent to the GATN generator starting at state G for printing. If *plantrace* is NIL, no trace is printed. This was the setting for the previous examples in this chapter, but the default is T.
- The preconditions of an act, a are all p for which propositions of the form $M! : \{\langle act, a \rangle, \langle precondition, p \rangle\}$ are deduceable.

```
* (describe
     (assert forall *person
             ant (build member *person class person)
                    (build act
                                         (build action greet object1 *person)
                           precondition (build agent *person
                                                state
                                                         is
                                                location here))))
(M34! (FORALL V6) (ANT (P27 (CLASS PERSON) (MEMBER V6)))
 (CO
  (P40 (ACT (P39 (ACTION GREET) (OBJECT1 V6)))
   (PRECONDITION (P38 (AGENT V6) (LOCATION HERE) (STATE IS))))))
(M34!)
 CPU time : 0.13
* (perform (build action greet object1 Stu))
About to do
((M9 (ACTION (GREET)) (OBJECT1 (STU))))
I wonder if the act
((M9 (ACTION (GREET)) (OBJECT1 (STU))))
has any preconditions ...
The act
((M9 (ACTION (GREET)) (OBJECT1 (STU))))
has a precondition:
((M35! (ACT (M9 (ACTION (GREET)) (OBJECT1 (STU))))
  (PRECONDITION (M33! (AGENT (STU)) (LOCATION (HERE)) (STATE (IS))))))
It is satisfied.
The act
((M9 (ACTION (GREET)) (OBJECT1 (STU))))
has a plan:
((M12! (ACT (M9 (ACTION (GREET)) (OBJECT1 (STU))))
  (PLAN
   (M11 (ACTION (SNSEQUENCE)) (OBJECT1 (SAYHI))
    (OBJECT2 (M10 (ACTION (SAY)) (OBJECT1 (STU)))))))
Intending to do
((M14 (ACTION (DO-ONE))
  (OBJECT1
   (M11 (ACTION (SNSEQUENCE)) (OBJECT1 (SAYHI))
    (OBJECT2 (M10 (ACTION (SAY)) (OBJECT1 (STU))))))))
Now doing: DO-ONE
((M11 (ACTION (SNSEQUENCE)) (OBJECT1 (SAYHI))
  (OBJECT2 (M10 (ACTION (SAY)) (OBJECT1 (STU)))))
Chose to do the act
((M11 (ACTION (SNSEQUENCE)) (OBJECT1 (SAYHI))
  (OBJECT2 (M10 (ACTION (SAY)) (OBJECT1 (STU)))))
```

```
About to do
((SAYHI))
I wonder if the act
((SAYHI))
has any preconditions...
The act
((SAYHI))
has no preconditions:
The act
((SAYHI))
has the following plans:
((M4! (ACT (SAYHI)) (PLAN (M3 (ACTION (SAY)) (OBJECT1 (Hello)))))
 (M6! (ACT (SAYHI)) (PLAN (M5 (ACTION (SAY)) (OBJECT1 (Hi)))))
 (M8! (ACT (SAYHI)) (PLAN (M7 (ACTION (SAY)) (OBJECT1 (Hiya))))))
Intending to do
((M15 (ACTION (DO-ONE))
  (OBJECT1 (M3 (ACTION (SAY)) (OBJECT1 (Hello)))
   (M5 (ACTION (SAY)) (OBJECT1 (Hi))) (M7 (ACTION (SAY)) (OBJECT1 (Hiya))))))
Now doing: DO-ONE
((M3 (ACTION (SAY)) (OBJECT1 (Hello)))
 (M5 (ACTION (SAY)) (OBJECT1 (Hi)))
 (M7 (ACTION (SAY)) (OBJECT1 (Hiya))))
Chose to do the act
((M3 (ACTION (SAY)) (OBJECT1 (Hello))))
About to do
((M3 (ACTION (SAY)) (OBJECT1 (Hello))))
I wonder if the act
((M3 (ACTION (SAY)) (OBJECT1 (Hello))))
has any preconditions...
The act
((M3 (ACTION (SAY)) (OBJECT1 (Hello))))
has no preconditions:
Hello
About to do
((M10 (ACTION (SAY)) (OBJECT1 (STU))))
I wonder if the act
((M10 (ACTION (SAY)) (OBJECT1 (STU))))
has any preconditions...
```

```
The act
((M10 (ACTION (SAY)) (OBJECT1 (STU))))
has no preconditions:

STU
CPU time : 3.10
```

- The current version of SNeRE will never give up trying to achieve the preconditions of an act it is trying to perform, even if some precondition is impossible to achieve.
- The effects of an act, a are all e for which propositions of the form M!:{ $\langle act, a \rangle$, $\langle effect, e \rangle$ } are deduceable.

```
* (describe
   (assert forall *person
           ant (build member *person class person)
                  (build act (build action call object1 *person)
                         effect (build agent
                                                *person
                                        state
                                                 is
                                        location here))))
(M36! (FORALL V6) (ANT (P27 (CLASS PERSON) (MEMBER V6)))
  (P41 (ACT (P28 (ACTION CALL) (OBJECT1 V6)))
   (EFFECT (P38 (AGENT V6) (LOCATION HERE) (STATE IS))))))
(M36!)
 CPU time : 0.11
* (perform (build action call object1 Bill))
About to do
((M27 (ACTION (CALL)) (OBJECT1 (BILL))))
I wonder if the act
((M27 (ACTION (CALL)) (OBJECT1 (BILL))))
has any preconditions...
The act
((M27 (ACTION (CALL)) (OBJECT1 (BILL))))
has no preconditions:
The act.
((M27 (ACTION (CALL)) (OBJECT1 (BILL))))
has a plan:
((M31! (ACT (M27 (ACTION (CALL)) (OBJECT1 (BILL))))
  (PLAN
   (M30 (ACTION (SNSEQUENCE))
    (OBJECT1 (M23 (ACTION (SAY)) (OBJECT1 (Come here))))
    (OBJECT2 (M17 (ACTION (SAY)) (OBJECT1 (BILL))))))))
```

```
Intending to do
((M40 (ACTION (DO-ONE))
  (OBJECT1
   (M30 (ACTION (SNSEQUENCE))
    (OBJECT1 (M23 (ACTION (SAY)) (OBJECT1 (Come here))))
    (OBJECT2 (M17 (ACTION (SAY)) (OBJECT1 (BILL))))))))
Now doing: DO-ONE
((M30 (ACTION (SNSEQUENCE))
  (OBJECT1 (M23 (ACTION (SAY)) (OBJECT1 (Come here))))
  (OBJECT2 (M17 (ACTION (SAY)) (OBJECT1 (BILL))))))
Chose to do the act
((M30 (ACTION (SNSEQUENCE))
  (OBJECT1 (M23 (ACTION (SAY)) (OBJECT1 (Come here))))
  (OBJECT2 (M17 (ACTION (SAY)) (OBJECT1 (BILL))))))
About to do
((M23 (ACTION (SAY)) (OBJECT1 (Come here))))
I wonder if the act
((M23 (ACTION (SAY)) (OBJECT1 (Come here))))
has any preconditions...
The act
((M23 (ACTION (SAY)) (OBJECT1 (Come here))))
has no preconditions:
Come here
About to do
((M17 (ACTION (SAY)) (OBJECT1 (BILL))))
I wonder if the act
((M17 (ACTION (SAY)) (OBJECT1 (BILL))))
has any preconditions...
The act
((M17 (ACTION (SAY)) (OBJECT1 (BILL))))
has no preconditions:
BILL
Now doing: DO-ALL
((M38 (ACTION (BELIEVE))
  (OBJECT1 (M25 (AGENT (BILL)) (LOCATION (HERE)) (STATE (IS))))))
Believe
(M25! (AGENT BILL) (LOCATION HERE) (STATE IS))
CPU time : 2.07
```

- The current version of SNeRE will believe that all effects of an act are achieved, even though this may be a naive assumption.
- The current version of the primitive action function do-all is

but the user could redefine it if she wanted to make a more intelligent decision about the order in which the acts should be performed.

• The current version of the primitive action function do-one is

but the user could redefine it if she wanted to make a more intelligent decision about which act should be performed.

Chapter 5

Program Interface

5.1 Transformers

These functions convert Lisp objects to SNePS nodes, and vice versa.

```
(apply-function-to-ns fn ns)
```

Converts the node set ns to a list of lisp objects, applies the function fn to that list, then converts the result to a node set, and returns that.

```
(lisp-list-to-ns list)
```

Returns a set of nodes whose identifiers look like the printed representations of the objects in the list list.

```
(ns-to-lisp-list ns)
```

Returns a list of Lisp objects corresponding to the SNePS nodes in the node set *ns*.

```
(node-to-lisp-object nde)
```

Returns a Lisp object corresponding to the SNePS node *nde*. The Lisp object will be either a number or a symbol.

```
(lisp-object-to-node obj)
```

Returns a SNePS node whose identifier looks like obj.

5.2 With-SNePSUL Reader Macro

The with-snepsul reader macro is provided so that users can easily incorporate calls to SNePSUL commands within Lisp code.

(#[i]! (snepsul-form₁... snepsul-form_n)) The form following #[i]! is taken to be a list of SNePSUL forms, each of which will be executed just as if it had been typed that way at the SNePS prompt, regardless of the package in which the #[i]! form is read. References to Lisp variables can be made via a $\tilde{}$ reader macro mechanism (similar to the comma within backquote syntax). Results of $\tilde{}$ expansions will be automatically interned into the SNePSUL package (i.e., any symbols that might be part of such a result), unless explicitly specified otherwise. All the special reader syntax available at the SNePS top-level is available, too.

The semantics of the ~ syntax is:

S-expression will be read with ordinary reader syntax and at execution time it will be evaluated and its value inserted into the SNePSUL expression. If the value is a symbol or a list containing symbols then these symbols will be interned into the SNePSUL package first.

```
Ex: #! ((describe ~' (m1 m2))) will act like (describe (m1 m2)).
```

Just like ~ but the value of the s-expression has to be a list which will be spliced into the SNePSUL expression. Any symbols occuring as leaves in the list will be interned into the SNePSUL package first. Ex: #! ((describe ~@' (m1 m2))) will act like (describe m1 m2).

~ ~ s-expression:

Just like ~ but symbols in the value will not be interned into the SNePSUL package.

~ ~ @ *s-expression*:

Just like ~@ but symbols in the value will not be interned into the SNePSUL package.

CAUTION: The $\tilde{}$ syntax can only be used within SNePSUL forms, but not to denote multiple forms, e.g., while #! ($\tilde{}$ com1 $\tilde{}$ com2 $\tilde{}$ com3) is legal (as long as the runtime values of com_i represent proper SNePSUL commands), #! ($\tilde{}$ @commands) is not!!

Supplying an optional digit argument can be used to select a specific evaluation function, or to suppress output:

arg	eval function	silent	syntax
no arg	topsneval	no	#!()
1	topsneval	no	#1!()
2	eval	no	#2!()
3	topsneval	yes	#3!()
4	eval	yes	#4!()

For example, #4! ((build relation node)) will use the function eval to evaluate the form (hence build can be used!!), and will suppress any output generated by the snepsul command.

5.2.1 Controlling the Evaluation of SNePSUL Forms Generated by #!

```
(defvar *with-snepsul-eval-function* #'with-snepsul-standard-eval
```

"The value of this variable has to be a function of two arguments, an *eval-function* and a *form* to which the function should be applied. Binding this variable to different functions can implement various different evaluation behaviors, such as normal evaluation, tracing, top-level-like echoing, evaluating and printing the result, etc., when the *form* gets evaluated inside with-snepsul-eval.")

The following evaluation functions are available:

```
(with-snepsul-standard-eval function form)
```

Standard function used by with-snepsul-eval to evaluate form with evaluation function.

```
(with-snepsul-trace-eval function form)
```

Does not actually evaluate *form*, only prints it for debugging purposes.

```
(with-snepsul-toplevel-style-eval function form)
```

Evaluates the SNePSUL *form* using *function* and returns the result. Additionally, prints the prompt, *form*, result and timing information just like the top-level SNePS loop does—good for monitoring the execution of the actual SNePSUL commands.

[~] s-expression:

^{~@} s-expression:

5.2.2 Example Use of #!

```
> (in-package 'user)
#<Package "USER" 79D15E>
> (defun myassert (relation nodes)
    (let ((base-node-var 'mybase))
      #!((define ~relation ~~relation myrel snip::test)
         (assert ~relation (~@nodes) snip::test #~base-node-var)
         (describe ~@(setq nodes (cdr nodes)))
         (assert ~~relation (~~@nodes) myrel *~base-node-var)
         (assert arg (build myrel hans ~relation franz)
                 myrel *mybase)
         (describe *nodes))))
MYASSERT
;; If the variable *with-snepsul-eval-function* is bound to the
;; function #'with-snepsul-trace-eval then the generated SNePSUL
;; expression will only be printed, but not actually executed:
> (let ((sneps:*with-snepsul-eval-function*
          #'sneps:with-snepsul-trace-eval))
    (myassert 'relrel '(hans franz otto)))
(SNEPS:DEFINE SNEPSUL::RELREL ;; Note "snepsulization" with single ~
              USER::RELREL ;; Package preservation with double ~
              SNEPSUL::MYREL ;; Unqualified symbols go into SNePSUL
              SNIP::TEST) ;; Qualified symbols keep their package
(SNEPS:ASSERT SNEPSUL::RELREL
              (SNEPSUL::HANS SNEPSUL::FRANZ
                             SNEPSUL::OTTO)
              SNIP::TEST
              ;; had to replace the |'s with !'s here (comment problem)
              (SNEPS:!#! 'SNEPSUL::MYBASE)) ;; Combination of # and ^
(SNEPS::DESCRIBE SNEPSUL::FRANZ SNEPSUL::OTTO)
(SNEPS:ASSERT USER::RELREL (USER::FRANZ USER::OTTO)
              SNEPSUL::MYREL (SNEPS:* 'SNEPSUL::MYBASE))
(SNEPS:ASSERT SNEPS:ARG (SNEPS:BUILD SNEPSUL::MYREL SNEPSUL::HANS
                                     SNEPSUL::RELREL SNEPSUL::FRANZ)
              SNEPSUL::MYREL (SNEPS:* 'SNEPSUL::MYBASE))
(SNEPS::DESCRIBE (SNEPS:* 'SNEPS:NODES))
;; Now actually run it:
> (myassert 'relrel '(hans franz otto))
(FRANZ)
(OTTO)
(B1)
(FRANZ)
         ;; user::franz
          ;; snepsul::franz
(FRANZ)
(HANS)
(M1! (RELREL FRANZ HANS OTTO))
```

```
(M2! (RELREL FRANZ OTTO))
(M3 (MYREL HANS) (RELREL FRANZ))
(M4! (ARG (M3)))
(M5! (RELREL FRANZ HANS OTTO)
     (TEST B1))
(M6! (MYREL B1)
     (RELREL FRANZ OTTO))
(M7! (ARG (M3)) (MYREL B1))
(B1 FRANZ FRANZ HANS M1! M2! M3 M4! M5! M6! M7! OTTO OTTO)
SNEPS:DEFAULT-DEFAULTCT
;; Here's what the definition of myassert looks like:
> (ppdef 'myassert)
(LAMBDA (RELATION NODES)
  (BLOCK MYASSERT
    (LET ((BASE-NODE-VAR 'MYBASE))
      (PROGN ;; progn generated by #!
        (SNEPS::WITH-SNEPSUL-EVAL
            '(SNEPS:DEFINE , (SNEPS::SNEPSULIZE RELATION) , RELATION
              SNEPSUL::MYREL SNIP::TEST)
          #'SNEPS:TOPSNEVAL NIL)
        (SNEPS::WITH-SNEPSUL-EVAL
            '(SNEPS:ASSERT , (SNEPS::SNEPSULIZE RELATION)
              (,@(SNEPS::SNEPSULIZE NODES)) SNIP::TEST
              (SNEPS: !#! ', (SNEPS::SNEPSULIZE BASE-NODE-VAR)))
          #'SNEPS:TOPSNEVAL NIL)
        (SNEPS::WITH-SNEPSUL-EVAL
            `(SNEPS::DESCRIBE
              ,@(SNEPS::SNEPSULIZE (SETQ NODES (CDR NODES))))
          #'SNEPS:TOPSNEVAL NIL)
        (SNEPS::WITH-SNEPSUL-EVAL
            '(SNEPS:ASSERT , RELATION (, @NODES) SNEPSUL::MYREL
              (SNEPS:* ', (SNEPS::SNEPSULIZE BASE-NODE-VAR)))
          #'SNEPS:TOPSNEVAL NIL)
        (SNEPS::WITH-SNEPSUL-EVAL
            '(SNEPS:ASSERT SNEPS:ARG
              (SNEPS:BUILD SNEPSUL::MYREL SNEPSUL::HANS
               , (SNEPS::SNEPSULIZE RELATION) SNEPSUL::FRANZ)
              SNEPSUL::MYREL (SNEPS:* 'SNEPSUL::MYBASE))
          #'SNEPS:TOPSNEVAL NIL)
        (SNEPS::WITH-SNEPSUL-EVAL
            '(SNEPS::DESCRIBE (SNEPS:* 'SNEPS:NODES))
          #'SNEPS:TOPSNEVAL NIL)))))
```

5.3 Defining New Commands

```
(defsnepscom\ command\ ([(\{arg\}^*)]\ [environments]\ [eval-args])\ \{body-form\}^*)
```

defsnepscom is a Lisp macro that defines SNePSUL commands. All standard SNePSUL commands such as find, assert, deduce, etc., are defined via defsnepscom. More importantly, defsnepscom is the only way to define commands which will be recognized as legal SNePSUL commands at the SNePS top level. The syntax of defsnepscom is very similar to that of a standard defun or defmacro.

command is a Lisp symbol which serves as the command name, e.g., find, deduce, my-find, isa, etc. command will get exported automatically from its home package and imported into the SNePSUL package, hence, even if the command was defined in a different package, it can be used at the SNePS top level without package qualifiers. The only catch is that if command is the name of a standard COMMON LISP function as in the case of find or assert, then that symbol has to be shadowed in its home package with the COMMON LISP function shadow before the command gets defined.

 $(\{arg\}^*)$ is an optional argument list in the standard COMMON LISP syntax. An actual call to the command has to be legal according to that argument list, otherwise an error will occur. The only difference to the standard defun style of specifying argument lists is an extra level of nesting as shown in the examples below.

The optional second argument *environments* defines the places in which the command can legally appear. An environment is basically a specification of a location in which a command can be used. For example, some commands can only be used at the top level, some commands can never be used at the top level but only inside some other command, some commands can only be used within find commands, etc. See Section 1.4 for more information on environments. *environments* can either be :all to define *command* as legal in all possible environments, or it can be a subset of (top rs bns fns ons rearrange) specified as a list, which will make it legal in the specified environments. These abbreviations indicate environments as specified in the following table.

top	The top level of SNePS 2	
rs	A relation-set position embedded in a command	
bns	A node-set position in build	
fns	A node-set position in find or findassert	
ons	A <i>node-set</i> position in any of the other commands	
rearrange	The command is an infix or postfix command.	

A third possibility, which is probably the one most commonly used, is to supply the name of an already existing command, in which case *command* will be legal in all environments in which the supplied command is legal. *environments* defaults to (top). According to the specified *environments*, defsnepscom automatically updates the SNePSUL variables commands, topcommands, etc. (See Section 1.7.)

By default, commands defined with defsnepscom do not evaluate their arguments. If one wants command arguments to be evaluated before they get passed (similar to the behavior of standard functions defined with defun), one has to specify the optional third argument, *eval-args* as t.

body-forms are a sequence of body forms, possibly including a documentation string and declarations just as in a normal defun. The value/s of the last form will be returned.

Here are some examples:

Example 1:

```
T
--> ^^ ;; back to the SNePS top level

CPU time : 0.03

* (mylist apples oranges hans franz) ;; let's try it out:

(APPLES ORANGES (HANS FRANZ))

CPU time : 0.01
```

Note, that we did not have to quote apples and oranges in the example above, because *eval-args* was not specified as t.

Example 2:

```
* ""
--> (defsnepscom isa ((who what) assert)
        "Asserts that WHO is a WHAT."
        #!((assert member "who class "what)))
T
--> ^^
CPU time : 0.08
* (describe (isa hans student))
(M1! (CLASS STUDENT) (MEMBER HANS))
(M1!)
CPU time : 0.02
```

The isa command defined above takes two arguments who and what, and it is legal in all places where the assert command is legal, because we specified assert as the value of *environments*. The body of the command has a documentation string just as a normal defun, and it uses the #! with-snepsul reader macro (see Section 5.2) to easily call the SNePSUL command assert in the body of the command definition.

Example 3:

```
* ^^
--> (defsnepscom lex-build ((word) (top bns) t)
        "Builds a node with a 'lex' arc to a WORD node."
        #2!((build lex ~word)))
T
--> ^^
CPU time : 0.25
```

```
* (lex-build (progn (format t "Word: ") (read)))
Word: Lucy
(M1)
CPU time : 0.03
```

This last example command uses all the features: It has an argument list, it explicitly specifies two environments in which the command will be legal, and it evaluates its arguments which is the reason why we could call it with the little interactive input specification. Note, that this command builds (not asserts) a node, and that it will be available as a top-level command because we specified top as one of the environments. For good reasons, the standard build command is not a top-level command, hence, in this example we forced SNePS to do something which is normally not allowed.

By convention, every command that returns a node set should return a context as a second value which will be used to display the node set. Commands which use an application of the #! reader macro as their last body form will achieve this automatically. Otherwise, a form such as (values nodes crntct) has to be used as the last body form.

defsnepscom is available in all standard SNePS packages. Hence, it can normally always be used without a package qualifier. If it is used in a non-standard package it should be written as sneps: defsnepscom.

```
(undefsnepscoms {commands}^*)
```

Undefines all *commands*. The function definitions of the individual commands will not be removed, but the listed commands will not be available as SNePSUL commands anymore. For example, the following will undo the inappropriate definition of Example 3 above:

```
* (^ (undefsnepscoms lex-build))
(T)
CPU time : 0.00
* (lex-build Lucy)
SNePS ERROR: Invalid top SNePSUL form: (LEX-BUILD LUCY)
Occurred in module TOP-EVALUATOR in function TOPSNEVAL
Do you want to debug it? n
```

*

Chapter 6

SNePSLOG

6.1 SNePSLOG Basics

SNePSLOG is a logic programming interface to SNePS. That is, almost everything that can be done interactively using SNePSUL can be done interactively using SNePSLOG, just with a syntax that looks more like traditional symbolic logic than SNePSUL does. Use of SNePSLOG rather than SNePSUL is recommended for the SNePS novice.

To enter SNePSLOG, load SNePS and evaluate

(snepslog)

To leave SNePSLOG, execute the SNePSLOG command

lisp

The default Common Lisp package for symbols read by the SNePSLOG reader is snepslog. The full details of the SNePSLOG syntax is in §6.2. The semantics are given in §6.3.

6.2 SNePSLOG Syntax

The SNePSLOG syntax is described in Tables 6.1 and 6.2 using the Extended BNF notation. Object language terminal symbols are in this font. Grouping parentheses are (and). Alternatives are separated by the | character. Square brackets [and] surround optional material. The Kleene star, *, indicates zero or more repetitions. The Kleene plus, +, indicates one or more repetitions. The character "b" indicates that whitespace is not allowed at that position. Object language parentheses are (and). The object language comma is , . The object language underscore character is _. The symbols i, j, and k are non-terminal symbols representing integers. Material starting with a semicolon is a comment indicating a restriction on the syntax.

A SNePSLOG command may continue on subsequent lines as long as the SNePSLOG command couldn't, according to the grammar, terminate on the initial line. If it could, and you want to continue the command on a subsequent line, end the line with the character "\" (without the quotation marks).

Note that a SNePSLOGsymbol may be any Lisp symbol, string, or number. If a SNePSLOGsymbol is a symbol, it is interned in the snepslog package. If a SNePSLOGsymbol is a string, it is coerced into a symbol whose symbol-name is the original string, and is interned in the snepslog package. If a SNePSLOGsymbol is a number, it is coerced into a symbol whose symbol-name is the Lisp printer representation of the original number, and is interned in the snepslog package. Two SNePSLOGsymbols are considered the same by SNePSLOG if and only if the Lisp being used considers the symbols constructed by this algorithm to be the same. When SNePSLOG prints a SNePSLOGsymbol, it does not print string-quotes nor escape characters.

Table 6.1: The Syntax of SNePSLOG Commands

```
command
                       wffNameCommand | snepslogCommand | wffCommand
                   ::=
wffNameCommand
                       wffName terminalPunctuation
                   ::=
wffCommand
                   ::= wff terminalPunctuation; wff must not be an atomic symbol
snepslogCommand
                       % SNePSULcommand | ^ LispForm | ^^
                        | activate wff[.]
                        | activate! wff [terminalPunctuation]
                        | add-to-context SNePSLOGsymbol termSet [.]
                        | ask wff [terminalPunctuation]
                        | askifnot wff [terminalPunctuation]
                        | askwh wff [terminalPunctuation]
                        | askwhnot wff [terminalPunctuation]
                        | beliefs-about pTermSet[.]
                        | br-mode [auto | manual][.]
                        | br-tie-mode [auto | manual][.]
                        | clear-infer[.]
                        | clearkb[.]
                        | copyright [.]
                        | define-frame SNePSLOGsymbol LispList [LispString] [.]
                        | define-path SNePSRelation SNePSPath [.]
                        | demo[filePath | ? | i][t | b | bv | a | av | n][.]
                        | describe-context [SNePSLOGsymbol][.]
                        | describe-terms [pTermSet] [.]
                        | expert [.]
                        |lisp[.]
                        | list-asserted-wffs [SNePSLOGsymbol][.]
                        | list-contexts[.]
                        | list-terms [pTermSet][.]
                        | list-wffs[.]
                        | load filePath [.]
                        | normal[.]
                        | perform atomicTerm [.]
                        | remove-from-context SNePSLOGsymbol pTermSet
                        | set-context SNePSLOGsymbol [pTermSet]
                        | set-default-context SNePSLOGsymbol
                        | set-mode-1[.]
                        | set-mode-2[.]
                        | set-mode-3 [t | nil][.]
                        | set-order (explicit | fluent | null-order | source | LispSymbol)
                        | show [pTermSet] [.]
                        | trace [SNePSLOGfunction]*[.]
                        | undefine-path SNePSRelation [.]
                        | unlabeled[.]
                        | untrace [SNePSLOGfunction]*[.]
SNePSLOGfunction ::=
                       inference | acting | translation | parsing
                        | LispSymbol
```

Table 6.2: The Syntax of SNePSLOG Wffs

```
wff
                      ::=
                           infixedTerm | entailment | prefixedTerm
infixedTerm
                           prefixedTerm [( and | or | <=> ) prefixedTerm]+
                      ::=
entailment
                           termSet (=> \mid v=> \mid \&=> \mid i=>) termSet
                      ::=
pTermSet
                           termSet; but taken to denote all terms that match
                      ::=
                           prefixedTerm | { termSequence }
termSet
                      ::=
                           prefixedTerm [, prefixedTerm]*
termSequence
prefixedTerm
                           negatedTerm | andorTerm | setTerm | threshTerm
                      ::=
                            | allTerm | nexistsTerm | atomicTerm
negatedTerm
                      ::=
                            ~ atomicTerm
andorTerm
                           andor b (i, j) termSet 0 <= i <= j
                      ::=
setTerm
                           (and | or | nand | nor | xor | iff) b termSet
                      ::=
threshTerm
                           thresh b (i [, j]) termSet; \theta \le i \le j
                      ::=
allTerm
                           all (symbolSequence) (wff); wff must not be an atomic symbol
                           nexists /b nexistsParameters (symbolSequence ) (termSet : termSet )
nexistsTerm
                      ::=
nexistsParameters
                           (i, j, k) \mid (\underline{\quad}, j, \underline{\quad}) \mid (\underline{\quad}, \underline{\quad}, k)
                      ::=
                           wffName | qvar | SNePSLOGsymbol
atomicTerm
                            | withsome/allTerm; in Mode 3 only
                            | (qvar | SNePSLOGsymbol) (termSetSequence )
withsome/allTerm
                           (withsome | withall) (symbolSequence, termSet, termSet[, termSet])
                      ::=
                           termSet [, termSet]*
termSetSequence
symbolSequence
                           SNePSLOGsymbol [, SNePSLOGsymbol]*
                      ::=
wffName
                           wffi[!]; wffi must already name a wff.
                      ::=
qvar
                      ::=
                           ? SNePSLOGsymbol
SNePSLOGsymbol
                      ::=
                           wffi \mid Lispsymbol \mid Lispstring \mid Lispnumber
terminalPunctuation
                            . | ! | ?? | ? [ (i [j] )]
                      ::=
```

6.3 SNePSLOG Semantics

6.3.1 Semantics of SNePSLOG Commands

Here we present a list of the SNePSLOG commands, with a description of what they do. See Table 6.1 for a concise list of the SNePSLOG commands and their syntax.

• % SNePSULcommand

Executes the *SNePSULcommand*, and prints the result. The default Common Lisp package for symbols in the *SNePSULcommand* is snepsul.

• ^ LispForm

Evaluates the *LispForm*, and prints the result.

• ^ ^

Enters a Lisp read-eval-print loop. To leave the loop, type end or ^^.

• activate wff

Performs forward inference on all asserted propositions that dominate the wff.

• activate! wff

Asserts wff, and performs forward inference on it, and on all asserted propositions that dominate it.

• add-to-context SNePSLOGsymbol termSet

Adds the wffs in termSet as hypotheses in the context named SNePSLOGsymbol.

ask wff

Performs backward inference on wff and prints the inferred positive instances of it.

• askifnot wff

Performs backward inference on wff, and prints the inferred negative instances of it.

• askwh wff

Performs backward inference on wff, and prints a list of substitutions, which, when applied to wff yield asserted wffs.

• askwhnot wff

Performs backward inference on wff, and prints a list of substitutions, which, when applied to the negation of wff yield asserted wffs.

• beliefs-about pTermSet

Returns a set of all the asserted wffs that dominate the terms described by pTermSet.

• br-mode [auto | manual]

Sets or prints the belief revision mode to be used for choosing the culprit(s) of a contradiction (*see* §8.5).

- br-mode without any arguments prints the currently active belief revision mode.
- br-mode auto causes SNeBR to attempt automatic belief revision, using the then current epistemic ordering function, whenever a contradiction is detected. (Default for mode 3.)
- br-mode manual causes SNeBR to use user-assisted belief revision whenever a contradiction is detected. (Default for modes 1 and 2.)

- br-tie-mode [auto | manual]
 - Sets or prints the method to be used to break ties in entrenchment ordering when necessary for belief revision (*see* §8.5).
 - br-tie-mode without any arguments prints the currently active method for breaking ties in entrenchment ordering.
 - br-tie-mode auto causes SNeBR to arbitrarily break entrenchment ties. In the current implementation, the lexicographic order of wffNames is used as the tie-breaking entrenchment order. (Default for mode 3.)
 - br-tie-mode manual causes SNeBR to query the user to break entrenchment ties when necessary. (Default for modes 1 and 2.)
- clear-infer

Deletes any information placed in the "active connection graph" version of the network.

- clearkb Empties the knowledge base.
- copyright Prints copyright information.
- define-frame SNePSLOGsymbol (rel₀ rel₁ ...rel_n) [LispString] If SNePSLOG is in Mode 3, this declares that every SNePSLOG term of the form $P(x_1, \ldots, x_n)$ is to be represented by a node of the form $\{\langle rel_0, \{P\} \rangle, \langle rel_1, x_1 \rangle, \ldots, \langle rel_n, x_n \rangle\}$. If rel₀ is nil, then the node will have no arc pointing to P. One function symbol may be associated with at most one frame, and it must be possible to uniquely determine the form of the SNePSLOG term from each frame. The LispString, if present, must contain the subststring "[rel_i]" for each non-null rel_i, and will be used by describe-terms to construct a gloss of the term.
- define-path *SNePSRelation SNePSPath*Defines a path-based inference rule. See §2.5.2.
- demo [filePath | ? | i] [t | b | bv | a | av | n]

 The input is taken from the file specified by filePath, until the end of file is reached. The input is then reset to the previous input stream. Notice that embebbed demos are allowed. If filePath? or omitted, a menu of possible demonstrations will be printed, and you will be able to choose one of them. If filePath is an integer, and the menu lists at least that many demonstrations, the one with that number will be run. For the meaning of the various pause controls (t, b, bv, a, av, and n), see page 10.
- describe-context [SNePSLOGsymbol]
 Lists the details of the context named SNePSLOGsymbol. If SNePSLOGsymbol is omitted, describes the default context.
- describe-terms [pTermSet]

This is only useful in Mode 3. If pTermSet is omitted, all the closed functional terms in the knowledge base are described. If pTermSet is included, all, but only, those closed functional terms that match the term patterns in pTermSet are described. The description of an individual constant is itself, The description of a functional term is formed from the LispString included when the frame is defined for the term's function symbol. The description is the LispString with every instance of "[rel_i]" replaced by the description of the filler(s) of the "[rel_i]" slot. For example, after the frame definitions:

```
define-frame mother (nil motherof) "the mother of [motherof]" define-frame female (property object) "[object] is [property]"
```

the description of female (mother (Betty)) will be

The mother of Betty is female.

• expert

Turns on the expert mode, in which the wffName of listed terms is shown, as in normal mode (cf), and, in addition, when a SNePSLOG proposition is printed, its support set is shown.

• lisp

Leaves the SNePSLOG loop, and returns to the Lisp listener.

• list-asserted-wffs [SNePSLOGsymbol]

Lists all propositions that are asserted in the context named SNePSLOGsymbol. If no argument is given, the default context is used.

• list-contexts

Lists the names of all the contexts that have been defined since the last time the knowledge base was cleared.

• list-terms [pTermSet]

If pTermSet is omitted, all the closed functional terms in the knowledge base are printed. If pTermSet is included, all, but only, those closed functional terms that match the term patterns in pTermSet are printed.

• list-wffs

Lists all propositions that are asserted in any context. That is, all propositions that have been asserted as hypotheses or have been derived, regardless of which context they are in.

• load *filePath*

Executes the contents of the specified file as a series of SNePSLOG commands, without doing any printing. All assertions specified by the file are done as one batch at the end of the loading process, and they are all asserted into the current context.

• normal

Returns to the (default) normal mode. In the normal mode, each term is printed using its SNePSLOG representation, and preceded by its wff name, which is wffn, for some integer n. Note that wffn is the same node referred to in SNePSUL as mn. The wff name is followed by an exclamation mark (!) if and only if the term is a proposition asserted in the current context.

• perform atomicTerm

If SNePSLOG is in Mode 3, the act denoted by atomicTerm (either an individual constant or ground functional term) is performed. (*See* §6.5.)

$\bullet \ \, \text{remove-from-context} \, \, SNePSLOG symbol \, pTermSet$

Removes the terms that match the patterns in pTermSet from the context named SNePSLOGsymbol.

• set-context SNePSLOGsymbol [pTermSet]

Defines a context named SNePSLOGsymbol, and sets its initial set of hypotheses to be the terms that match the patterns in pTermSet. Note that pTermSet could be empty or omitted, in which case, the new context is initialized with an empty set of hypotheses.

• set-default-context SNePSLOGsymbol

Makes the context named SNePSLOGsymbol the current, default, context.

61

• set-mode-1

The knowledge base is cleared, and SNePSLOG is put into Mode 1 (the default mode). In this mode, every term of the form $P(x_1, ..., x_n)$ is represented by a node of the form

$$\{\langle r, \{P\} \rangle, \langle a1, \{x_1\} \rangle, \dots, \langle a_n, \{x_n\} \rangle\}$$

Mode 1 is the mode to use when there is no specific reason to use Mode 2 or Mode 3. It requires less set-up effort for the user than Mode 3, because no frames need to be defined. Inference in Mode 1 is less efficient than in the other modes because more terms match any given pattern.

• set-mode-2

The knowledge base is cleared, and SNePSLOG is put into Mode 2. In this mode, every proposition of the form P(x1, ..., xn) is represented by a node of the form

```
\{<| rel P|, \{P\}>, <| rel-arg #P1|, \{x1\}>, ..., <| rel-arg #Pn|, \{xn\}>\}
```

Mode 2 is a compromise between Modes 1 and 3. It requires no more user set-up effort than Mode 1 does; inference is more efficient than in Mode 1, because fewer terms match any given pattern; but, unlike in Mode 1, variables may not be used as function symbols in queries.

• set-mode-3

The knowledge base is cleared, and SNePSLOG is put into Mode 3. In this mode, the user must specify how terms are represented by using define-frame. Inference can be more efficient if the user uses a wide variety of frames. This mode facilitates path-based reasoning, and is required if the SNePSLOG version of SNeRE (§6.5) is to be used. In this mode, SNePSLOG syntax may be used to build almost any SNePS network that can be built using SNePSUL.

- set-order (explicit | fluent | null-order | source | LispSymbol) Specifies the epistemic ordering function to be used by SNeBR when automatically choosing the culprit(s) of a contradiction ($see \S 8.5.2$). If the epistemic ordering function is Ele, then $Ele(p_1, p_2)$ must return True whenever p_1 is less epistemically entrenched than or as epistemically entrenched as p_2 . The possible entrenchment ordering functions are:
 - explicit: Based on the assumption that if Less-Entrenched (p1, p2) is derivable in the knowledge base, then p1 is strictly less entrenched than p2.
 - fluent: Based on the assumption that a proposition whose predicate symbol is in the list *fluents* is less epistemically entrenched than any proposition whose predicate symbol is not in that list, and that if the two predicate symbols of two propositions are either both in *fluents* or both not in *fluents* then those two propositions are equally entrenched. (Default for mode 3.)
 - null-order: Considers all propositions to be equally entrenched. (Default for modes 1 and 2.)
 - source: Based on the assumption that if Source (p1, s1), Source (p2, s2), and Better-Source (s2, s1) are derivable in the knowledge base, then p1 is strictly less entrenched than p2.
 - LispSymbol: must be the name of a Lisp function of two arguments, p1 and p2, both of which are propositions. (LispSymbol p1 p2) must evaluate to True if and only if p1 is less entrenched than p2, or is as equally entrenched as is p2.

• show [pTermSet]

Displays the knowledge base in graphical form as a network, If pTermSet is omitted, all the closed functional terms in the knowledge base are printed. If pTermSet is included, all, but only, those terms

that match the term patterns in pTermSet are printed. Depending on the SNePS installer's choice, show either uses dot or JUNG and JIMI. dot produces a static figure. JUNG/JIMI produces a graph that can be manipulated by hand. Neither dot, JUNG, nor JIMI are part of the SNePS distribution. dot is part of the Graphviz package which can be downloaded from http://graphviz.org/). JUNG and it's associated packages, Xerxes, Colt, and Jakarta Common Collections, can be downloaded from http://jung.sourceforge.net/. JIMI can be downloaded from http://java.sun.com/products/jimi/. The SNePS installer may install either the dot version or the JUNG/JIMI version, both, or neither. If both are installed, the user can dynamically pick the version to be used by setting the global variable cl-user:*use-gui-show* to t for the JUNG/JIMI version, or to nil for the dot version.

• trace [SNePSLOGfunction]*

If SNePSLOGfunction is

inference: Inference tracing is turned on.

acting: Tracing of acting is turned on.

translation: The translation of each SNePSLOG command into SNePSUL is shown.

parsing: The parsing of each SNePSLOG command is traced.

The name of any Lisp function: That function is traced.

• undefine-path SNePSRelation

Deletes the path-based inference rule from the SNePSRelation.

• unlabeled

Turns on unlabeled mode, in which, when a term is printed, neither its wffName (see normal mode), nor its support set (see expert mode) is printed.

• untrace [SNePSLOGfunction]*

If SNePSLOGfunction is

inference: Inference tracing is turned off.

acting: Tracing of acting is turned off.

translation: The translation of each SNePSLOG command into SNePSUL is not shown.

parsing: The parsing of each SNePSLOG command is not traced.

The name of any Lisp function: That function is not traced.

6.3.2 Semantics of wffNameCommands

A wffNameCommand is a wffName followed by one of the terminalPunctuation marks: ".", "!", "??", or "?". A wffName is a symbol made up of "wff" followed by an integer. WffNames are assigned to terms by SNePSLOG. If the wffName wffi, for some i, has already been assigned to a term, then using wffi in a wffNameCommand or in any SNePSLOG expression is equivalent to using the term that it names. Actually, it is even better. Whenever SNePSLOG parses a new variable (not just a new occurrence of a variable), it creates a new variable node (see S1.5), even if the variable has the same name as a previous one. So a variable-containing term in one wffCommand will never be the same, identical, term as one included in a previous wffCommand. However, the wffName assigned to a term will always refer to that term. Note the difference between the two techniques here:

```
: all(x)(Robin(x) => Bird(x)).
wff1!: all(x)(Robin(x) => Bird(x))
: Source(all(x)(Robin(x) => Bird(x)), "World Book").
wff3!: Source(all(x)(Robin(x) => Bird(x)), World Book)
```

```
: list-terms
  wff1!: all(x)(Robin(x) => Bird(x))
  wff2: all(x)(Robin(x) => Bird(x))
  wff3!: Source(all(x)(Robin(x) => Bird(x)), World Book)

: clearkb
Knowledge Base Cleared

: all(x)(Robin(x) => Bird(x)).
  wff1!: all(x)(Robin(x) => Bird(x))

: Source(wff1, "World Book").
  wff2!: Source(all(x)(Robin(x) => Bird(x)), World Book)

: list-terms
  wff1!: all(x)(Robin(x) => Bird(x))
  wff2!: Source(all(x)(Robin(x) => Bird(x)), World Book)
```

If a wffName wffi is used before having been assigned to a term, it will be interpreted as being an individual constant. It will continue to be that individual constant **until** SNePSLOG assigns it to a term. After that, it will always refer to its assigned term, and no longer be recognized as the individual constant.

An assigned wffName in a wffNameCommand refers to its assigned term, and the meaning of the wff-NameCommand depends on the terminalPunctuation in exactly the same way as for wffCommands (see §6.3.3).

6.3.3 Semantics of wffCommands

A wffCommand is a wff followed by one of the terminalPunctuation marks: ".", "!", "??", or "?". The effect of the wffCommand depends on the terminalPunctuation as follows:

- . The wff is asserted into the knowledge base as an hypothesis of the current context, and it is printed. However, if in Mode 3 and the wff is a policy, it is adopted instead of asserted.
- ! The wff is asserted into the knowledge base as an hypothesis of the current context, and forward inference is done on it. It and all wffs newly asserted as a result of this wffCommand are printed.
- ?? If the wff is asserted in the knowledge base, it is printed; otherwise nothing is printed. If qvars (*see* Table 6.2) occur in the wff, they are taken as free variables, and all ground instances that are asserted are printed.
- ? [_(i [j] _)] Backward inference is done on the wff. If quars (see Table 6.2) occur in the wff, they are taken as free variables. If either instances of the wff or of its negation are inferred (or already asserted), those wffs are printed. If no instances of it or its negation are asserted or inferred nothing is printed. If (i) is included after the question mark, backward inference stops as soon as at least i instances of the wff or its negation are inferred. If (i j) is included after the question mark, backward inference stops as soon as at least i positive instances and j negative instances of the wff are inferred.

Forward and backward inference create and use an active connection graph (acg). The acg prevents infinite recursion when recursive rules are used, and answers some queries without further inference. It also focusses the interaction on the current reasoning problem. However, occasionally it causes inferences not to be made even though the knowledge base contains enough information to make them. In that latter case, it may help to perform the clear-infer SNePSLOG Command, and then try again.

6.3.4 Semantics of SNePSLOG Wffs

In this section, we will mainly present the intended semantics of SNePSLOG wffs. We realize, however, that any particular user might have different semantics in mind. If SNePS is useful for that user under those semantics that's fine with us!

We intend a SNePS knowledge base to represent the mental entities conceived of by some individual agent. Some of those entities will be propositions, and some propositions will be asserted, that is, believed by the agent.

A SNePS knowledge base has one or more contexts. A context has a set of hypotheses, which are propositions that were introduced to the system (agent) without justification—typically by the user using a wff-Command terminated by "." or "!". At any time, one context is the current context. The agent believes all the propositions that are hypotheses in the current context, as well as all propositions that have been derived from those hypotheses. The set of hypotheses and derived propositions that are currently believed is called the current belief space. Every currently believed proposition is also called "asserted", and when its wffName is printed, it is terminated by an "!".

Every well-formed expression of SNePSLOG is a term of the language. Expressions that look to the logically-trained user like formulas or sentences are actually proposition-valued terms (even though SNeP-SLOG uses wffi for its "wffName"). The significance of this is that, because terms may be arguments of terms, and may have variables ranging over them, without leaving first-order logic, metapropositions (propositions about propositions) are allowed in SNePSLOG.

Given that background, we will now discuss the intended semantics of SNePSLOG expressions.

An **individual constant**, expressed in SNePSLOG as a Lisp symbol, string, or number, denotes a mental entity. The unique names assumption holds, meaning that no two mental entities may be considered to be entirely equal.

A **function symbol**, also expressed in SNePSLOG as a Lisp symbol, string, or number, denotes a conceptualized function or relation in the domain. (Recall that what is considered a truth-functional relation in standard logic is a proposition-valued function in SNePS.) Function symbols do not have fixed arity in SNePSLOG. In fact p(a,b,c) implies p(a,b) by reduction inference. The user must be careful to always give a function symbol the same number of arguments if this behavior is not wanted.

A **functional term**, consisting of a function symbol and its arguments, denotes a mental entity, possibly a proposition, in the domain, namely that mental entity that results from applying the denotation of the functional term to the denotations of the arguments. No two functional terms that are syntactically different denote the same mental entity. This is called the Uniqueness Principle.

Functional terms with **sets as arguments** takes the elements of the sets conjunctively. For example, motherOf({John, Jane, Tom, Betty}) is the mother of John, Jane, Tom, and Betty. Also Isa({Rover, Fido}, {dog, pet}) is the proposition that Rover and Fido are both dogs and pets.

andor (i, j) {P1, ..., Pn} denotes the proposition that at least i and at most j of P1, ..., Pn are true.

```
P1 and ...and Pn is an abbreviation of andor (n, n) {P1, ..., Pn}.

P1 or ...or Pn is an abbreviation of andor (1, n) {P1, ..., Pn}.

and{P1, ..., Pn} is an abbreviation of andor (n, n) {P1, ..., Pn}.

or{P1, ..., Pn} is an abbreviation of andor (1, n) {P1, ..., Pn}.

nand{P1, ..., Pn} is an abbreviation of andor (0, n-1) {P1, ..., Pn}.

nor{P1, ..., Pn} is an abbreviation of andor (0, n-1) {P1, ..., Pn}.

xor{P1, ..., Pn} is an abbreviation of andor (1, n) {P1, ..., Pn}.

thresh(i, j){P1, ..., Pn} denotes the proposition that either fewer than i or more than j of P1, ..., Pn are true.

thresh(i){P1, ..., Pn} is an abbreviation of thresh(i, n-1){P1, ..., Pn}.

P1 <=> ...<=> Pn is an abbreviation of thresh(1, n-1){P1, ..., Pn}.

iff{P1, ..., Pn} is an abbreviation of thresh(1, n-1){P1, ..., Pn}.
```

```
\{P1, \ldots, Pn\} i \Rightarrow \{Q1, \ldots, Qm\} denotes the proposition that if any i of P1,..., Pn are true,
than so are Q1, ..., and Qm.
   \{P1, \ldots, Pn\} \Rightarrow \{Q1, \ldots, Qm\} is an abbreviation of \{P1, \ldots, Pn\} 1 \Rightarrow \{Q1, \ldots, Pn\}
   \{P1, \ldots, Pn\} v=> \{Q1, \ldots, Qm\} is an abbreviation of \{P1, \ldots, Pn\} 1=> \{Q1, \ldots, Pn\}
Qm}.
   \{P1, \ldots, Pn\} &=> \{Q1, \ldots, Qm\} is an abbreviation of \{P1, \ldots, Pn\} n=> \{Q1, \ldots, Pn\}
Qm}.
   all (x1, \dots xn) (P (x1, \dots, xn)) denotes the proposition that every ground instance of P (x1, \dots, xn)
..., xn) that obeys the Unique Variable Binding Rule (UVBR) is true. A ground instance of P(x_1, \ldots, x_n)
obeys UVBR if no term already in \mathbb{P}(x_1, \ldots, x_n) substitutes for any of the variables x_1, \ldots, x_n, and
if no one term substitutes for more than one variable.
   nexists(i, j, k) (x1, ..., xn) ({P1, ..., Pnn} : {Q1, ...Qmm} denotes the propo-
sition that there are k substitution instances (obeying UVBR) of x1, ..., xn that satisfy P1, ...,
Pnn, and of them, at least i and at most j also satisfy Q1, ...Qmm.
   nexists(i, k) (x1, ..., xn) (\{P1, ..., Pnn\} : \{Q1, ..., Qmm\} abbreviates
nexists(i, k, k)(x1, ..., xn)(\{P1, ..., Pnn\}: \{Q1, ...Qmm\} nexists(_, j,_)(x1,
..., xn) (\{P1, \ldots, Pnn\}: \{Q1, \ldots, Qmm\} denotes the proposition that there are at most k
substitution instances (obeying UVBR) of x1, ..., xn that satisfy P1, ..., Pnn and also Q1,
```

In all cases "... are true" does not mean the same as "... are believed". Truth is from the point of view of the agent. For example, if the agent believes $p() \Rightarrow q()$ (that is, the wff $p() \Rightarrow q()$ is asserted in the current belief space), and also believes p(), it still might not believe q() if the "rule" $p() \Rightarrow q()$ hasn't "fired", but when the rule $p() \Rightarrow q()$ does fire, the agent will believe q(). (That is, when the agent "reasons" using $p() \Rightarrow q()$, it will conclude q().)

6.4 Inference in SNePSLOG

6.4.1 Rules of Inference

The implemented rules of inference of SNePSLOG are listed in this section. Not all logically possible operations have been implemented. Each connective and quantifier could have introduction rules and elimination rules. Each of those could operate while forward chaining, while backward chaining, and during bi-directional inference. There are two aspects to bi-directional inference:

- 1. If a proposition forward chains into one antecedent of a rule, backward chaining is performed on the other antecedents, and first, if necessary, on the rule itself. This backward inference triggered by forward inference operates whenever forward inference operates.
- 2. If backward inference creates a subgoal that is not satisfied, the subgoal remains as an active process until the next time clear-infer is issued. If the subgoal is later matched during forward inference, the backward inference that created it is resumed. Forward inference that causes one of these backward-inference processes to be resumed is called "forward-in-backward chaining" below. Forward-in-backward chaining operates for whatever rules of inference normal forward chaining operates, but sometimes it is operational even though normal forward chaining isn't.

Reduction inference and path-based inference are used when open terms are matched during forward and backward chaining. The Unique Variable Binding Rule is also enforced during matching. According to this rule, two different variables in one wff cannot be instantiated by different terms, and no variable in a wff can be instantiated by another term in its wff.

Whenever a set of wffs is indicated in this section, the wffs are listed in a convenient order. For example, in the andor (n, n)-Elimination rule, any wff can be inferred, not just the first one listed.

Reduction Inference: If t, t1, ..., tn are terms, α and β are sets of terms, $\beta \subset \alpha$, and $t \in \alpha$, then

- 1. $P(t1, \ldots, \alpha, \ldots, tn) \vdash P(t1, \ldots, \beta, \ldots, tn)$
- 2. $P(t1, ..., \alpha, ..., tn) \vdash P(t1, ..., t, ..., tn)$

Path-Based Inference: If

- 1. define-frame P(r r1 ...ri ...rn) has been done,
- 2. define-path $ri \rho$ has been done,
- 3. P(a1, ..., ai, ..., an) is asserted,
- 4. and the path ρ exists in the network from ai to b,

then $P(a1, \ldots, \{ai, b\}, \ldots, an)$ can be derived.

- andor (n, n)-Elimination: andor (n, n) {P1, ..., Pn} \vdash P1 operates during both forward and backward chaining.
- andor (n, n)-Introduction: $P1, \ldots, Pn \vdash \text{andor}(n, n) \{P1, \ldots, Pn\}$ operates during backward chaining and forward-in-backward chaining.
- andor (0,0) -Elimination: andor (0,0) {P1, ..., Pn} \vdash ~P1 operates during both forward and backward chaining.

andor (0,0)-Introduction:

- 1. ~P1,..., ~Pn \= andor (0,0) {P1, ..., Pn} operates during backward chaining and forward-in-backward chaining.
- 2. If P is asserted with the origin set α , and ${}^{\sim}P$ is asserted with the origin set β , and H is in $\alpha \cup \beta$ and is chosen as the culprit of the contradiction, then ${}^{\sim}H$ is derived in the origin set $(\alpha \cup \beta) \setminus \{H\}$.

andor (i, j) (i < n, j > 0) -Elimination:

- 1. andor (i, j) {P1, ..., Pn}, P1, ..., Pj \vdash $\tilde{}$ Pn, for $0 \le i \le j < n$, 0 < j < n, operates during both forward and backward chaining.
- 2. andor (i, j) $\{P_1, \ldots, P_n\}$, $P_1, \ldots, P_{n-i} \vdash P_n$, for $0 < i < n, i \le j \le n$, operates during both forward and backward chaining.

thresh-Elimination:

- 1. thresh (i, j) $\{P_1, \ldots, P_n\}$, $P_1, \ldots, P_i, P_{i+1}, \ldots, P_{i+n-j-1} \vdash P_n$, operates during both forward and backward chaining.
- 2. thresh (i, j) $\{P_1, \ldots, P_n\}$, $P_1, \ldots, P_{i-1}, P_i, \ldots, P_{i+n-j-1} \vdash P_n$, operates during both forward and backward chaining.
- *i*=>-Elimination: $\{P1, \ldots, Pn\}$ i=> $\{Q1, \ldots, Qm\}$, $P1, \ldots, Pi \vdash Q1$ operates during both forward and backward chaining.
- **v=>-Introduction:** If $P1 \vdash \{Q1, \ldots, Qm\}$, then $\vdash P1 \lor => \{Q1, \ldots, Qm\}$, operates during backward chaining.
- &=>-Introduction: If P1, ..., $Pn \vdash Q1$, and ..., and P1, ..., $Pn \vdash Qm$ such that Q1, and, ..., and Qm have an origin set in common, then $\vdash \{P1, \ldots, Pn\}$ &=> $\{Q1, \ldots, Qm\}$, operates during backward chaining.

67

nexists-Elimination:

```
nexists (i, j, k) (\vec{x}) (\{P_1(\vec{x}), \ldots, P_n(\vec{x})\} : \mathcal{Q}(\vec{x})), P_1(\vec{a}_1), \ldots, P_n(\vec{a}_1), Q(\vec{a}_1), ..., P_1(\vec{a}_j), \ldots, P_n(\vec{a}_j), Q(\vec{a}_j), P_1(\vec{a}_{j+1}), \ldots, P_n(\vec{a}_{j+1}) \vdash \mathcal{Q}(\vec{a}_{j+1}) operates during both forward and backward chaining.

2.

nexists (i, j, k) (\vec{x}) (\{P_1(\vec{x}), \ldots, P_n(\vec{x})\} : \mathcal{Q}(\vec{x})), P_1(\vec{a}_1), \ldots, P_n(\vec{a}_1), \mathcal{Q}(\vec{a}_1), ..., P_1(\vec{a}_{k-i}), \ldots, P_n(\vec{a}_{k-i}), \mathcal{Q}(\vec{a}_{k-i+1}) \vdash Q(\vec{a}_{k-i+1}) operates during both forward and backward chaining.
```

all-Elimination:

- 1. all (\vec{x}) (andor (i, j) $\{P1(\vec{x}), \ldots, Pn(\vec{x})\}$), $P1(\vec{a}), \ldots, Pj(\vec{a}) \vdash {}^{\sim}Pn(\vec{a}), \text{ for } 0 \leq i \leq j < n. 0 < j < n$
- 2. all (\vec{x}) (andor (i, j) $\{P_1(\vec{x}), \ldots, P_n(\vec{x})\}$), $P_1(\vec{a}), \ldots, P_{n-i}(\vec{a}) \vdash P_n(\vec{a}), \text{ for } 0 < i < n, i \le j \le n$
- 3. all (\vec{x}) (thresh (i,j) $\{P_1(\vec{x}), \ldots, P_n(\vec{x})\}$), $P_1(\vec{a}), \ldots, P_i(\vec{a}), P_{i+1}(\vec{a}), \ldots, P_{i+n-j-1}(\vec{a}) \mapsto P_n(\vec{a})$
- 4. all (\vec{x}) (thresh (i, j) $\{P_1(\vec{x}), \ldots, P_n(\vec{x})\}$), $P_1(\vec{a}), \ldots, P_{i-1}(\vec{a}), P_i(\vec{a}), \ldots, P_{i+n-j-1}(\vec{a})$ $\vdash P_n(\vec{a})$
- 5. all(\vec{x})({P1(\vec{x}), ..., Pn(\vec{x})} $i \Rightarrow \{Q1(\vec{x}), \ldots, Qm(\vec{x})\}$), P1(\vec{a}), ..., Pi(\vec{a}) $\vdash Q1(\vec{a})$

operate during both forward and backward chaining.

6.4.2 Recursion

Recursive rules such as

```
all(x,y,z) (ancestor(x,y), ancestor(y,z) &=> ancestor(x,z))
```

may be used without causing an infinite loop.

Infinite loops caused by backward chaining on rules such as

$$all(x) (duck(motherOf(x)) => duck(x))$$

or by forward chaining on rules such as

```
all(x)(number(x) => number(successorOf(x)))
```

are terminated under the control of the global parameters *depthCutoffBack* and *depthCutoffForward*, respectively. If a subgoal is generated during backward chaining whose depth, in terms of parenthesis nesting, exceeds *depthCutoffBack*, it is not pursued. Also, if a result is generated during forward chaining whose depth, in terms of parenthesis nesting, exceeds *depthCutoffForward*, it is not pursued. *depthCutoffBack* and *depthCutoffForward* are each set by default to 10, and can be changed independently via setf.

6.5 SNeRE in SNePSLOG

6.5.1 SNePSLOG Versions of SNeRE Constructs

With the introduction of Mode 3 in SNePSLOG (*see* p. 61), almost every structure that can be built *via* SNePSUL can be build *via* SNePSLOG. (For some restrictions, *see* §6.5.2.) Therefore, SNeRE agents can be defined and operated *via* SNePSLOG. In fact, the examples of Chapter 4 are available as a SNePSLOG demo in the distributed version of SNePS.

Each SNeRE caseframe documented in Chapter 4 has a SNeRE version predefined in Mode 3. These are listed below.

Policies: Policies connect propositions to acts, and must be adopted in order to operate as described.

```
ifdo (p, a): If SNIP backchains into p, perform a.

whendo (p, a): If SNIP forward chains into p, perform a, and then unadopt the whendo.

wheneverdo (p, a): If SNIP forward chains into p, perform a.
```

Mental Acts:

- **adopt (p):** The policy p is adopted, and forward chaining is performed on it. That is, if the system is ready to act in accord with p, it does so.
- **believe (p):** p is asserted and forward inference is performed on it, but if a contradiction results, then prioritized belief revision is performed ($see \S 8.5.3$).
- disbelieve (p): The proposition p, which must be a hypothesis, is unasserted.
- unadopt (p): The policy p is unadopted.

Control Acts:

- **achieve (p):** If the proposition p is asserted, do nothing. Otherwise, use deduce to infer plans for bringing about the proposition p, and then do-one of them.
- do-all({a1, ..., an}): Perform all the acts a1, ..., an in a nondeterministic order.
- do-one({a1, ..., an}): Nondeterministically choose one of the acts a1, ..., an, and
 perform it.
- snif({if(p1,a1), ..., if(pn,an)[, else(da)]}): Using deduce determine which
 of the pi hold. If any do, nondeterministically choose one of them, say pj, and perform aj.
 If none of the pi can be inferred, and if else(da) is included, perform da. Otherwise, do
 nothing.
- sniterate({if(p1,a1), ..., if(pn,an)[, else(da)]}): Using deduce determine
 which of the pi hold. If any do, nondeterministically choose one of them, say pj, perform
 aj, and then perform the entire sniterate again. If none of the pi can be inferred, and if
 else(da) is included, perform da. Otherwise, do nothing.
- snsequence(a1, a2): Perform a1, and then perform a2.
- withall(?x, p(?x), a(?x), da): Using deduce, determine which, if any, entities satisfy the open proposition p(?x). If any do, say e1, ..., en, perform a(ei) on each of them in a nondeterministic order. If no entity satisfies p(?x), perform da. Note: the question mark must appear to identify the open variable, and the default act da must be included.
- withsome (?x, p(?x), a(?x), da): Using deduce, determine which, if any, entities satisfy the open proposition p(?x). If any do, nondeterministically choose one, say e, and perform a(e). If no entity satisfies p(?x), perform da. Note: the question mark must appear to identify the open variable, and the default act da must be included.

Propositions about Acts:

- **ActPlan(a1, a2):** The way to perform the act a1 is to perform the act a2. Typically, a1 will be a simple, but non-primitive act, and a2 will be an act structured using the control acts listed above.
- **Effect (a, p):** The effect of performing the act a is that the proposition p will hold. The SNeRE executive described in $\S4.6$ will automatically cause p to be asserted after a is performed.
- **GoalPlan (p, a):** The act a is a plan for bringing about the proposition p. GoalPlan assertions are inferred by achieve (p) to find plans for achieving p.
- **Precondition (a, p):** In order to be able to perform the act a, the proposition p must hold. It is assumed that the SNeRE agent is able to achieve (p). Before the SNeRE executive described in §4.6 performs any act which has inferrable preconditions, it will attempt to achieve all the preconditions.

6.5.2 Restrictions

Snsequence

The primitive control action snsequence (p. 30) can take an arbitrary number of acts, but SNePSLOG cannot accept a function of an arbitrary number of arguments, so in SNePSLOG Mode 3, snsequence is limited to two argument acts. The way around this is to define versions of snsequence for more than two arguments. This is illustrated for a sequence of four acts below:

```
: set-mode-3
Net reset
In SNePSLOG Mode 3.
: ;;; Define the case frame for a 4-act sequence
define-frame snsequence4 (action object1 object2
                                 snepsul::object3 snepsul::object4)
snsequence4(x1, x2, x3, x4) will be represented by
     {<action, snsequence4>, <object1, x1>, <object2, x2>,
                                             <object3, x3>, <object4, x4>}
: ;;; but attach it to the original snsequence primitive action
^(attach-primaction snsequence4 snsequence)
: ;;; Define a specific primitive action to do four times
define-frame say (action object)
say(x1) will be represented by {<action, say>, <object, x1>}
: ^(define-primaction sayAction ((object))
     (print object))
sayAction
: ;;; Attach it
^(attach-primaction say sayAction)
```

```
: ;;; Test it
perform snsequence4(say(one), say(two), say(three), say(four))
one
two
three
four
```

Zero-Argument Predicates and Functions

SNePSLOG syntax does not accept atomic propositions, but it does accept zero-argument predicates and zero-argument functions as long as the parentheses are included. A way to perform zero-argument actions In SNePSLOG is shown here:

```
: set-mode-3
Net reset
In SNePSLOG Mode 3.
--> ;;; Define a zero-argument action
(define-primaction reportAction ()
   (princ "I'm here."))
reportAction
--> ;;; Attach it
(attach-primaction report reportAction)
--> ^^
: ;;; Define the frame so that the action arc goes to the action.
define-frame report (action)
report(x1) will be represented by {<action, report>, <nil, x1>}
: ;;; Test it
perform report()
I'm here.
```

6.6 The Tell-Ask Interface

The Tell-Ask interface, is an easy way to interface with SNePS from Common Lisp programs, and should be used for this purpose whenever parts of the knowledge base are built via SNePSLOG.

```
(snepslog:tell string &rest arguments)
```

string must be a format string, and arguments its arguments. The result of the conversion must be a valid SNePSLOG input. Tell gives that string to the SNePSLOG interpreter, does no printing, and returns whatever the SNePSLOG command would return.

```
(parser:nl-tell string)
```

Assuming that a lexicon and GATN grammar have been loaded, passes string to the parser, and returns a string containing whatever the parser returns. May be called without a package qualifier from the snepslog package.

```
(snepslog:ask string &key verbose)
(snepslog:askifnot string &key verbose)
(snepslog:askwh string &key verbose)
(snepslog:askwhnot string &key verbose)
```

string must be a valid argument to the SNePSLOG command ask, askifnot, askwh, or askwhnot, respectively. These functions all give *string* to the appropriate SNePSLOG command, and return what the SNePSUL command would print. If :verbose is t, the functions print the results as well as returning them.

```
(snepslog:foreachsub variables subs &body forms)
```

For each substitution in *subs*, evaluates the forms in *forms* with the variables in *variables* taking on the values specified by that substitution. This is particularly useful for processing the values returned by (askwh ...) or by (tell "askwh...").

6.7 The Java-SNePS API

Users who are either running SNePS under Franz's ACL, or as the distributed executable have a Java-SNePS API available.

To use SNePS from a Java program:

• include in the Java program the import statements

```
import java.util.HashSet;
import edu.buffalo.sneps.JavaSnepsAPI;
import edu.buffalo.sneps.Substitution;
```

• include the locations of the files <code>jlinker.jar</code> and <code>JavaSnepsAPI.jar</code> in the Java classpath.

The Java program must create an object of the JavaSnepsAPI class. There are two constructors for JavaSnepsAPI:

- 1. public JavaSnepsAPI(java.lang.String config_file, int interface_port) Creates an instance of JavaSnepsAPI using the specified config_file and interface_port, and starts SNePS using information specified in the config_file. The config_file is normally in the JavaSnepsAPI subdirectory of the SNePS home directory, and is named java_sneps_config.config, but ask the individual who installed SNePS for specifics.
- 2. public JavaSnepsAPI(int interface_port)
 Creates an instance of JavaSnepsAPI using the specified interface_port. It is presumed that the user will then manually start SNePS and invoke the connection from Common Lisp using the function, snepslog:init-java-sneps-connection:

```
(snepslog:init-java-sneps-connection port classpath)
Initialize a connection between SNePS and Java on the specified port using the given java classpath string. Call this function after creating the JavaSnepsAPI object in the Java process.
```

The JavaSnepsAPI class provides the methods:

• void tell(java.lang.String command)

- java.util.HashSet<java.lang.String> ask(java.lang.String command)
- java.util.HashSet<java.lang.String> askifnot(java.lang.String command)
- java.util.HashSet<Substitution> askwh(java.lang.String command)
- java.util.HashSet<Substitution> askwhnot(java.lang.String command)
- boolean isConnected()
- void endLispConnection()

The Substitution class provides the method

• java.lang.String getValFromVar(java.lang.String var).

See the Java Documentation for details on using the API and its classes and methods. The JavaSnepsAPI subdirectory of the SNePS home directory contains the documentation and a file that provides an example of using the Java-SNePS API, named TestAPI.java. The documentation is also located at http://www.cse.buffalo.edu/sneps/Docs/javadocs/.

Chapter 7

Procedural Attachment

Normally, if the system backchains into a proposition-valued function node, it will use inference to determine what instances of the (negation of the) node may be asserted. If, however, the node has an arc labelled attachedfunction to a node that has been attached to a function, the system will determine what instances of the (negation of the) node may be asserted by evaluating the attached function. For instance, backchaining into the node

```
(p1 (attachedfunction Sum) (add1 3) (add2 4) (sum v1)) could result in a computation to determine that the node  (m1 \ (attachedfunction \ Sum) \ (add1 \ 3) \ (add2 \ 4) \ (sum \ 7))
```

should be asserted.

To use the procedural attachment facility, the user must do three things:

- 1. if using SNePSLOG, define the frames for the predicates to which functions will be attached, if using SNePSUL, define the relations to be used as function arguments;
- 2. define the attached function;
- 3. attach the function to a SNePS predicate node.

These steps are more fully explained below.

1. For an example of (1) using the above example, the SNePSLOG user would do:

```
define-frame Sum(attachedfunction add1 add2 sum)
```

and the SNePSUL user would do:

```
(define add1 add2 sum)
```

The relation, attachedfunction is defined by the SNePS system.

2. Attached functions must be defined by

```
(define-attachedfunction fun (lambda variables) &body)
```

where:

(a) fun will be the name of the attached function.

- (b) each lambda variable must either be a relation used for the arguments of the predicate node, or such a relation enclosed in a pair of parentheses. If the lambda variable is an atomic relation name, it will be bound to the (modified) set of nodes that that relation points to. If it is a relation enclosed in parentheses, the relation symbol will be bound to one element of the (modified) set of nodes that that relation points to (presumably, there will only be one). The way that the nodes will be modified is
 - i. if the node is a variable, it will be left alone;
 - ii. if the node's name looks like a Lisp number, the number will be provided;
 - iii. otherwise, a Lisp symbol whose name is the same string as the node's name will be provided.

In the body of the attached function, the three Lisp predicates numberp, symbolp, and sneps:isvar.n may be used to distinguish the three types of argument.

- (c) the attached function must return a list, each of whose members is a list of two members:
 - i. Either: snip:pos to indicate that the instance of the proposition is to be asserted; or snip:neg to indicate that the negation of the instance of the proposition is to be asserted;
 - ii. A substitution of the form (... (var term) ...) to indicate the appropriate instance of the proposition, where each var is a variable-node argument, and term is a Lisp object to be converted into a node giving the instance.

If the attached function returns nil, that indicates that neither any instance of the proposition nor any instance of its negation is to be asserted.

A simple attached-function definition for the above example is:

3. The user must attach functions to SNePS predicates using

```
(attach-function node fun node fun \dots)
```

For example

```
(attach-function Sum sumfn)
```

After which, the SNePSLOG user can ask questions such as

```
sum (3, 4, 7)?
and Sum (4, 6, ?x)?
```

and the SNePSUL user can ask questions such as

```
(deduce attachedfunction Sum add1 3 add2 4 sum 7) and (deduce attachedfunction Sum add1 3 add2 4 sum $x)
```

Chapter 8

SNeBR: The SNePS Belief Revision System

8.1 Hypotheses, Contexts, and Belief Spaces

A proposition may be asserted as an **hypothesis** or as a **derived belief**. An hypothesis is a proposition asserted into the SNePS knowledge base (KB) by the user or by the believe mental act. A derived belief is one whose assertion status depended on derivation, via the implemented rules of inference, from other beliefs.

A **context** (*see also* §1.6) is a named structure that contains a set of hypotheses. There is always a **current context** within which all reasoning is performed. (In SNePSUL, many commands take an optional context argument to change this default behavior.)

A **belief space** (BS) defined by a context is the union of the set of hypotheses of the context and the set of derived beliefs that were derived from the hypotheses of the context. The current BS is the BS defined by the current context. Whenever it is said that a proposition is asserted, it should be understood as being asserted in the current BS.

8.2 Responsibilities of SNeBR

SNeBR, the SNePS Belief Revision System has five responsibilities:

- 1. Recognize when the current BS is contradictory.
- 2. Identify the possible culprits of a contradiction.
- 3. Help the user choose the culprit to be blamed for a contradiction, and disbelieve it.
- 4. Disbelieve any proposition derived from an hypothesis that is disbelieved (disbelief propagation).
- 5. Warn the user about contexts already known to be contradictory.

These responsibilities are discussed in the following sections, using the SNePSLOG (Chapter 6) syntax.

8.3 Recognizing a Contradiction

SNeBR recognizes that the current BS is contradictory when both some proposition p and $nor\{p, \ldots\}$ are asserted. (They could be asserted in either order.) Thus SNeBR doesn't recognize that the BS is contradictory in the sense that a contradiction *could be* derived; it only recognizes that contradiction *has been* explicitly

believed. We therefore speak of a BS being "known to be contradictory." Similarly, we speak of a context being known to be contradictory when a contradiction has been derived from a subset of its hypotheses.

8.4 Identifying Possible Culprits

Every proposition that was ever asserted in any BS will have a **support set**, a set of supports, each of which consists of an origin tag and an origin set. If the proposition p has been introduced as an hypothesis, one of its supports will be $\langle \text{hyp}, \{p\} \rangle$, where hyp is the origin tag indicating that p is an hypothesis and $\{p\}$ is the origin set containing p as its only element. If a proposition p has been derived, it will have a support containing an origin tag of either der or ext, and an origin set which will be a set of hypotheses from which p was derived. The SNePS inference engine, SNIP, is an implementation of a version of the logic of relevant entailment, and guarantees that every hypothesis in the origin set of p was relevantly used to derive p, at least in one way—a proposition may be derived in multiple ways, and so have multiple supports.

Whenever a contradictory pair of propositions, p and $nor\{p, \ldots\}$ is asserted, the two propositions will have support sets $\{\langle \tau_1, \sigma_1 \rangle, \ldots, \langle \tau_n, \sigma_n \rangle\}$ and $\{\langle \tau'_1, \sigma'_1 \rangle, \ldots, \langle \tau'_n, \sigma'_n \rangle\}$. Every set of hypotheses $\sigma_i \cup \sigma'_j$ is now known to be contradictory, and comprises a set of possible culprits for the contradiction. At least one member of each of those sets must be chosen as a culprit, and removed from the current context if the current BS is to be restored to a state of not being known to be contradictory.

8.5 Choosing a Culprit

8.5.1 Manual (Assisted) Culprit Choosing

Manual (also known as "assisted") culprit choosing is the default when using SNePSLOG mode 1 or 2, and when using SNePSUL. To explicitly specify that manual culprit choosing is to be used, use the SNePSLOG command br-mode manual, or the SNePSUL command (br-mode nil).

If the manual belief revision mode is in force, the user must decide, with the assistance of SNeBR, what to do about a contradictory BS.

First, SNeBR informs the user that "a contradiction was detected," and specifies the contradictory context and the two contradictory propositions, showing the support set of each.

Then, SNeBR gives the user a choice (not necessarily in the order shown):

- 1. The user may choose to not do the input that led to the contradiction. The context and BS are left as they were.
- 2. The user may choose to continue in an inconsistent context. That situation is not disastrous—since SNePS uses a paraconsistent logic, a contradiction does not imply irrelevant other propositions. To remind the SNePSLOG user that the current BS is inconsistent, the SNePSLOG prompt is changed from ":" to "*:".
- 3. The user may choose to have SNeBR attempt to resolve the contradiction automatically. In this case, automatic culprit choosing is done (*see* §8.5.2), but for this contradiction only. Afterwards, assisted culprit choosing is resumed.
- 4. The user may choose to revise the context now known to be inconsistent.

In case the user chooses to revise the context, SNeBR presents the user with each set of possible culprits, as follows.

1. If any of the possible culprits is in the origin set of both contradictory propositions, the user is warned that choosing that as the culprit "might be too extreme a revision."

- 2. Then SNeBR lists each of the possible culprits, listing all the propositions it supports, and showing how many propositions are in the list. Choosing this as the culprit and disbelieving it will result in all these supported propositions also being removed from the BS (unless they have alternate derivations).
- 3. The user may then
 - "discard" some of the possible culprits from the context, choosing them as actual culprits;
 - examine all the hypotheses in the context, even those that are not possible culprits;
 - see the culprits already chosen;
 - get instructions;
 - or "quit revising this set" of possible culprits.

This choice repeats until the user chooses to "quit revising this set".

This entire process is repeated for each set of possible culprits until at least one actual culprit has been chosen for each one.

After identifying at least one actual culprit in each set of possible culprits, the user is shown the remaining list of consistent (really, not known to be inconsistent) hypotheses in the context, and given the same choices as though it were a list of possible culprits. Thereby, the user may disbelieve additional hypotheses, even though they were not responsible for the contradiction.

Finally, the user is given a chance to add new hypotheses to the context. This is especially useful if a rewording of one of the culprits is desired.

8.5.2 Automatic Culprit Choosing

Epistemic Entrenchment Ordering

When choosing the culprit(s) of a contradiction automatically, SNeBR prefers not to choose a proposition p_2 if it is more **epistemically entrenched** than an alternative, p_1 . In this section, we will use the notation $p_1 < p_2$ to mean that p_1 is strictly less epistemically entrenched than p_2 , $p_1 > p_2$ to mean that p_1 is strictly more epistemically entrenched than p_2 , $p_1 = p_2$ to mean that p_1 is as epistemically entrenched as p_2 , and $p_1 \le p_2$ to mean that $p_1 < p_2$ or $p_1 = p_2$.

In order to use automatic culprit choosing, the user must specify an epistemic entrenchment ordering function, which, in this section, we will call Ele, for "epistemically less than or equal to". It must be the case that, for any two propositions p_1 and p_2 , $Ele(p_1, p_2)$ is: defined; returns True if $p_1 \leq p_2$; and returns False if $p_1 > p_2$. Ele provides what is called a total ordering, but not a well ordering. A well ordering would have to specify that either $p_1 < p_2$ or $p_2 < p_1$ for any two propositions p_1 and p_2 . If the user's epistemic entrenchment ordering function is a total ordering but not a well ordering, there might be ties when SNeBR is trying to decide which proposition to choose as the culprit of a contradiction. More on this below.

The user specifies the epistemic entrenchment ordering function by using the set-order command. The argument of set-order must be the name of a function that will be used as this ordering function, and thus must provide a total ordering among propositions, and might provide a well ordering. Several such functions are predefined. The user may use one of these, or may define a new one using one of these as a model:

null-order:

```
(defun null-order (p1 p2)
  "Always returns t,
  meaning that all propositions are equally entrenched."
  (declare (ignore p1 p2))
  t)
```

fluent:

```
(defun fluent (p1 p2)
      "Returns t if pl is a fluent and p2 isn't,
                 or if p1 and p2 are both fluents,
                 or if neither p1 nor p2 are fluents,
        meaning that p1 \le p2 in the epistemic entrenchment ordering;
       otherwise, if p2 is a fluent and p1 is not, returns nil."
      (or (is-fluent p1) (not (is-fluent p2))))
    (defun is-fluent (n)
      "Returns t if the function symbol for the proposition node n
         is on the list of fluents;
       nil, otherwise."
      (let ((pred (relation-predicate n)))
        (member (if (consp pred)
                    (get-node-name (first pred))
                  pred)
                *fluents*)))
source:
    (defun source (p1 p2)
      "Returns t iff p1 <= p2 in the epistemic entrenchment ordering.
       Uses assertions:
            HasSource(p,s) to mean that proposition p's source is s;
            IsBetterSource(s1,s2) to mean
                                      that s1 is a more credible source than s2.
       If p1 and p2 are the same, then they're epistemically tied.
       If neither p1 nor p2 has a source, then they're epistemically tied.
       If only one of p1 or p2 has a source,
          then the one without the source
               is more epistemically entrenched than the other.
       If they both have sources,
          then p1 \le p2 \pmod{(p1 > p2)}
              iff it is not the case
                  that for every source of p2
                       there is a source of p1 that is more credible than p2's source."
      (or (eq p1 p2)
          (let ((p1sources (mapcar #'(lambda (sub) (match:value.sbst 'x sub))
                                    (tell "askwh HasSource(~A, ?x)" p1)))
                (p2sources (mapcar #'(lambda (sub) (match:value.sbst 'x sub))
                                    (tell "askwh HasSource(~A, ?x)" p2))))
            (if (and plsources p2sources)
                (not (every #'(lambda (s2)
                                 (some #'(lambda (s1)
                                           (and (not (eq s1 s2))
                                                (tell "ask IsBetterSource(~A, ~A)"
                                                      s1 s2)))
                                       plsources))
                            p2sources))
              (not p2sources)))))
```

explicit:

```
(defun explicit (p1 p2)
  "Returns t iff p1 <= p2 in the epistemic entrenchment ordering.
  Assumes that if IsLessEntrenched(p1,p2) is derivable,
      then p1 is strictly less entrenched than p2."
  (not (tell "ask IsLessEntrenched(~A, ~A)" p2 p1)))</pre>
```

In Case of a Tie

It might be the case that two or more possible culprits are equally epistemically entrenched, but less epistemically entrenched than the other possible culprits. In that case, the tie is broken according to the current br-tie-mode method:

- auto mode causes SNeBR to arbitrarily break entrenchment ties. In the current implementation, the lexicographic order of wffNames is used as the tie-breaking entrenchment order.
- manual mode causes SNeBR to query the user to break entrenchment ties. SNeBR will then remember that the chosen culprit is less epistemically entrenched than the others with which it had been tied.

8.5.3 Prioritized Belief Revision

The discussion, so far, has been about nonprioritized belief revision, meaning that the input that caused the contradiction is as liable to be declared the culprit as any other possible culprit.

If the SNeRE believe act is performed on the proposition p, it is assumed that belief in p is to take priority over any contradictory belief. Thus, prioritized belief revision is performed, meaning that p is considered more epistemically entrenched than any other possible culprit. Therefore, SNeBR behaves as follows.

- 1. if br-mode is set to manual, then the user will be given a choice to perform assisted culprit choosing (but without the choice to choose *p* as the culprit), to attempt automated prioritized belief revision, or to continue in an inconsistent context.
- 2. if br-mode is set to auto, then automated prioritized belief revision will be attempted.

Recall that "automated prioritized belief revision" means that automatic culprit choosing, as described in $\S 8.5.2$, will be done but p will be considered to be more epistemically entrenched than any other possible culprit.

8.6 Disbelief Propagation

Every culprit chosen either automatically or by the user is removed from the set of hypotheses of the current context.

The assertion status of a proposition is computed dynamically whenever it is needed. A proposition is asserted in a given BS if the origin set of at least one of its supports is a subset of the hypothesis set of the context of the BS. Thus, if an hypothesis is removed from a context, any derived belief of the BS defined by that context that needed the hypothesis for its derivation is automatically no longer asserted in the BS.

8.7 Warning About a Belief Space Known to be Contradictory.

Every set of possible culprits, α , is a set of hypotheses known to be contradictory, called a **nogood**. A minimal nogood is a nogood such that no subset of it is known to be contradictory. A global set of minimal nogoods is maintained. Any attempt to create a context that is a superset of any minimal nogood is an attempt to create a context already known to be contradictory, and the user is warned about it.

Chapter 9

SNaLPS: The SNePS Natural Language Processing System

The SNePS Natural Language Processing System consists of a Generalized Augmented Transition Network (GATN) grammar interpreter/compiler and a morphological analyzer/synthesizer.

9.1 Top-Level SNaLPS Functions

The top-level SNaLPS functions are not SNePSUL commands, so to use them from the top-level SNePSUL loop, use the ^ command.

```
(atnin file &key :check-syntax)
```

Loads the GATN grammar in *file*. See Section 9.3 for the syntax of the grammar file. If

: check-syntax is t, syntax checks and some simple semantic checks are performed on the grammar as it is input. It reports errors such as undefined target states, pre-actions after actions (on push arcs), and syntactically ill-formed arcs. If : check-syntax is nil (default), this checking is not done.

```
(lexin file)
```

Loads a lexicon from file. See Section 9.4.1 for the syntax of a lexicon file.

```
(parse [state] [trace-level])
```

Enter the SNaLPS read-parse-print loop. The optional parameters *state* and *trace-level* may appear in either order. If present, *state* must be a symbol, and becomes the initial state of the GATN grammar (the default is 'S). If present, *trace-level* must be an integer (default, 0), and becomes the trace level. See below for the effects of the possible trace-levels.

```
(break-arc state arc-no [break-message])
```

Causes a Lisp break to occur on the arc numbered *arc-no* (in the order as input by atnin) out of state *state* just before the *test* is performed; if a *break-message* is present it is passed to the Lisp format function and printed. In the break package, the contents of registers (and SNaLPS variables) may be examined and modified (by using the GATN actions and forms). Additionally, the current configuration of the parser may be viewed by using current-configuration. Resuming, by entering ^^, :continue, or continue to the break listener, continues the parse at the point where it was broken. This function, unbreak-arc, and current-configuration are intended to help debug grammars.

(unbreak-arc *state arc-no*)

Removes a break from an arc previously set by break-arc.

```
(current-configuration [trace-level])
```

Prints out the current configuration of the GATN parser. Depending on the value of *trace-level* (defaults to *trace-level*, see below) the configuration is printed in lesser or greater detail.

9.2 The Top-Level SNaLPS Loop

9.2.1 Input to the SNaLPS Loop

Having executed the parse command, the user will enter the SNaLPS top-level read-parse-print loop, the prompt of which is ":". At each prompt, the user may enter any of the following:

- ^end: Terminate the SNaLPS read-parse-print loop. If *terminating-punctuation-flag* (see below for a description of SNaLPS variables) is non-nil then this must be terminated by a terminating punctuation character.
- or ^^: Enter an embedded Lisp read-eval-print loop. This is especially useful to set SNaLPS variables (see below). This Lisp loop is left by entering continue, or :continue, or ^^. (If *terminating-punctuation-flag* (see below for a description of SNaLPS variables) is non-nil then the command for entering an embedded Lisp loop must be terminated by a terminating punctuation character.)

A sentence: A sentence to be parsed is written in the normal fashion—as a sequence of words, not enclosed in parentheses, with punctuation immediately following a word rather than separated by blanks. The initial word may be capitalized. The sentence may extend over several lines either by ending every line except the last with one or more blanks, or by setting the variable *terminating-punctuation-flag* to a list of sentence-terminating punctuation marks (See below for a description of SNaLPS variables). Each punctuation mark must be parsed by the grammar as a separate word.

Besides the grammar, the behavior of SNaLPS is affected by a set of variables and by the trace-level. These are described below.

9.2.2 SNaLPS Variables

These variables affect the behavior of SNaLPS, and may be set within an embedded Lisp loop within the SNaLPS loop.

- *all-parses* If nil (default), only the first parse is produced; if t, all parses are produced, with the user queried as to whether or not to produce more parses after each one is printed.
- *parse-trees* If nil (default), the contents of all GATN registers are assumed to be sequences (flattened lists), any list structure stored into a register is automatically flattened, and an atom and a list of one atom are considered to be the same; if t this flattening is not done, and list structure is preserved.
- *terminating-punctuation-flag* A list of punctuation marks that will be used to signal the end of a sentence. Each punctuation mark should be enclosed in quote marks to make it a string. E.g. the list might be ("." "?" "!"). If this variable is nil (default), the only way to let a sentence extend over more than one line is to end each line before the last with a blank. If this variable is non-nil, the SNaLPS top-level reader will continue to read words from successive lines until a terminating punctuation mark is encountered.

- *trace-level* An integer indicating what printing is to be done by SNaLPS. The possibilities are listed below. Each trace level also does what every lower level does.
 - -2: SNaLPS does no printing.
 - -1: Prints the time taken by each parse.
 - 0: Default. Prints the trace level, the starting state, and the results of each parse. If the result is a SNePS node it is printed using SNEPS::DESCRIBE. Various error messages may also be printed at this trace level.
 - 1: A warning is printed if a word is looked up in the lexicon, but not found there.
 - 2: Reserved for future trace information.
 - 3: Reserved for future trace information.
 - 4: Prints the string representation of the original sentence, and prints a trace of the execution of each arc traversed and its associated configuration.
 - 5: Prints the current configuration of the GATN parser prior to taking any transitions. Any HOLDs, SENDRs, or LIFTRs associated with a configuration being output are printed.
 - 6: Prints the arc currently being attempted, regardless of success. Also prints all blocked arcs.
 - 7: Reserved for future trace information.
 - 8: Parent configurations of a configuration being output are also printed. This is voluminous, but useful for debugging deeply embedded (via PUSH, CALL, or RCALL) configurations.
 - 9: All the acts associated with a configuration that was PUSHed, CALLed, or RCALLed to are printed. This is not normally useful.
 - 10: Reserved for future trace information.

Higher trace levels result in more voluminous trace output. For straight-forward trace output, trace level 4 is suggested. For the purposes of printing configurations, if a particular field of the configuration is empty it is not printed regardless of the trace level. For example, if in the configuration being printed, there are no registers, this field is not printed. Note that this does NOT apply to the LEVEL, STATE, and STRING fields, which are always printed regardless of the trace level.

Trace levels up to level 8 can be utilized with little effort and beneficial effects. It is suggested that a novice user closely examine a level 8 trace to become familiar with the operation of the parser.

9.3 Syntax and Semantics of GATN Grammars

In this section, syntactic variables are in *italic* font, optional constituents are enclosed in "[" and "]" brackets, "*" means zero or more occurrences, "+" means one or more occurrences, parentheses and items in typewriter font are object language symbols.

```
gatn-grammar ::= arc-set<sup>+</sup>
```

The contents of a grammar-file is a sequence of arc-sets.

```
arc\text{-set} ::= (state \ arc^+) \mid (^ \cdot \ . \ Lisp\text{-form})
```

An *arc-set* is either a list whose car is a state and whose cdr is a list of GATN arcs, or it is a list whose car is the symbol ^^ and whose cdr is a Lisp form which will be evaluated at grammar load time.

9.3.1 Arcs

arc ::=

The syntax and semantics of GATN arcs follows. Except as noted, all *forms* and *actions* on an arc are evaluated in left-to-right order, in the environment of the arc that they are on.

```
(cat category test action* terminal-action)
```

If the input buffer is empty, the arc blocks. The lex register is set to the current word. If any sense(s) of the word have the given lexical *category* in the lexicon, the arc is taken non-deterministically for each sense. For each sense, \star is set to the root of the word sense, and *test* is performed. If *test* fails, the arc blocks for the given word sense; otherwise, *actions* are done, and the *terminal-action* is taken.

```
(call state form test preaction-or-action* register action* terminal-action)
```

If the input buffer is empty, the arc blocks. The \star register is set to the current word, and *test* is performed. If *test* fails, the arc blocks. Otherwise: the *preaction-or-actions* are done; the value of *form* replaces the current word in the input buffer (if the value of *form* is a list, it is spliced in); and parsing continues recursively at *state*. If the recursively called network blocks, this arc blocks also. When that level pops back to this one: the value popped to this level is put into *register*; the value of the \star register is pushed onto the front of the input buffer; the *actions* are done, and the *terminal-action* is taken.

```
(group arc^+)
```

Presumably, at most one *arc* has a *test* that succeeds. That arc is taken. group is provided for efficiency only. If a group arc is backed into, alternate sub-arcs are not tried, but the entire group fails.

```
(jump state test action*)
```

The \star register is set to the current word, and *test* is performed. If *test* fails, the arc blocks. Otherwise the *actions* are done, and parsing continues at *state*.

```
(pop form test action*)
```

If test is non-nil and the hold register doesn't contain anything put into it on this level, the actions are done, and the value of form is popped to the level that recursively called this one. If this is the top level (level 1), then not only must test be non-nil and the hold register not contain anything put into it on this level, but also the input buffer must be empty. If this is level 1 and the input buffer is not empty, or this is any level and test is nil or the hold register contains something put into it at this level, this arc blocks.

```
(push state test preaction* action* terminal-action)
```

If the input buffer is empty, the arc blocks. Otherwise, the * register is set to the current word, and test is performed. If the *test* is non-nil, the *preactions* are done, and parsing continues recursively at *state*. When that level pops back to this one the value popped to this level is put into the * register, that value is pushed onto the front of the the input buffer, the *actions* are done, and the *terminal-action* is taken. If the *test* is nil, or the recursively called network blocks, this arc blocks.

```
(to (state [form]) test action*)
```

If the input buffer is empty, the arc blocks. Otherwise, the * register is set to the current word, and test is performed. If the *test* is non-nil; the *actions* are done; the front symbol in the input buffer is removed from it; if *form* is present, its value is pushed onto the front of the input buffer; and parsing continues at *state*. If the *test* is nil, the arc blocks.

```
(rcall state form test preaction-or-action* register action* terminal-action)
```

If the input buffer is empty, the arc blocks. Otherwise, the * register is set to the current word, and test is performed. If the *test* is non-nil the *preaction-or-actions* are done, the current input buffer is saved and replaced by the value of *form*, and parsing continues recursively at *state*. When that level pops back to this one, the input buffer is restored as it was saved, the value popped to this level is put into *register*, if *register*

is * that value replaces the front of the input buffer, the *actions* are done, and the *terminal-action* is taken. If the *test* is nil, or the recursively called network blocks, this arc blocks.

```
(tst label test action* terminal-action)
```

If the input buffer is empty, the arc blocks. Otherwise, the * register is set to the current word, and test is performed. If the *test* is non-nil, the *actions* are done, and the *terminal-action* is taken. If the *test* is nil, the arc blocks. *label* is only there so that different tst arcs may be distinguished during tracing.

```
(vir category test action* terminal-action)
```

If the *test* is non-nil and the hold register contains an entry of the given *category* put into it at this or a higher level, then the arc is taken non-deterministically for each such entry. The entry taken is removed from the hold register, put into the * register, and pushed onto the front of the input buffer. Then the *actions* are done and the *terminal-action* is taken. If the *test* is nil, or hold contains no appropriate entry, this arc blocks.

```
(wrd word-list test action* terminal-action)
```

If the input buffer is empty, the arc blocks. Otherwise, the current word is compared to *word-list*. If it is among the words in *word-list*, the * register is set to the current word, and test is performed. If the *test* is non-nil, the *actions* are done, and the *terminal-action* is taken. If either the *test* is nil or the current word is not on the *word-list*, the arc blocks.

9.3.2 Actions

action ::=

The syntax and semantics of GATN actions follows:

```
(addl register form<sup>+</sup>)
```

The value of *form* is appended to the front (left end) of *register*. If more than one *form* appears, a list of their values, in the order given, is appended to the front of *register*. If *parse-trees* is nil, the value of *register* is then flattened and a list of one object is changed to just the single object.

```
(addr register form<sup>+</sup>)
```

The value of *form* is appended to the end (right end) of *register*. If more than one *form* appears, a list of their values, in the order given, is appended to the end of *register*. If *parse-trees* is nil, the value of *register* is then flattened and a list of one object is changed to just the single object.

```
(hold category form)
```

The value of *form* is put into the hold register as an entry whose category is the value of *category*.

```
(liftr register[form])
```

register is set to the value of form on the next higher level. If form is omitted, register at that level is set to the value of register at this level. If *parse-trees* is nil, the value of register at the higher level is flattened and a list of one object is changed to just the single object.

```
(setr register form<sup>+</sup>)
```

register is set to the value of form. If more than one form appears, register is set to a list of their values, in the order given. If *parse-trees* is nil, the value of register is then flattened and a list of one object is changed to just the single object.

S-expression

Any Lisp S-expression not otherwise listed as a GATN action or form evaluates normally.

9.3.3 Preactions

preaction-or-action ::= preaction | action

A preaction-or-action is either a preaction or an action.

```
preaction ::= (sendr register form*)
```

The only *preaction* is sendr. sendr sets the value of *register* on the level about to be called to the value of *form*. If more than one *form* appears, *register* is set to a list of their values, in the order given. If *form* is omitted, *register* at the lower level is set to the value of *register* at this level. If *parse-trees* is nil, the value of *register* at the lower level is flattened and a list of one object is changed to just the single object.

9.3.4 Terminal Actions

terminal-action ::=

The syntax and semantics of the two terminal actions are:

```
(to state [form])
```

The front symbol in the input buffer is removed from it; if *form* is present, its value is pushed onto the front of the input buffer; and parsing continues at *state*.

```
(jump state)
```

Parsing continues at state.

9.3.5 Forms

form ::=

The syntax and semantics of GATN forms follows:

(buildg fragment form*)

A form consisting of only the symbol \star evaluates to the value of the \star register on the current level.

Evaluates to the given fragment list structure, with each special symbol replaced as indicated below:

```
+: Replaced by the value of the corresponding form.
```

- *: Replaced by the value of the * register.
- (@ fragment⁺): Each fragment is handled as described here, and the resulting sublists are spliced together.

```
(geta unitpath form)
```

Returns the set of SNePS nodes at the end of *unitpath* arcs from all the nodes in the value of *form. form* must evaluate to a set of SNePS nodes.

```
(getf feature [word])
```

Looks up *word* in the lexicon, and returns the value of the given *feature*. If *word* is omitted, it defaults to the current word—this is only allowed on cat arcs.

```
(getr register [level-number])
```

Evaluates to the value of the given *register*. If *level-number* is present, the value of *register* on the given level is returned. The top level of the network is level number 1, and each push increments the level number by 1. If *level-number* is present, it must be a higher level (smaller integer) than the current level.

lex

Evaluates to the current word (first symbol on the input buffer) as it appears before any morphological analysis has been done.

```
(nullr form)
```

Evaluates to non-nil if the *form* evaluates to nil, and to nil otherwise.

```
(overlap form form)
```

Evaluates to the set-intersection of the values of the two *forms*. For this purpose, an atom is treated as a singleton set containing itself.

register

A form consisting of only the name of a register evaluates to the value of that register on the current level. If the *register* has never been given a value on the current level, its value is nil.

S-expression

Any Lisp S-expression not otherwise listed as a GATN form evaluates to its Lisp value. Within a form to be evaluated by Lisp, buildq, geta, getf, getr, nullr, and overlap are all Lisp functions that operate as described in this Subsection.

9.3.6 Tests

A test fails if it evaluates to nil, and succeeds otherwise.

test ::=

The syntax and semantics of GATN tests are:

```
(disjoint form form)
Evaluates to (not (overlap form form)).
```

```
(endofsentence)
```

Returns t iff the current input buffer is empty (nil), or contains only a terminating punctuation character (as specified by *terminating-punctuation-flag*); nil otherwise.

```
(packageless-equal form form)
```

Equality checker for use in grammars, it should be used rather than Lisp's equal. It avoids possible packaging problems associated with the use of Lisp's equal.

form

Any GATN form may be used as a test—any non-nil value corresponds to True, and nil corresponds to False.

t

The always True test.

9.3.7 Terminal Symbols

The following is a description of Terminal Symbols of the above grammar (right hand sides are informal English):

category ::= Any Lisp symbol used in the lexicon as a lexical category.

feature ::= Any Lisp symbol used in the lexicon as a lexical feature.

```
label ::= Any Lisp symbol.

register ::= Any Lisp symbol used as the name of a GATN register.

S-expression ::= Any Lisp S-expression not otherwise recognizable as a GATN form or test.

state ::= Any Lisp symbol used to name a GATN state.

word-list ::= word | (word+)

word ::= Any Lisp string potentially used as a lexicon entry or a word appearing in a sentence.
```

9.4 Morphological Analysis and Synthesis

9.4.1 Syntax of Lexicon Files

The syntax of the contents of a lexicon file is:

```
lexicon ::= lexical-entry*

lexical-entry ::= (lexeme feature-list<sup>+</sup>)
```

A multi-sense lexeme is given one feature-list for each sense. Lexemes on which morphological synthesis is to be done for generation must have only one feature-list.

```
feature-list ::= (feature-pair<sup>+</sup>)

feature-pair ::= (feature . value)

lexeme ::= Any Lisp string

feature ::= Any Lisp atom, but see below for standard features.

value ::= Any readable Lisp object, but see below for standard values.
```

Standard Lexical Features and Values

The following lexical features will be recognized by GATN arcs and/or the morphological analyzer/synthesizer. With each feature it is shown whether it is used for morphological analysis or synthesis or both. A feature whose value is the default for that feature may be omitted from the feature-list.

ctgy The lexical category of the entry. Used for analysis. The following values of this feature are recognized by the morphological analyzer/synthesizer:

```
adj An adjective.

n A common noun.

v A verb.

multi-start This lexeme is the first word of a multi-word lexeme.

See the feature multi-rest described below.
```

multi-rest A list of the rest of the words (after this one) that form a multi-word lexeme. Each word in the list must be a string. There must also be a lexical entry for the multi-word lexeme as a whole.

num The number of a noun or verb. Used for analysis. Its recognized values are sing for singular (default), and plur for plural.

- past The past tense form of a verb that is irregular in this form. Used for synthesis. The value must be a string.
- pastp The past participle form of a verb that is irregular in this form. Used for synthesis. The value must be a string.
- plur The plural form of a noun that is irregular in this form. Used for synthesis. The value must be a string.
- pprt A flag indicating whether the lexeme is a past participle. Used for analysis. Possible values are t indicating that it is a past participle, and nil (default) indicating that it is not.
- pres The third person singular form of a verb that is irregular in this form. Used for synthesis. The value must be a string.
- presp The present participle form of a verb that is irregular in this form. Used for synthesis. The value must be a string.
- presprt A flag indicating whether the lexeme is a present participle. Used for analysis. Possible values are t indicating that it is a present participle, and nil (default) indicating that it is not.
- tense The tense of a verb. Used for analysis. Its recognized values are pres, indicating present tense (default), and past, indicating past tense.
- root The root, stem, infinitive, or uninflected form of the lexeme. Used for analysis and synthesis. The value must be a string. If omitted, will default to the lexeme itself.
- stative Whether or not the verb is stative. Used for synthesis. Its recognized values are nil, indicating not stative (default), and t, indicating stative.

Any additional features and values may be used in a lexicon if a grammar is written to make use of them.

If a lexeme is a root form and has only one feature-list, the lexical entry may be used for both analysis and synthesis. If the principle inflected parts of the noun (plural) or verb (third person singular, past, past participle, present participle) are irregular, those parts must have their own lexical entries, which will only be used for morphological analysis. If a lexeme has multiple lexical entries (because it has multiple lexical categories), they can only be used for analysis. You should give each feature-list its own root form, even if it is a made-up word, and then give each of these root forms a lexical entry with a single feature-list to be used for morphological synthesis. Those feature-lists should have root forms that are correctly spelled forms. The example lexicon in Section 9.5 has a regular and an irregular noun, a regular and an irregular verb, a word ("saw") that is both a noun and a verb, and a multi-word lexeme ("Computer Science").

9.4.2 Functions for Morphological Analysis

(englex:lookup word)

Looks up the word, which must be a string, in the lexicon, and returns its lexical-entry, possibly expanded with default values. If word is not in the lexicon, tries to remove prefixes and suffixes until it finds a root form that is in the lexicon, whereupon it returns an appropriately modified lexical-entry. Uses the standard features and values listed above as used for morphological analysis. englex:lookup has been imported into the parser package for use in grammars, but it is seldom necessary for a grammar-writer to call this function directly, because it is called automatically on appropriate GATN arcs. Nevertheless, when writing a lexicon and grammar, it is useful to use this function to test the lexicon and see which forms englex:lookup considers to be regular.

9.4.3 Functions for Morphological Synthesis

The two functions in this section should be used in appropriate places on arcs of GATN generation grammars in order to produce correct surface forms of nouns and verb groups. They both require a loaded lexicon for irregular words, but will assume a word is inflected regularly if it doesn't have a lexical entry. It's a good idea to try them out from a top-level Lisp listener, as they are surprisingly powerful.

```
(verbize [tense] [number] [person] [mode] [progressive-aspect] [perfective-aspect] [voice] [quality]
modal* lexeme)
```

Returns a list of strings which forms a verb group. *lexeme* should be a string (but a symbol or node will be coerced into a string), and is presumed to be the root (infinitive) form of a verb. All the other parameters are optional. If *modals* appear, they must immediately precede *lexeme*. The other parameters may appear in any order. The possible values and the default values of the optional parameters are:

tense The tense of the verb group. Possible values are:

```
pres Present tense. Default.
      past Past tense. Alternative: p.
      future Future tense. Alternatives: futr, ftr, fut.
number The number of the verb group. Possible values are:
      sing Singular. Default. Alternative: singular
      plur Plural. Alternatives: pl, plural.
person The person of the verb group. Possible values are:
      p1 First person. Alternatives: firstperson, person1
     p2 Second person. Alternatives: secondperson, person2.
      p3 Third person. Default.
mode Whether the verb group is in a declarative, interrogative, etc. sentence. Possible values are:
      decl Declarative. Default.
      int Interrogative. Alternatives: yng, interrogative, interrog, ques, question, intrg,
          Q.
      imp Imperative. Alternatives: imper, imperative, impr, command, request, req
      inf Infinitive. Alternatives: infinitive, infin, root
      gnd Gerundive. Alternatives: gerund, ing, grnd
```

progressive-aspect Whether the verb group is progressive. Possible values are:

```
non-prog Non-progressive. Default.

prog Progressive. Alternatives: progr, prg, progress, progressive. A lexeme with (stative . t) in its lexical feature-list will not be put into progressive form.
```

perfective-aspect Whether the verb group is perfective. Possible values are:

```
non-perf Non-perfective. Default.
perf Perfective. Alternatives: pft, prft, prfct, perfect, perfective.
```

voice The voice of the verb group. Possible values are:

```
active Active voice. Default.

pass Passive voice. Alternative: passive.

quality Whether the verb group is negated. Possible values are:

affirmative Affirmative. Default.

neg Negative. Alternatives: nega, negative, not, negated.

modal A modal to be included in the verb group. Possible values are: "will", "shall", "can",
 "must", and "may".

(wordize number lexeme)
```

Returns the singular or plural form of *lexeme*, according to *number*. *lexeme* should be a string(but a symbol or node will be coerced into a string), and is presumed to be a noun. If *number* is nil or 'sing the singular form will be returned, otherwise the plural form will be returned. The singular form will be the value of the root feature of *lexeme* if it has one, otherwise it will be *lexeme* itself. The plural will be formed regularly unless there is a lexical entry for *lexeme* that contains a plur feature. Regular plural formation is sensitive to an extensive set of spelling rules.

9.5 Examples

In this section, we present an example lexicon and two example GATNs, both of which use the one lexicon. The GATN in Section 9.5.1 produces parse trees of acceptable sentences. The one in Section 9.5.2 builds SNePS representations of the information in statements, and answers questions. Both GATNs accept the same fragment of English.

9.5.1 Producing Parse Trees

Here is an example of the use of SNaLPS to parse simple sentences and return parse trees. The GATN is shown below. It is presented graphically in Figure 9.1.

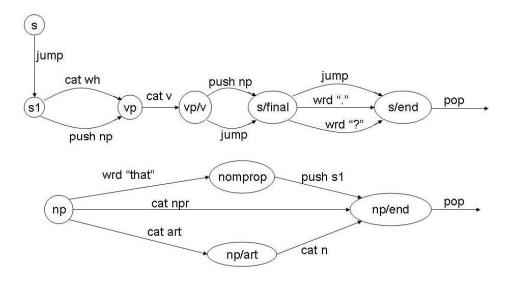


Figure 9.1: Graphical version of the example GATN.

```
(s/end (pop (buildq (s (mood +) + (vp (v +))) mood subj verb) (nullr obj))
       (pop (buildq (s (mood +) + (vp (v +) +)) mood subj verb obj) obj))
(np (wrd "that" t (to nomprop)); An embedded S has "that" in front of it.
    (cat npr t (setr np (buildq (npr *))) (setr def t) (to np/end))
    (cat art t (setr def (getf definite)) (to np/art)))
(np/art (cat n t (setr np (buildq (n *))) (to np/end)))
(nomprop (push s1 t (sendr embedded t) (setr def t) (setr np *) (to np/end)))
(np/end (pop (buildg (np (definite +) +) def np) t))
  Here is the accompanying lexicon:
("a"
                    ((ctgy . art)(definite . nil)))
("the"
                    ((ctgy . art)(definite . t)))
("Computer Science" ((ctgy . npr)))
("John"
                    ((ctgy . npr)))
("Mary"
                    ((ctgy . npr)))
("computer"
                    ((ctgy . n)))
                    ((ctgy . multi-start) (multi-rest . ("Science")))
("Computer"
                    ((ctgy . n)(root . "computer")))
("doa"
                    ((ctqy . n)))
("man"
                    ((ctgy . n)(plur . "men")))
                    ((ctgy . n)(root . "man")(num . plur)))
("men"
("woman"
                    ((ctgy . n)(plur . "women")))
("women"
                    ((ctgy . n) (root . "woman") (num . plur)))
("saw"
                    ((ctgy . n))
                    ((ctgy . v) (root . "see") (tense . past)))
("believe"
                    ((ctgy . v)(stative . t)))
("bit"
                    ((ctgy . v)(root . "bite")(tense . past)))
("bite"
                    ((ctgy . v) (num . plur) (past . "bit")))
("like"
                    ((ctgy . v) (num . plur)))
                    ((ctgy . v)(past . "saw")))
("see"
("sleep"
                    ((ctgy . v)(past . "slept")))
("slept"
                    ((ctgy . v)(root . "sleep")(tense . past)))
("study"
                    ((ctgy . v)))
("use"
                    ((ctqy . v)))
("who"
                    ((ctqy . wh)))
("what"
                    ((ctgy . wh)))
```

and here is a test run. The output has been edited by changing some line breaks and some indentation in order to show the parse trees more clearly.

```
USER(29): (sneps)
Welcome to SNePS-2.5 [PL:1 1999/08/19 16:38:25]
```

```
Copyright (C) 1984--1999 by Research Foundation of
State University of New York. SNePS comes with ABSOLUTELY NO WARRANTY!
Type '(copyright)' for detailed copyright information.
Type '(demo)' for a list of example applications.
  6/21/2002 9:51:59
--> (atnin "grammar.lisp")
State S processed.
State S1 processed.
State VP processed.
State VP/V processed.
State S/OBJ processed.
State NP processed.
State NP/ART processed.
State NP/END1 processed.
State NP/END2 processed.
State S/END1 processed.
State S/END2 processed.
Atnin read in states: (S/END2 S/END1 NP/END2 NP/END1 NP/ART NP S/OBJ VP/V VP
                        S1 S)
--> (lexin "lexicon.lisp")
undefined- (NIL)
("a" "the" "some" "doq" "man" "men" "bite" "bites" "like" "likes")
--> (parse)
ATN parser initialization...
Trace level = 0.
Beginning at state 'S'.
 Input sentences in normal English orthographic convention.
 Sentences may go beyond a line by having a space followed by a <CR>
To exit the parser, write ^end.
: A dog bit John.
Resulting parse:
(S (MOOD DECL)
   (NP (DEFINITE NIL) (N "dog"))
   (VP (V "bite")
       (NP (DEFINITE T) (NPR "John"))))
 Time (sec.): 0.05
 : The dog slept.
Resulting parse:
(S (MOOD DECL)
   (NP (DEFINITE T) (N "dog"))
   (VP (V "sleep")))
 Time (sec.): 0.05
: Mary believes that John likes the dog.
Resulting parse:
```

```
(S (MOOD DECL)
   (NP (DEFINITE T) (NPR "Mary"))
   (VP (V "believe")
       (NP (DEFINITE T)
           (S (MOOD DECL)
              (NP (DEFINITE T) (NPR "John"))
              (VP (V "like")
                  (NP (DEFINITE T) (N "dog")))))))
Time (sec.): 0.117
 : Mary studies Computer Science.
Resulting parse:
(S (MOOD DECL)
  (NP (DEFINITE T) (NPR "Mary"))
   (VP (V "study")
      (NP (DEFINITE T) (NPR "Computer Science"))))
Time (sec.): 0.05
: Mary used a computer.
Resulting parse:
(S (MOOD DECL)
   (NP (DEFINITE T) (NPR "Mary"))
   (VP (V "use")
       (NP (DEFINITE NIL) (N "computer"))))
Time (sec.): 0.05
```

```
: John saw a saw.
Resulting parse:
(S (MOOD DECL)
   (NP (DEFINITE T) (NPR "John"))
   (VP (V "see")
       (NP (DEFINITE NIL) (N "saw"))))
Time (sec.): 0.067
 : What bit John?
Resulting parse:
(S (MOOD QUESTION)
   (NP ?)
   (VP (V "bite")
       (NP (DEFINITE T) (NPR "John"))))
Time (sec.): 0.05
 : Who sleeps?
Resulting parse:
(S (MOOD QUESTION)
   (NP ?)
   (VP (V "sleep")))
Time (sec.): 0.034
: Who studied?
Resulting parse:
(S (MOOD QUESTION)
   (NP ?)
   (VP (V "study")))
Time (sec.): 0.05
: Who uses the computer?
Resulting parse:
(S (MOOD QUESTION)
   (NP ?)
   (VP (V "use")
       (NP (DEFINITE T) (N "computer"))))
Time (sec.): 0.067
 : Who likes a dog?
Resulting parse:
(S (MOOD QUESTION)
   (NP ?)
   (VP (V "like")
       (NP (DEFINITE NIL) (N "dog"))))
Time (sec.): 0.067
```

9.5.2 Interacting with SNePS

The GATN in this section accepts the same fragment of English as the one in the previous section, but, instead of building and returning parse trees, it builds a SNePS network representing the information in the statements and answers the questions. The statements are echoed and the questions are answered in English generated by the generation part of this GATN.

```
;;; First, the SNePS relations used in the GATN are defined.
(^^ define agent act object propername member class lex)
;;; Next, a global variable, a global constant, and two functions are defined.
(^^ defvar *SaynBeforeVowels* nil
    "If true and the next word starts with a vowel,
    print 'n ' before that next word.")
(^^ defconstant *vowels* '(#\a #\e #\i #\o #\u)
    "A list of the vowels.")
;;; The following two functions implement a "phonological" component
;;; that can be used to output words and phrases from arcs of the GATN.
;;; In this way, the beginning of the sentence can be uttered before
;;; the rest of the sentence has been composed.
(^^ defun SayOneWord (word)
    "Prints the single WORD, which must be a string or a node.
    If the word is 'a', sets *SaynBeforeVowels*.
     If *SaynBeforeVowels* is set, then prints 'n ' before word/s
    if the first letter of word/s is a vowel."
    (check-type word (or string sneps:node))
    (when (sneps:node-p word) (setf word (format nil "~A" word)))
    (when *SaynBeforeVowels*
      (when (member (char word 0) *vowels* :test #'char=) (format t "n"))
      (setf *SaynBeforeVowels* nil))
    (when (string\= word "a") (setf *SaynBeforeVowels* t))
    (format t " ^{\sim}A" word))
(^^ defun say (word/s)
    "Prints the single word or the list of words.
    If the word is 'a', sets *SaynBeforeVowels*.
     If *SaynBeforeVowels* is set, then prints 'n ' before word/s
     if the first letter of word/s is a vowel."
    (if (listp word/s) (mapc #'SayOneWord word/s)
        (SayOneWord word/s)))
```

```
;;; The initial arc is used to make two SNePSUL variables, each of
;;; which holds a SNePS variable node. This results in a major
;;; efficiency gain over creating new SNePS variable nodes each time a
;;; question or an indefinite NP is parsed.
(s (jump s1 t
         (or (* 'wh) ($ 'wh)); a SNePS variable to use for Wh questions
         (or (* 'x) ($ 'x)); a variable for indef NP's in questions
(s1 (push ps t
                              ; Parse a sentence, and send results to RESPOND
          (jump respond)))
(ps (cat wh t
                                     ; A Wh question starts with "who" or "what".
                                    ; set AGENT to a variable node.
         (setr agent (* 'wh))
         (setr mood 'question) (liftr mood) (to vp))
    (push np t (sendr mood 'decl); The only acceptable statements are NP V [NP].
                                  ; MOOD must be sent down, because an indefinite
                                  ; NP introduces a new individual in a statement,
                                  ; but must be treated as a variable to be found
                                  ; in a question.
          (setr agent *)
                                ; set AGENT to parse of subject.
          (setr mood 'decl) (liftr mood); The state RESPOND must know whether
                                         ; it is echoing a statement or answering
                                         ; a question.
          (to vp)))
(vp (cat v t
                                ; Accept just a simple verb for this example,
         (setr act *) (to vp/v))); and ignore tense.
(vp/v (push np t (sendr mood)
            (setr object *) ; Set OBJECT to parse of object.
            (to s/final))
      (jump s/final t))
                               ; If no object.
(s/final (jump s/end (overlap embedded t)); an embedded proposition
         (wrd "." (overlap mood 'decl) (to s/end))
         (wrd "?" (overlap mood 'question) (to s/end)))
(s/end (pop #!((assert agent ~(getr agent) ; Assert a top-level statement.
                            (build lex ~(getr act))
                       act
                       object ~(getr object)))
            (and (overlap mood 'decl) (nullr embedded)))
       (pop #2!((build agent ~(getr agent); Build an embedded statement.
                             (build lex ~(getr act))
                       act
                       object ~(getr object)))
            (and (getr embedded) (overlap mood 'decl)))
       (pop \#! ((deduce agent \tilde{\ } (getr agent) ; Use deduce to answer a question.
                       act (build lex ~(getr act))
                       object ~(getr object)))
            (overlap mood 'question)))
;;; Notice in all three above arcs that if there is no object,
;;; (getr object) will evaluate to NIL,
;;; and the node will be built without an OBJECT arc.
```

```
(np (wrd "that" t (to nomprop)) ; an embedded proposition
    (cat npr t
        (setr head (or
                    ;; First try to find someone with the given name.
                    #!((find (compose object- ! propername) ~ (getr *)))
                    ;; Otherwise, create one.
                    #!((find object-
                             (assert object #head propername ~ (getr *)))))
        (to np/end))
    (cat art t (setr def (getf definite)) (to np/art)))
(np/art (cat n (overlap def t) ; a definite np
            (setr head; Find the referent. (Assume there is exactly one.)
                  #!((find member-
                           (deduce member *x
                                  class (build lex ~ (getr *))))))
            (to np/end))
        (cat n (and (disjoint def t) (overlap mood 'decl))
            (setr head ; Create a new referent.
              #!((find member-
                       (assert member #hd
                         class (build lex ~(getr *)))))
            (to np/end))
        (cat n (and (disjoint def t) (overlap mood 'question))
            (setr head (* 'x)); a variable node.
            (to np/end)))
(nomprop (push ps t ; Return the parse of embedded sentence.
              (sendr embedded t) (setr head *) (to np/end)))
(np/end (pop head t))
;;; Generation Section
(respond (jump g (and (getr *) (overlap mood 'decl))
              (say "I understand that")); Canned beginning of echo of statement.
        (jump g (and (getr *) (overlap mood 'question))); Answer of question.
        (jump g/end (nullr *) (say "I don't know."))); Question not answered.
(g (rcall gnp (geta agent) (geta agent); Generate the agent as an np.
         reg (jump g/subj)))
(g/subj (jump g/v (geta act)
             (say (verbize 'past ; For this example, always use past tense.
                           (first (geta lex (geta act)))))))
(q/v (reall gnp (geta object) (geta object); Generate the object.
           reg (to g/end))
     (to (g/end) (null (geta object)))); No object.
```

```
(g/end (pop nil t))
(qnp (to (qnp/end) (qeta propername (qeta object-))
         (say (geta propername (geta object-)))); Generate an npr.
     (to (gnp/end) (geta class (geta member-)); An indef np.
         (say (cons "a" #!((find (lex- class- ! member) ~ (getr *))))))
     (call g * (geta act) (say "that") * ; An embedded proposition
           (to gnp/end)))
(gnp/end (pop nil t))
  Here is a sample run using this grammar and the same lexicon as before:
--> (parse)
ATN parser initialization...
Trace level = 0.
Beginning at state 'S'.
 Input sentences in normal English orthographic convention.
 Sentences may go beyond a line by having a space followed by a <CR>
 To exit the parser, write ^end.
 : A dog bit John.
 I understand that a dog bit John
Time (sec.): 0.25
 : The dog slept.
 I understand that a dog slept
Time (sec.): 1.884
 : Mary believes that John likes the dog.
 I understand that Mary believed that John liked a dog
 Time (sec.): 0.4
 : Mary studies Computer Science.
 I understand that Mary studied Computer Science
 Time (sec.): 0.2
 : Mary used a computer.
 I understand that Mary used a computer
 Time (sec.): 0.233
 : John saw a saw.
 I understand that John saw a saw
Time (sec.): 0.217
 : What bit John?
 a dog bit John
 Time (sec.): 0.167
```

9.5. EXAMPLES

```
: Who sleeps?
a dog slept
Time (sec.): 0.917

: Who studied?
Mary studied
Time (sec.): 0.167

: Who uses the computer?
Mary used a computer
Time (sec.): 0.267

: Who likes a dog?
I don't know.
Time (sec.): 0.167

: Who sees a saw?
John saw a saw
Time (sec.): 0.217
```

The SNePS network built as a result of this interaction is shown in Figure 9.2. Note especially that when definite noun phrases occurred in statements, they were represented by nodes that were already in the net because of previous indefinite noun phrases.

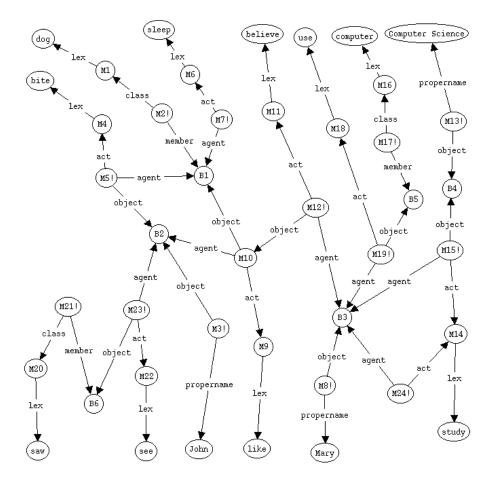


Figure 9.2: SNePS network after running the example.

Chapter 10

SNePS as a Database Management System

SNePS can be used as a network version of a relational database system in which every element of the relational database is represented by a base node, each row of each relation is represented by a molecular node, and each column label (attribute) is represented by an arc label. Whenever a row r of a relation R has an element e_i in column c_i , the molecular node representing r has an arc labeled R to the special node relation, and an arc labelled c_i pointing to the base node representing e_i . Table 10.1 shows two relations from the Supplier-Part-Project database of Date¹, p. 114. Figure 10.1 shows a fragment of the SNePS network

Table 10.1: From Date's Supplier-Part-Project Database

SUPPLIER

S#	SNAME	STATUS	CITY
s1	Smith	20	London
s2	Jones	10	Paris
s3	Blake	30	Paris
s4	Clark	20	London
s5	Adams	30	Athens

PROJECT

J#	JNAME	CITY
j1	sorter	Paris
j2	punch	Rome
j3	reader	Athens
j4	console	Athens
j5	collator	London
j6	terminal	Oslo
j7	tape	London

version of this database.

10.1 SNePS as a Relational Database

The three basic operations on relational databases are **select**, **project**, and **join**. The next three subsections show how these operations may be expressed in SNePSUL.

10.1.1 Project

Project is a database operation that, given one relation, produces another that has all the rows of the first, but only specific columns. (Actually some of the rows might collapse if the only distinguishing elements were

¹C. J. Date, An Introduction to Database Systems 3rd Edition (Reading, MA: Addison-Wesley) 1981.

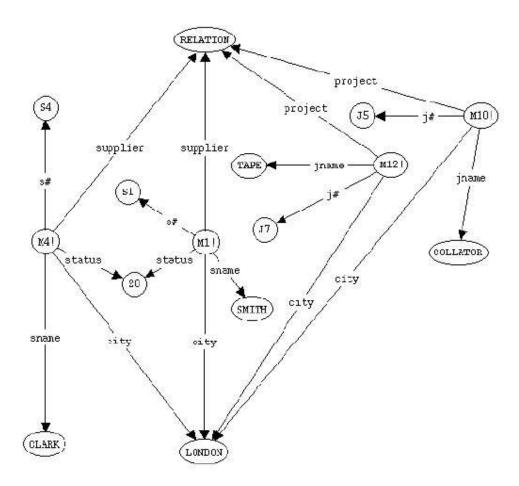


Figure 10.1: Fragment of SNePS network for the Supplier-Part-Project Database

in columns that were eliminated.) The SNePSUL dbproject function has been designed for this purpose. For example, to show the STATUS and CITY of all suppliers, one can do

```
* (dbproject (find supplier relation) status city)
((STATUS (20) CITY (LONDON)) (STATUS (10) CITY (PARIS))
(STATUS (30) CITY (PARIS)) (STATUS (30) CITY (ATHENS)))
CPU time: 0.07
```

The dbproject function forms and returns a *virtual* relation, which is represented as a SNePS data type called a *set of flat cable sets*. Compare the following two ways of getting complete details of the SUPPLIER relation. The first uses the SNePSUL describe function to print the details of the nodes that make up the relation:

```
* (describe (find supplier relation))

(M1! (CITY LONDON) (S# S1) (SNAME SMITH) (STATUS 20) (SUPPLIER RELATION))

(M2! (CITY PARIS) (S# S2) (SNAME JONES) (STATUS 10) (SUPPLIER RELATION))

(M3! (CITY PARIS) (S# S3) (SNAME BLAKE) (STATUS 30) (SUPPLIER RELATION))

(M4! (CITY LONDON) (S# S4) (SNAME CLARK) (STATUS 20) (SUPPLIER RELATION))

(M5! (CITY ATHENS) (S# S5) (SNAME ADAMS) (STATUS 30) (SUPPLIER RELATION))

(M1! M2! M3! M4! M5!)

CPU time: 0.15
```

The second uses dbproject to display a virtual relation with the same information:

```
* (dbproject (find supplier relation) supplier s\# sname status city)
((SUPPLIER (RELATION) S# (S1) SNAME (SMITH) STATUS (20) CITY (LONDON))
(SUPPLIER (RELATION) S# (S2) SNAME (JONES) STATUS (10) CITY (PARIS))
(SUPPLIER (RELATION) S# (S3) SNAME (BLAKE) STATUS (30) CITY (PARIS))
(SUPPLIER (RELATION) S# (S4) SNAME (CLARK) STATUS (20) CITY (LONDON))
(SUPPLIER (RELATION) S# (S5) SNAME (ADAMS) STATUS (30) CITY (ATHENS)))
CPU time: 0.12
```

Virtual relations are created without building any new SNePS network structure. To make these relations permanent, use the SNePSUL dbAssertVirtual function. For example, to create a CITYSTATUS relation that is a projection of the SUPPLIER relation down the CITY and STATUS attributes, we would first define CITYSTATUS as a new SNePS relation:

```
* (define citystatus)
(CITYSTATUS)
CPU time : 0.03
```

Then we would do

10.1.2 Select

Select is an operation that is given a relation and specific values for some of its attributes, and yields the rows of the relations in which those attributes take on those values. A selection from relation R_1 in which attribute a_{1i} takes on value v_{1i} is expressed in SNePSUL as

```
(find R_1 relation a_{11} v_{11} ...a_{1n} v_{1n}).
```

For example, to select rows of the SUPPLIER relation where the CITY is Paris or Athens and the STATUS is 30, we could do:

```
* (describe (find supplier relation city (paris athens) status 30))
(M3! (CITY PARIS) (S# S3) (SNAME BLAKE) (STATUS 30) (SUPPLIER RELATION))
(M5! (CITY ATHENS) (S# S5) (SNAME ADAMS) (STATUS 30) (SUPPLIER RELATION))
(M3! M5!)
CPU time: 0.08
```

If we want a new permanent relation, say supplier2, to be this selection from the SUPPLIER relation, we could do:

10.1.3 Join

Join is a database operation that, given two relations, R_1 and R_2 , with attributes a_{11}, \ldots, a_{1n} and a_{21}, \ldots, a_{2m} , respectively, and an attribute $a = a_{1i} = a_{2j}$ produces a relation with attributes $a_{11}, \ldots, a_{1n}, a_{21}, \ldots, a_{2j-1}, a_{2j+1}, \ldots, a_{2m}$, and every row, $e_{11}, \ldots, e_{1n}, e_{21}, \ldots, e_{2j-1}, e_{2j+1}, \ldots, e_{2m}$ where e_{11}, \ldots, e_{1n} was a row of R_1 , and $e_{21}, \ldots, e_{2j-1}, e_{1i}, e_{2j+1}, \ldots, e_{2m}$ was a row of R_2 . For example, Table 10.2 shows the join of the relations in Table 10.1 on the attribute CITY.

This join may be created and displayed by the SNePSUL dbjoin command, which, like dbproject creates a virtual relation.

S#	SNAME	STATUS	CITY	J#	JNAME
s1	Smith	20	London	j5	collator
s1	Smith	20	London	j7	tape
s2	Jones	10	Paris	j1	sorter
s3	Blake	30	Paris	j1	sorter
s4	Clark	20	London	j5	collator
s4	Clark	20	London	j7	tape
s5	Adams	30	Athens	j3	reader
s5	Adams	30	Athens	j4	console

Table 10.2: The join of SUPPLIER and PROJECT on CITY

Again, to make the virtual relation permanent, dbAssertVirtual is used:

```
* (define supplierproject)
(SUPPLIERPROJECT)
CPU time : 0.03
* (describe
   (dbAssertVirtual
    (dbjoin city
            (find supplier relation) (s\# sname status city)
            (find project relation) (j\# jname))
    (supplierproject relation)))
(M19! (CITY LONDON) (J# J7) (JNAME TAPE) (S# S1) (SNAME SMITH) (STATUS 20)
      (SUPPLIERPROJECT RELATION))
(M20! (CITY LONDON) (J# J5) (JNAME COLLATOR) (S# S1) (SNAME SMITH) (STATUS 20)
      (SUPPLIERPROJECT RELATION))
(M21! (CITY PARIS) (J# J1) (JNAME SORTER) (S# S2) (SNAME JONES) (STATUS 10)
      (SUPPLIERPROJECT RELATION))
(M22! (CITY PARIS) (J# J1) (JNAME SORTER) (S# S3) (SNAME BLAKE) (STATUS 30)
      (SUPPLIERPROJECT RELATION))
(M23! (CITY LONDON) (J# J7) (JNAME TAPE) (S# S4) (SNAME CLARK) (STATUS 20)
      (SUPPLIERPROJECT RELATION))
(M24! (CITY LONDON) (J# J5) (JNAME COLLATOR) (S# S4) (SNAME CLARK) (STATUS 20)
      (SUPPLIERPROJECT RELATION))
(M25! (CITY ATHENS) (J# J4) (JNAME CONSOLE) (S# S5) (SNAME ADAMS) (STATUS 30)
      (SUPPLIERPROJECT RELATION))
(M26! (CITY ATHENS) (J# J3) (JNAME READER) (S# S5) (SNAME ADAMS) (STATUS 30)
      (SUPPLIERPROJECT RELATION))
(M19! M20! M21! M22! M23! M24! M25! M26!)
CPU time : 0.92
```

10.2 SNePS as a Network Database

Although SNePS can be treated as a relational database, as shown in the previous section, it is more naturally a network database. For example, to find the names of suppliers with the same status as suppliers in the same city as the sorter project using relational database techniques, one would join the SUPPLIER and PROJECT

relations on CITY, join the result with SUPPLIER again on STATUS, select rows where PROJECT is sorter, and project the result on the SNAME attribute.

However, in SNePSUL, one could just do

```
* (find (sname- status status- city city- jname) sorter) (ADAMS BLAKE JONES) 
 CPU time : 0.02
```

Additional examples of these techniques may be found in the SNePS DBMS demonstration.

10.3 Database Functions

Functions specifically supplied for treating SNePS as a Database Management System are documented in this section. Additional ones may be created using the functions documented in Chapter 5. Note also innet and outnet, documented in Section 2.4, for saving the database across runs.

```
(dbAssertVirtual virtualexp [([relation nodeset]*)])
```

Evaluates *virtualexp*, which must return a virtual relation (set of flat cable sets), appends the list ([*relation nodeset*]*) to each flat cable set, asserts each resulting flat cable set as a SNePS molecular node, and returns the set of asserted nodes.

```
(dbcount nodesetexp)
```

Evaluates the SNePSUL nodeset expression, *nodesetexp*, and returns a node whose identifier looks like the number which is the number of nodes in the resulting set.

```
(dbjoin relation nodesetexp1 relations1 nodesetexp2 relations2)
```

A virtual relation (a set of flat cable sets) is created and returned. The virtual relation is formed by taking the nodes returned by the SNePSUL node set expression, *nodesetexp1* and the nodes returned by the SNePSUL node set expression, *nodesetexp2*, joining these two relations on the attribute *relation*, and then projecting the result down the *relations1* attributes from the first nodeset and the *relations2* attributes from the second nodeset. Note that relations1 and relations2 is each a list of relations.

```
(dbmax nodesetexp)
```

Evaluates the SNePSUL nodeset expression, *nodesetexp*, which must evaluate to a set of nodes all of whose identifiers look like numbers, and returns the node whose identifier looks like the biggest of the numbers.

```
(dbmin nodesetexp)
```

Evaluates the SNePSUL nodeset expression, *nodesetexp*, which must evaluate to a set of nodes all of whose identifiers look like numbers, and returns the node whose identifier looks like the smallest of the numbers.

```
(dbproject nodesetexp relations)
```

A virtual relation (a set of flat cable sets) is created and returned. The virtual relation is formed by taking the nodes returned by the SNePSUL node set expression, *nodesetexp*, and projecting down the SNePSUL relations included in the sequence, *relations*.

```
(dbtot nodesetexp)
```

Evaluates the SNePSUL nodeset expression, *nodesetexp*, which must evaluate to a set of nodes all of whose identifiers look like numbers, and returns a node whose identifier looks like the sum of the numbers.

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Index

!, 7, 16	attachedfunction, 73
*, 8, 17	
+, 2, 17	belief revision
-, 12, 17	prioritized, 79
=, 8, 17	belief revision, 75
>, 18	nonprioritized, 79
?, 8, 19	belief space, 75
#, 7, 8, 16	beliefs-about, 19,58
#!, 47	believe, $2, 29, 68, 79$
\$, 7, 8, 16	blieve, 75
%, 58	bnscommands
&, 2, 17	SNEPSUL variable, 8
_, 18	br-mode, 58, 76
^ , 10, 17, 58	br-tie-mode, 59, 79
^ ^ , 10, 58	break-arc, 81
	build, 6, 7, 13, 16
achieve, 39, 68	
act-effect, 43	<pre>snip::*choose-randomly*, 30</pre>
act-plan, 36	clear-infer, 17, 59
act-precondition, 40	clear-infer-all, 17
activate, 2, 16, 58	clearkb, 59
activate!, 2, 58	commands
active connection graph, 59, 63	infix, 6
ActPlan, 69	macro, 6
add, 16	postfix, 6
add-to-context, 15,58	prefix, 6
adopt, 16, 29, 68	SNEPSUL, 5
all-hyps, 9	commands
and, 14	SNEPSUL variable, 8
apply-function-to-ns,47	compose, 14
arc labels, 12	context, 75
ask, 2, 58, 71, 72	current, 7
askifnot, 2, 58, 71, 72	default, 7
askwh, 2, 58, 71, 72	:context,9
askwhnot, 2, 58, 71, 72	context-specifier, 9
assert, 7, 16	contexts, 7
assertions	extensionally defined, 7
SNEPSUL variable, 8	intensionally defined, 7
parser::atn-read-sentence, 11	names, 7
atnin, 81	nodes in, 8
attach-function, 74	operating on, 15
attach-primaction, 35	converse, 14
-	

INDEX 119

copyright, 59	ev-trace, 25
current context, 75	exception, 14
current-configuration, 82	expert, 60
,	explicit, 79
dbAssertVirtual, 108	<u>-</u>
dbcount, 108	files
dbjoin, 108	auxiliary, 10
dbmax, 108	compatibility, 11
dbmin, 108	find, 6, 19
dbproject, 108	findassert, $6, 19$
dbtot, 108	findbase, 19
dc-lisp, 11	findconstant, 19
dc-no-pause, 11	findpattern, 19
dc-pause-help, 11	findvariable, 19
dc-quit, 11	fluent, 78
dc-quit-all, 11	fnscommands
dc-read-pause, 11	SNEPSUL variable, 8
dc-set-pause, 11	foreachsub, 71
dc-sneps, 11	Franz ACL, 5, 18, 71
dc-snepslog, 11	full-describe, 18
deduce, 12, 19	function, SNEPSUL, 5
deducefalse, 2, 19	
deducetrue, 2, 19	getValFromVar,72
deducewh, 2, 19	goal-plan, 39
deducewhnot, 2, 19	GoalPlan, 69
default-defaultct, 7	
defaultct	hypotheses, 7
SNEPSUL variable, 8, 9, 15	hypothesis, 75
define, 12	
define-attachedfunction, 73	if-do, 28
define-frame, 59	ifdo, 68
define-path, 13, 59	in-trace, 25
define-primaction, 28	inference
defsnepscom, 51	path-based, 13
demo, 10, 59	reduction, 12, 13
depthCutoffBack, 25, 67	*infertrace*,25
depthCutoffForward, 25, 67	innet, 10
derived belief, 75	intext, 10
describe, 18	irreflexive-restrict, 14
describe-context, 15, 59	isConnected,72
describe-terms, 59	1 ON PG 1 DI 5 51
disbelieve, 2, 29, 68	Java-SNePS API, 5, 71
do-all, 30, 45, 68	JavaSnepsAPI, 71
do-one, 30, 45, 68	JIMI, 3, 5, 18
do-one, 50, 45, 06 domain-restrict, 15	JUNG, 3, 5, 18
dot, 3, 18	line engistent 7
dump, 18	kinconsistent, 7
camp, 10	kplus, 14
Effect, 69	kstar, 14
endLispConnection, 72	lexin, 81
erase, 16	lisp, 9, 60
01400,10	±±0p, 2, 00

120 INDEX

lisp-list-to-ns,47	primitive actions, 28
lisp-object-to-node,47	primitive acts, 28
list-asserted-wffs, 60	procedural attachment, 73
list-context-names, 15	procedure, SNEPSUL, 5
list-contexts, 60	
list-hypotheses, 15	range-restrict, 15
list-nodes, 17	reduction inference, 12, 13
list-terms, 60	relations, 12
list-wffs, $2,60$	converse, 12
load, 60	initial, 12
	relations
multi::print-regs, 26	SNEPSUL variable, 8, 12
	relative-complement, 14
nl-tell, 71	remove-from-context, 15,60
node-to-lisp-object,47	resetnet, 17
nodes	rscommands
asserted, 7	SNEPSUL variable, 8
base, 7	
in contexts, 8	set-context, 15, 60
molecular, 7	set-default-context, 15,60
pattern, 7	set-mode-1,61
proposition, 7	set-mode-2,61
types of, 7	set-mode-3,61
unasserted, 7	set-order, 61 , 77
variable, 7, 62	show, 2, 3, 5, 18, 61
nodes	silent-erase, 16
SNEPSUL variable, 8	SNeBR, 75
nogood, 79	sneps, 9
normal, 60	snepslog:ask,71
not, 14	snepslog:foreachsub,71
ns-to-lisp-list,47	<pre>snepslog:init-java-sneps-connection,</pre>
nscommands	71
SNEPSUL variable, 8	snepslog:tell,70
null-order, 77	SNeRE, 27, 68
	snif, 30, 68
or, 14	SNIP, 21, 65
outnet, 10	sniterate, 31, 68
01	snsequence, 30, 68
parse, 81	source, 78
parser:nl-tell,71	support set, 62
path-based inference, 13	support set, 60, 76
paths	surface, 19
syntax and semantics, 13	
patterns	tell, 70, 71
SNEPSUL variable, 8	terminalPunctuation, 62, 63
perform, 27, 40, 60	topcommands
plan-act, 36	SNEPSUL variable, 8
plan-goal, 39	trace, 62
plantrace, 40	20.60
Precondition, 69	unadopt, 29, 68
primitive action functions, 28	unbreak-arc, 82
table of, 36	undefine, 12

INDEX 121

```
undefine-path, 13, 62
undefsnepscoms, 53
unev-trace, 25
unin-trace, 26
Unique Variable Binding Rule, 65
unitpath, 12, 13
unlabeled, 62
untrace, 62
cl-user:*use-gui-show*, 3, 62
variables
   SNEPSUL, 8
variables
   SNEPSUL variable, 8
varnodes
   SNEPSUL variable, 8
verbize, 90
wff, 63, 64
wffCommand, 62, 63
wffName, 62
   unassigned, 63
wffNameCommand, 62
when-do, 27
whendo, 68
whenever-do, 27
wheneverdo, 68
\verb|with-snepsul-standard-eval|, 48|
with-snepsul-toplevel-style-eval, 48
with-snepsul-trace-eval, 48
withall, 32, 68
withsome, 33,68
wordize, 91
```