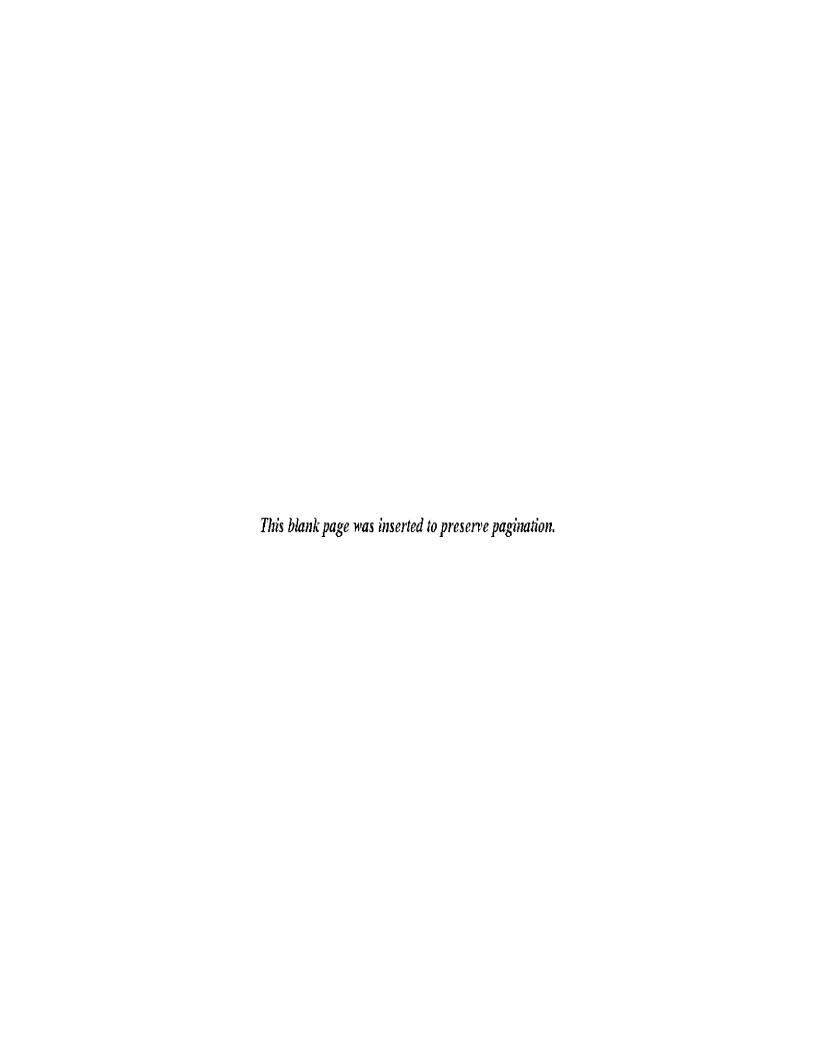
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# SIR: A COMPUTER PROGRAM FOR SEMANTIC INFORMATION RETRIEVAL

Betram Raphael

June 1964



# SIR: A COMPUTER PROGRAM FOR SEMANTIC INFORMATION RETRIEVAL

by

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SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
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at the

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June, 1964

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# SIR: A COMPUTER PROGRAM FOR SEMANTIC INFORMATION RETRIEVAL

### by BERTRAM RAPHAEL

Submitted to the Department of Mathematics on April 8, 1964, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

#### ABSTRACT

SIR is a computer system, programmed in the LISP language, which accepts information and answers questions expressed in a restricted form of English. This system demonstrates what can reasonably be called an ability to "understand" semantic information. SIR's semantic and deductive ability is based on the construction of an internal model, which uses word associations and property lists, for the relational information normally conveyed in conversational statements.

A format-matching procedure extracts sementic content from English sentences. If an input sentence is declarative, the system adds appropriate information to the model. If an input sentence is a question, the system searches the model until it either finds the answer or determines why it cannot find the answer. In all cases SIR reports its conclusions. The system has some capacity to recognize exceptions to general rules, resolve certain semantic ambiguities, and modify its model structure in order to save computer memory space.

Judging from its conversational ability, SIR is more "intelligent" than any other existing question-answering system. The author describes how this ability was developed and how the basic features of SIR compare with those of other systems.

The working system, SIR, is a first step toward intelligent manmachine communication. The author proposes a next step by describing how to construct a more general system which is less complex and yet more powerful than SIR. This proposed system contains a generalized version of the SIR model, a formal logical system called SIR1, and a computer program for testing the truth of SIR1 statements with respect to the generalized model by using partial proof procedures in the predicate calculus. The thesis also describes the formal properties of SIR1 and how they relate to the logical structure of SIR.

Thesis Supervisor: Marvin L. Minsky

Title: Professor of Electrical Engineering.

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# TABLE OF CONTENTS

Chapter		Page		
I.	INTRODUCTION	7		
	A. The Problem	7		
	B. Where the Problem Arises			
II.	SEMANTIC INFORMATION RETRIEVAL SYSTEMS	13		
	A. Semantics	1.3		
	B. Models ,			
	C Some Existing Question-Answering Systems			
III.	REPRESENTATIONS FOR SEMANTIC INFORMATION			
	A. Symbol-Manipulating Computer Languages	34		
	B. Word-Association Models			
		44		
	D. The SIR Model	£}£+		
IV.	SIR TREATMENT OF RESTRICTED NATURAL LANGUAGE	52		
	A. Background	52		
	B. Input Sentence Recognition	54		
	C. Output: Formation and Importance of Responses	60		
V.	BEHAVIOR AND OPERATION OF SIR	6/		
	A Delations and Donations	64		
	A. Relations and Functions	85		
	B. Special Features	ره		
VI.	FORMALIZATION AND GENERALIZATION OF SIR	92		
	A. Properties and Problems of SIR	92		
	B. Formalism for a General System	101		
	C. Implementation of the General Question-			
	Answering System	113		
VII.	CONCLUSIONS	127		
	A. Results	127		
	B. Extensions of SIR	131		
	C. Concerning Programming	136		
	D. Subjects for Future Experiments	140		
	b. Subjects for future experiments	7.+()		
	RTRI.TOGRAPHY	143		

POLITICAL MAI CLIEAR		rage
APPENDIX I: Notation	lures	146 148 7 - Jq <b>157</b>
FIGURE 1: Sample Conversation  2: A Word-Association Model  3: Sentence Recognition Rules 1001 507  4: Sample Conversation in Full Response  5: Selected Conversations  6: Special Features 11132 MOLTAMSOTM 00		40 59 62 66 43 86
TABLE a: Relational Notation	is∵ <sup>{ </sup>	97 100 108 108 -21 111
BIOGRAPHICAL NOTE		169
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Section of the sectio	. G	
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## Chapter I: Introduction

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#### A. The Problem.

This report discusses the problem of developing a computer\* which "understands." The method of study involved the construction of a computer system having certain cognitive abilities and exhibiting some human-like conversational behavior.

This computer system is called "SIR" -- Semantic Information

Retriever. The conversation presented in Fig. 1 between a person

(identified by "\*\*\*.") and SIR illustrates some of the system's

capabilities. Although it is capable of "understanding" statements

dealing with set relations, part-whole relations, ownership, and

certain spatial relations, SIR has no initial builter in associations

for nouns like "John," "boy," and "table."

"Understanding" is difficult to a define precisely. The present

i) "Understanding" can be demonstrated by dialogue, which requires the participants to indicate an awareness of the meaning of their subject matter. Therefore a computer should be considered able to "understand" if it can converse intelligently, which is to an remember what it is told, answer questions and make responses which a human observer considers reasonable.

POPAPAGETO ELIMABE A GRADEN

<sup>\*</sup> The term "computer" refers to the combination of digital computer hardware and operating computer program.

```
(***.
           EVERY BOY IS A PERSONI
(I UNDERSTAND)
           A FINGER IS PART OF A HAND)
(I UNDERSTAND)
           EACH PERSON HAS TWO HANDS!
(THE ABOVE SENTENCE IS AMBIGUOUS ** PLEASE RE-PHRASE IT)
           THERE ARE TWO HANDS ON EACH PERSON)
(I UNDERSTAND)
           HOW MANY FINGERS DOES JOHN HAVE Q)
(THE ABOVE SENTENCE IS AMBIGUOUS ** BUT I ASSUME (HAS) MEANS (HAS AS PARTS))
[I DON'T KNOW WHETHER FINGER IS PART OF JOHN)
           JOHN IS A BOY)
(I UNDERSTAND)
           HOW MANY FINGERS DOES JOHN HAVE Q)
(THE ABOVE SENTENCE IS AMBIGUOUS ** BUT [ ASSUME (HAS) MEANS (HAS AS PARTS)) ((HOW MANY FINGER PER HAND Q))
          EVERY HAND HAS 5 FINGERS!
(THE ABOVE SENTENCE IS AMBIGUOUS .. BUT I ASSUME (HAS) MEANS (HAS AS PARTS)) (I UNDERSTAND)
           HOW MANY FINGERS DOES JOHN HAVE Q)
(THE ABOVE SENTENCE IS AMBIGUOUS ** BUT I ASSUME (HAS) MEANS (HAS AS PARTS)) (THE ANSMER IS 10)
           HOW MANY AUTOMOBILES DOES JOHN HAVE Q1
(THE ABOVE SENTENCE IS AMBIGUOUS .. PLEASE RE-PHRASE IT)
           WHO IS PRESIDENT OF THE UNITED STATES OF
(STATEMENT FORM NOT RECOGNIZED)
           THE BOY IS JUST TO THE LEFT OF THE TABLE)
(GO2840 IS A TABLE)
          THE LAMP IS JUST TO THE LEFT OF THE TABLE)
(GO2841 IS A LAMP)
(THE ABOVE STATEMENT IS IMPOSSIBLE)
          THE TABLE IS TO THE RIGHT UF THE CHAIR)
(GO2842 IS A CHAIR)
           WHAT IS THE RELATIVE POSITION OF A PERSON Q1
(THE LEFT-TU-RIGHT ORDER IS AS FOLLOWS) (CHAIR (BOY TABLE))
```

### FIGURE 1: SAMPLE CONVERSATION

Note: I am concerned here with the computer's internal information representation and retrieval techniques. For this purpose I assume that abstract words are the baste signal unit. There is no need to be concerned with speech recognition, sensory receptors, or other problems involving the physical mature of the committee for channel and signals.

ii) In addition to echoing, upon request, the facts it has been given, a machine which "understands" must be able to recognize the logical capacities of bresent temporalist could be experienced implications of those facts. It also must be able to identify (from application as a state of the region of the control of the a large data store) facts which are relevant to a particular question. olless the searcher is espable of hocognizing what iii) The most important prerequisite for the ability to "understand" for and intelling bospicer systems for information in is a suitable internal representation, or model, for stored information. c specifying and the office, the objects This model should be structured so that information relevant for 75 Y 15 19 13 deilgna to spart to systems generally occurred to descript the description certified systems generally occurred to descriptions. text is not suitable since the structure of an English statement generators of feet retrieval of the statement generators of the statement gen ally is not a good representation of the meaning of the statement. On synend apon i human pre-essignment if "describtors" to be focusive the other hand, models which are direct representations of certain A seem in the laretem may know the list of descriptors but manned form kinds of relational information usually are unsuited for use with other useful and its wind in the description of the second process and described and the second process and described and the second process are second process. relations. A general-purpose "understanding" machine should utilize a วิธีเวลเกษะ Bull the willing the action Rimitable Stat model which can represent semantic content for a wide variety of subject අවස වාට මා කොම් වැට් අවසම් පත්වෙව් වැඩිවීමට මිනුම්ස් මතේ වස පට වෙනවා වෙනුවේ areas.

SIR is a prototype of an "understanding" machine. It demonstrates assumed were an investigation of the property of the state of the property of the property

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1) Information retrieval: The high speeds and huge memory

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mostly and bear aids of decreased at the standard of secondard and scientific literature. Unfortunately, high-speed search is useless

and and a self-order of secondard are daidy sized (arone also equal to unless the searcher is capable of recognizing what is being searched

"Decreased and allowed and the additional and the search and existing computer systems for information retrieval use too

and isometric beauty are labour to another present and the search and the search and the search and identifying the objects of the search.

Information retrieval systems generally provide either document retrieval or fact retrieval. Document retrieval programs usually depend upon a human pre-assignment of "descriptors" to the documents.

A user of the system may know the list of descriptors but cannot know precisely what the descriptors meant to the cataloguer. It is difficult for the user to determine what the semantic interactions between the descriptors are and how these interactions help determine the content of the documents obtained.

Fact retrieval systems usually require that the information to be reliable sound in a political decided and the sound of a particular books. A cost sound form designed for a particular books. A cost sound form designed for a particular subject area. This rigid representation for the data, and the corresponding rigid formulation of the retrieval requests, could be produced understands by a computer which "understands" statements expressed in a form more natural to the human user. Further, if the computer could "understand" information expressed in some general manner, specialized formal representations would be unnecessary.

In order to make a computer serve as a reference librarian, it is not sufficient simply to store a large volume of information. The computer must also have the ability to find and retrieve information in response to flexible descriptive commands. Further, the computer should be able to modify both the information in storage and the requests it is receiving, and it should be able to describe its actions and to request clarifying information. The most useful information retrieval system will be one which can "converse" with its users, to make sure that each request is well-defined and correctly "understood."

- ment, and context-dependent restrictions, have proven inadequate for achieving good translations. The vital feature missing from present computer translating systems is the ability of human translators to human conversations, answer questions, and exhibit other features of human conversational behavior, and therefore appears to have some such as a such as a store facts, make they read in one language, and then same thing in another. The SIR computer system can store facts, make they read in one language, and then same the same thing in another. The SIR computer system can store facts, make they read to the such as a store facts, make they are a such as a store facts, make they read to the such as a store facts, make they are a such as a store facts, make they are a such as a store facts, make they are a such as a store facts, make they are a such as a store facts, make they are a such as a store facts, make they are a such as a store facts, make they are a such as a store facts, make the such as a store facts, make as a store facts, make the such as a store facts, make as a store facts, make the such as a store facts, make as a store facts as a store facts. The store facts as a store
- 3) General computer applications: During the past decade there

  and can be tackled by a computer someone must perform the arduous

task of "programming" a solution, i.e., encoding the problem into a form acceptable to a computer.

Various "problem-oriented" computer languages have been developed to ease this encoding problem. Unfortunately, such languages are useful only when programs ("compilers" or "interpreters") are available to translate automatically from the problem-oriented language to the basic "order-code" of the computer. At present all such problem-oriented languages are very rigid systems. This means that the problem domain must be one which lends itself to rigorous, complete, formal definition, e.g., algebraic manipulations, accounting procedures, or machine tool operations.

Many interesting problems are not sufficiently well defined or clearly understood to be expressed in any of the conventional computer programming languages. Still, people are able to describe these problems to each other and to assist each other in making the problems more precise and in solving them. In order to utilize the high speed and large memory capacities of computers while working on such ill-defined problems, people need some useful way to communicate incomplete information to the computer; some way which will make the computer "aware" of facts and enable it to "understand" the nature of the problems which are described to it. SIR is a prototype of a computer system which captures some measure of the "meaning" of the information presented to it, and can act upon its stored body of knowledge in an "intelligent" manner.

is absorbed by of compater applications. The stock between the and a continuous sources can be eackled by a compater assessment as a continuous sources.

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and meaning alless of sections as some sections of the

Bid Chapter HI: Semantic Information Retrieval Systems as to broken

The word "semantic" is used in the title of this paper for two Keasons: "First, the actual information expracted afrom text and stored by the program is intended to approximate the linguistic oper-"semantic content" or "mesning" of the material. His econd, the scomput ter representation of diaformation cused wind SIR (Chapter HIL.B) cis redu derived from the busement icu model structures of aforms be mathematical ? - logic. ""Information retrieval" refers to the fact that the systems? discussed operate on collections of statements pretrieving facts siny response to questions. Question-answering was chosen because at ais " a straight-forward context in which to rexperiment with the underraint such Chings as marriags) is use to be reliesed with the object. Jastanding pand communicative ability of sale computer graph in the larger of estain though words in them may, hencement sempty but singula ua aprikdīsirustamautriizesarešukta from two matororesearchdareastot mendings): and the meaning of an ocompat sentester is the object the study of the semantics of instural misaguage mand they study so fine to dind singular term will have a meaning in arm (if we a province previously developed computer programming techniques for solving mass find a this approach the caption of the classic fields had of the monecutaries various specific question-answering problems go al 1000 677 salestude else particular de comparta de la comparta del comparta del comparta de la comparta del comparta del la comp Schaptics. The Theorem as as madaband on the fire oran admir so engine Missell Semantics is generally studied from one of two viewpoints: 250 m. ಾ<del>ರ್</del>ಷರಿ sand descriptive ಇಂ<u>Pore</u> is emaktics ; dees tudked ಇಶ್ರಂ Carnap. (5), ಕಾರ್ಡಿ deals with the properties of eartificially agonstructed formal dames to systems (which may or may inot have analogues in the real sworld); Associated and the real sworld); " with frespect to trains for sentence for mation band designation of the incommentation band. formal models and truth walues. Heshall rather the conderned with the

descriptive semantics, an empirical search for rules governing truth and meaningfulness of sentences in natural language.

or with the district book or to tapped above and

1) Semantics and meaning: When discussing meaning, one quickly encounters difficulties in having to use words with which to discuss the meaning of words, especially that of the word "meaning." Therefore one finds it difficult to distinguish between object—

language and meta-language. A common device is to define "meaning" in a very specialized sense, or to deny that it can be defined at all.

Quine, tongue in cheek, recognizes this difficulty in the following paragraph: (33)

"One must remember that an expression's meaning fif we are sto a -admit such things as meanings) is not to be confused with the object, if any, that the expression designates ide Sentence and a onota designate at all..., though words in them may; sentences are simply not singular terms: : But sentences: still have meanings of fige cadmit aught things as meanings); and the meaning of an eternal sentence is the object designated by the singular term found by bracketing the sentence . add That singular term will have a meaning in turn (if we are prodigal enough with meanings), but it will presumably be something further to Under this approach the meaning (if such there be) of the non-eternal sentence 'The door is open' is mothan proposition was billings ageinst Quine continues that the elusive meaning of "The door is open" is some complete intuitive set of circumstances surrounding a particular occasion for which the statement "The door is faren" was uttered at Clearly this kind of concept does not lend itself to 4 computer usage. Dr Inberder to construct a computer system which behaves as it it understands the meaning of a statement, one must find specific words and relations ve which can be represented within the computer's memory yet which somehow capture that significance of the statement athey tepresents formed

words into him and and processes in making the following distinction: of words into him and and point not significance or untermined (phrases) sentences) may have significance or distance or meaning. The words, he states that an analysis of the significance of whole difference dannot be completed without an analysis of the meaning of the words in the factor of the distance of the meaning of the words in the factor of the distance of the meaning of the words in the factor of the distance of the meaning of the description of the distance of the words of the meaning of the distance of the words of the distance of the words of the distance of the significance of the distance of the

Ullmann considers a word as the smallest stadificant with witho isolated ("content," whosee virses and sentences corress relations thic all kinds of groupings held reacther by a complex; unstable and shotween the ethings which are symbolised by bindlolded words. Held i names and the senses, associations based on similarity or some other "Imagering" Is vietfined as the reciprocal value fough he between the mane make themselves felt; ... The sum total of these assectative network and the sense, which enables the one to call (up) the course By "sense" is meant the thought or reference to an object of westeries which is represented by the word. Note that meaning here relates word with thought about to best pinot more event pour thick because and plant. 29% a "thought about object" dis top vegue an idea for computed formalisation. However five composed with a verbalization of a relought; numely of the words which name objects and features associated with the thought. we will may consider the meaning of a word which dismes an object on within of objects to be extrement thing and or . This which when, the most common thoughts people have inveniestical little the thing assist.

computer regresentations for second of information

In either case, in the SIR systems approximate the meaning of the word by building up, in the computer to a description of the electron class. This description, itself-composed of words, presents properties of the described entity and names other objects and classes to which that entity is related. The meaning of an autterance cas then be represented in a natural way by particular entities in the descriptions of the objects named in the outparance.

Walpole (45) points out similarly that a word may be defined (i.e., the meaning of a word may be explained) by any kind of association, connection, or characteristic, and these features of a word are usually described verbally. Thus such features can be part of the computer's description of the word being defined.

"Words do not live in isolation in a language mystemet. They enter into all kinds of groupings held together by a complex, unstable and highly subjective network of associations are marked into a little by their affects that these associative connections make themselves felt;... The sum total of these associative networks is the vocabulary." (45) to our out as ideas doing the same and has

133

SIR uses an approximation to those seseciative networks as its basic data store.

Walpole also notes that some word relationships, such as part to whole, or class to subclass, determine partial orderings of large classes of nouns and thus can be represented by tree structures. This fact leads to certain search procedures which are useful in our computer system. However, the class of abstract nouns ("factions"), which do not name any object in any specific sense experience, do not lend themselves to such ordering, and hence exercited from early wereions of computer representations for semantic information.

2) Quantamental meaning: Thus for it have blacked meaning (feman-ties) while demanting the ignomer of syntax) of languages showiver paudonals grammar its important winder would obtain the computed program to disks ugil advantage of whitever weeful informations to available in the grammatical advantage of white tinguts languages on whiteher in the grammatical advantage of white tinguts languages on each doll of thoughts doll in discussed and (3) dislows the their syntax least one deducted for white and satequate viz method for phinaining semantic college of treatments and satequate viz sider the nature of terminal grammatic restant and the sate of the same of

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Although syntactic protedures and gainerally supposed togiquered even meaning, the boundary between dyntactic and supposed togic for distinct and supposed to the protest and supposed to the second description of the second description d

structure. Words which are necessary in a particular grammaticals structure. Words which are necessary in a particular grammatidal vone of figuration; such as frequent occurrenced of "to; "Hodo; "Hodo; "words getonvia the likes are said to have no meaning; On the other hand; twords getonvia which could be replaced by: a large number of abternatives within and the given grammatical contexts are considered very meaningful?) Summons would given grammatical contexts are considered very meaningful?) Summons would even more sharp, as we shall see later (Paragraphs C.3) to Thurse and words distinction between fluoration would end in these ideas to the extent that only more which were immensed. A objects of classes, or classes, or of properties of objects of classes, impleased in the internal representation used in Silber The frequently-occurring down the internal representation used in Silber The frequently-occurring down between other "meaningful" words appearing in the bracket is meaningful.

"meaningless" words of Ziff are used as indicators of relations labitation (See Section IV.B). Cong. To the of words appearing in the objects of snothers are in agains of snothers.

Significant transfer the meaning of what iteds, sold in the first same as and and remember the mannes of what iteds, sold in the order of the first iteds, sold in the meaning of what iteds, sold in the meaning of the formal representations of the formal representations of the formal iterations of the formal iterations of the formal transfer of the meaning which is the been proposed, and see which ideas from those representations if A meaning, the boundary between appropriate representations of the formal in a computer representation of the solution of

One, way to deal with the problem of schantics is becauded by quees translating ordinary language into an formal system which could be (" object handled syntactically (1) as Thus fary attempts to formally encode of 22 31s all of natural English seem to introduce a mass of detailed notation 22.33

ing must be selved in order to develop a lood virens lation scheme if Africa and first view Recordental's LINCOS (15) may seem like a viocative term for the self describing shames behaviors sectually the LINCOS system it wow practical sense since it masses after greater while the eraceiver than six expected of the source of and situations ioning part of the eraceiver than six expected of the source of and successful the state of the eraceiver than six expected of the source of and successful the state of th

Another approach, used, for example, by Whein (19), is teminorease and the number and deiminor categories in the actual syntactic analysis and will exempte properties are promoting, at seems to me this approach are all expressions of theoreaults are promoting, at seems to me this approach are will eveningly obtain the same tablinate system of word associations and a can be approached more simply by contributing and depresenting bias vitues directly the dimensions followed between words. To the approach and still and directly the dimensions followed between words.

Quillian (32) attempte to represent the seamont continue of words and seater of "concepts," which can be combined to represent the meaning of the of phrases and seatempte which the batic presses that learning were the word involves meanyings to values on a set of basic braid seatempte to trying to build up an experience suitable coordinate scales is gard word involved in seatempte of suitable coordinate scales is gard word in seatempte of suitable coordinate scales is gard word in seatempte to build up an experience of suitable coordinate scales is gard word in the seatempte of suitable coordinate scales is gard word in the seatempte of suitable coordinates such as seatempte in the scale of the seatempte of suitable coordinates such as seatempte words in terms of spreads in down ords and show ords and start the scale of the seatempte words in the scale of the seatempte words in the scale of the seatempte words and the seatempte was preached by the seatempte words and the seatempte was preached by the seatempte words and the seatempte was preached by the seatempte words and the seatempte was preached by the seatempte was a se

Sommers (42) is more concerned with permissible sword combinations of the state of than with the meanings of sindividual swords we the cfirst odescribes as a first of second as hierarchy of sentence types: 1) Sungrammattical; A 2) a Grammatical but nonsense; (3). Sensible but afalse; (4)(1 True. ) He then vargues athat and discussion the crucial semantic distinction lies between the grammatical declarate some tive sentences which are nonsense, and those which are significant had a bus (but may be true or false). Any pair of monadic predicates at seasons are said by Sommers to have a sense value b(P 10 2) diff theirs excists entons any significant sentence conjoining them. Otherwise they have value does and  $\sim$  U=N(P<sub>1</sub>,P<sub>2</sub>). The U-relation is symmetric and is preserved under the scale certain logical operations on its arguments, but it is notitransitively oddia A stronger relation Q P is true if "of what is Pritter decided slignifits fit is cantly said that with is Q. . . e. g. . Parcine minister's Orquickad action of and an permits the arrangement of these "monadic predicates" into as simple (1999) tree, where all words in the same meaning class, or growalls colors; or no all words describing weight, occupy the same modelable "eriqualist" do 1998 as

My main objection to this work is an where the important distinct about tions lie. Sommers would argue that "The idea is always green" is sensible: (since sky lies or monsense, but "The yellow sky is always green" is sensible: (since sky lies or may have color, "The sky is blue" and "The sky is not blue" areve buses as significant), although false. Note that "Ideas cannot be green" be seen that would be considered nonsense rather than true; by Sommers. If feel other in the world is not precise enough to be a basis of or a computer are precise enough to abe a basis of or a computer are precise enough to abe a basis of or a computer are precise enough to abe a basis of or a computer are precise enough to abe a basis of or a computer are precise enough to abe a basis of or a computer are precise enough to abe a basis of or a computer are precise and are the consequences are the consequences.

from a given body of statements, rather than judgements of "nonsense" and or "sensible."

es. Changes of the model represent, in the leadersheet way, corre-

In summary, many schemes have been developed in the literature for close formally describing the semantic properties of language. Some of these were described above. Nost of the schemes are vague, and although a total klein's and Quillian's, among others, are being programmed for computers, and the presently available semantic systems have been developed to the presently available semantic systems have been developed to the point where they could provide a useful basis for computer under the point where they could provide a useful basis for computer under the standing." However, I have used some of the ideas from the showers (x systems in the cloping six. The idea of representing meaning by world a like years and have been developed the successful the standing of the ideas from the showers (x some second the second that is particularly important for the important for representation representation associations is particularly important for the important for representation as it is not specificable and no sealed the second of the second that is particularly important for the important for representation as it is not specificable to a second the second of the sec

orestcomes about the segments, connections, sheres, are the very book and contents, sheres, are the very book of the segments, connections, sheres, are the very book of the segments of the chart of the selection of the content of the segments of the selection of the second of the selection of t

it does not iseed to date the generally agriculture definition (Vi semicion) and (Vi semicion) and the constant of the semicion of the present the following definition: and the constant of the present the following definition is an example the constant of the constant o

- a. Certain features of the model correspond in some well-defined way to certain features of  $\underline{\mathbf{x}}$ .
- b. Changes in the model represent, in some well-defined way, corresponding changes in the longestand development of the summer o
- c. There is some distinct advantage to studying effects of changes upon it in order to learn about a rather than ever described about a rather than ever described about a rather than ever described and consider the studying a directly.

  \*\*There is some distinct and every to learn about a studying a directly.

  \*\*There is some distinct a manual interesting of each and the studying a statement of the study of a mathematical concept. The study of the statement of of the statement
  - 2) Examples of models; this eds to some of the indistance ". However, I have used some of the indistance."
- i) A small-scale wind-tunnel test-section for part of an airplane is a model for the actual part because aerodynamicists under and how air flow around the test-section is related to air flow around an actual since airplane part (whose shape corresponds to the shape of the test-section in a well-defined way). An obvious advantage of such a model significant convenient size.
- ii) A verbal statement of a plane geometry problem usually includes statements about line segments, connections, shapes, etc. The usual box model is a pencil or chalk diagram which has the geometric features described in the statement. The advantage of the model is that it is at conceptually easier for people to interpret geometric relationships from a diagram than from a verbal statement, which is really an encoding of the geometric information into a linear string of words.
- iii) Problem solving ability in human beings has been modeled by a computer program developed by Newell. Shaw and Simon (28) of The model I can be improved by modifying the program so that its external behavior corresponds more closely to the behavior of people working on the same of problems. The advantage of this model for behavior is that its internal workings are observable, and hence provide a hypothesis for the corresponding mechanisms involved at the information-processing level in human problem-solving as an arm of the same of the corresponding mechanisms involved at the information-processing level in human problem-solving as a sai "lebom" are said inclinated (1
- iv) Logicians develop and study formal systems. Occasionally these soon as have no significance other than their syntactic structures. Sometimes, however, systems are developed in order to study the properties of second external (usually mathematical) relationships. On these occasions one says that statements in the formal system correspond "under standard" A interpretation" to facts about the relationships. The model for such a

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formal (syntactic) system usually consists of outs of objects which in the satisfy our intuitive notions of the "meaning" of the original relationships, yet whose preparties correspond to certain features of the 2 massic syntactic statements. Thus one may study the abstract formal system by manipulating a model which has intuitive eightfleance. Seminticism bus in mathematical logic, refers to the study of such models (6).

There may not always be a clear-cut distinction between entities

The information store of a system is a model for a set of English

which are models and those which are not really representations of

something else. For extracted the information which can be extracted from the

-maldorq s'nomi2 has, ward? (level, such a self-defined was to, and in fact suched be identified ease to, at least some of the information available in the sentences.

The principal advantage of such a model is char it is easier to identify the principal advantage of such a model is char it is easier to identify the such as the content of the from the and extract desired information from the model than it would be from the and extract desired information from the model than it would be from the complete English sentences. Question-asswering systems have been devel-

uped which use various kinds of models and which have achieved varying

gnirawana-noitaup a gningiash nI : lebom gnirawana-noitaup (6 degrees of success. The best-known examples of such systems are disa no, noitam of nicked as a gnibivord with providing section. The structure of the model used in a gnique of the model used in gnipher of a mainaham any new question-answering system is discussed in Chapter III of this puper.

The store may noitaup and moral moral moral moral as a property of the store of the model used of this of this of this puper.

The store was a provided to the store was a property of the store was a puper of the s

form of simple declarative English sentences, as it is in SIR, or it ... Some Existing Question-Answering Systems.

may be a prepared data structure. In either case, it generally contains Several computer programs have been whose asias computer programs have been whose asias computer programs.

information which people would normally communicate to each other in are somewhat related to those of SIR. None of these "question-

English sentences. I consider the store of information which is the answering systems uses a model for storing arbitrary similarity information.

basis of any question-answering system as a model for any set of them deal with the same general kind of subject

matter as SIR. However, each or these systems has certain interesting

"information contained" refers here to the semantic content, not the leatures, some of which have unfluenced the design of SIR.

number of information-theoretic bits. Note that, due to the present

vague state of semantic analysis in natural language, the most effective

way of discovering this information; sentents as superior remains general actions of the antique control of the sentence of th

There may not always be a closur-cut decidited her der den a thiries The information store of a system is a model for a set of English which are models and those which are not mosily turnesentations of sentences because the information which can be extracted from the something class. For example, Newell, Story and Stren's publicastore corresponds in a well-defined way to, and in fact should be identisolving program discussed in (iii) above is trafy a ageal, in the sense cal to, at least some of the information available in the sentences. defined earlier, only insofar as it is intended to represent than or The principal advantage of such a model is that it is easier to identify sebavior Otherwise the progress would have so be treesed tast or its and extract desired information from the model than it would be from the norits as an independent problem-solving mechine. complete English sentences. Question-answering systems have been developed which use various kinds of models and which have achieved varying 3) Question-answering model: In designing a pagerign-angwering degrees of success. The best-known examples of such systems are dissystem and is concerned with providing a stone of intermetion, or a cussed in the following section. The structure of the model used in mechanism for developing such a store, and a process of for exciseting my new question-answering system is discussed in Chapter III of this appropriate information from that store when we write with a eggstion. paper. The store may be built up on the basis or infrare, as promental in the

C. Some Existing Question-Answering Systems.

may be a prepared data structure. In election case, in generally contains

Several computer program awad several computer programs and results

rr reduced to those of SIR. None of these "question-

answering" systems uses a model for storing arbitrary semantic information

tion; and none of them deal with the same general kind of subject

English sentences which contains the same information. Of sentences which contains the same as SIR. However, each of these systems has certain interesting satisfies the seamed contains the seame of which have influenced the design of SIR.

anaber of information-theoretic bits. Gost Gorty due to the grave at

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However a faited amount of addressed that a specific staiget

The stored performation (model) doublets of antistratise containing said all the relevant baselett gaie results arranged adoubling to a pipe instruction and the relevant baselett gaie results arranged adoubling to a pipe instruction selected hierarchical format. There is no provide ton for automatically and modifying this model. Each question is translated into a specification—list with the desired information represented by blacks. This inscription—tion—list with the the received against the model, return blacks. This inscript is entire final appropriate on the printed cont. The section is desired mide to classes respond in grammatical English.

The bulk of the program is devoted to the task of translating as ignored question sentence into a specification within the program is devoted to the task of translating as ignored question sentence into a specification within the program is devoted in a dictionary, (1800017) in a part of specific translation as set of entries for each word, such as its part of specific their the word of the part of specific translation and sits "meaning?" "Meaning," which costly appears of the part of specific words of the sentence of the sentence of the sentence within the words; reference a campatent translation of the words. The within the words of the sentence of the subject matter enables it is simple; and had procedures to solve what would otherwise be very difficult.

problems. The model consists of a fixed etructure of information of income arranged to facilitate the process of filling blanks in specification of the lists.

The "Baseball" system gives the illusion of intelligent behavior conquision of intelligent behavior conquision of intelligent of English question forms. However, a limited amount of information about a specific subject must be pre-arranged in a fixed data structure and the data must lend itself to bierarchical ordering. Such a scheme cannot be generalized and conveniently to handle the larger variety of information which is a sense of the larger variety of information which is a sense of the larger variety of information which is a sense of the larger variety of information which is a sense of the larger variety of information which is a sense of the larger variety of the larger in the larger is a sense of the larger variety of the larger in the larger is a sense of the larger in the larger in the larger is a sense of the larger in the larger in the larger is a sense of the larger in the larger in the larger is a sense of the larger in the larger in the larger is a sense of the larger in the lar

written him the LISP programming language, (23) can correctly answer; would certain coimple English questions on the hesis of a logramming backs.

English sentences.

modifying this andes. Back weastled is and because the copyright wather

Example: galle of the paragram of devited to the best of the galle galle.

input: po((AT SCHOOL JOHNNY MEETS: THE TEACHER) age a part surgines not samp

(THE TEACHER READS BOOKS IN THE CLASSBOOK), viend to it as not show

output: (IN THE CLASSROOM). A decrease the section of the properties of the model for a sentence is a list of up to five telements; busine to verb, object, place, and time, a This model is constructed for weach the corpus, and for the question (whereas is special symbol of the in the question-list identifies the unknown sitem) on The question-list identifies the sunknown sitem) on The question-list identifies the sunknown sitem) on The question-list identifies the sunknown sitem) and The question-list identifies the sunknown sitem and the question-list identifies the sunknown sitem as a special site of the question sitem and the question-list identifies the sunknown sitem and the question-list identifies the sunknown sitem and the question-list identifies the sunknown sitem and the question sitem sitem sitem and the question sitem site

seatance is afound at he accreet a reply big destructed afrom the course is hard appropriate and the sortisinal accordance from the long section of the sortisinal accordance.

This is a sprimitive expense in a wind in a wind in the control of the control of

3) selfNRHEX. (36) This programs written in the 10VIAL programming language (37); can ensure a wide weitlety of questions absert anformation contained in a larger corpus of simple natural English such as the mean in Golden; Beak Encrelopation. Ensure that all themse thus no based sebom A input: val'Matade birds eat? Well 312 . enchanced political descriptions of special political descriptions. (somewhere in the encyclopedia): a "Worms are estem by birds value of output: "Birds est worms."

The program classification ald a words acceptable function words; which have structural (syntactic); significances (angle the admitted grant transmission content words, which have sementic; significance, (inspective prospective prospe

Initially the corpus (the encyclopedia) is indexed with respect to malle a occurrences of all content words and this index occupies about the same of a mount of space as the corpus itself. When a question misqueked, athe system selects these sentences from the scorpus which shave the spicetest is number of content words sin common with the squestions. At it is point a very elaborate grammatical analyses are used to adetermine whether any roll the selected sentences provide an answer of other questions and describe and describe any roll the selected sentences provide an answer of other questions and describe a

in its original form and referred to swhen necessary subtrough the Just of an index. Since the dinformation is snot pre-prodessed into a more from usable form the grammatical analysis required at the time the questions is answered is equite complex. Recent relaited work by Klein (19) 20 10011 indicated that some of the rules of the grammar can be developed automs? matically from the corpus, and information from several sentences well information by use of syntactic methods to help answer questions.

"dependency grammar" methods can be discovered more reasily by means and of semantic analysis, and they would there be more districted meaningful.

A model based on such semantic relations would significantly significantly of gain directly storing and using semantic relations would are the feasibility of gain directly storing and using semantic relations will at the feasibility of gain directly storing and using semantic relations will be as a second of the supplies of the storing and using semantic relations.

4) Eindsay's USAD-SAM: Sentence: Apprelservands Diagrammein undgood off Semanting Analysing, Machine. U. (21) This program; written in the IPL Woods (26) iprogramming language, acceptsons inputsus, sentencedin Basic Institute.

words are any gords which have not been comen as in milon words).

THE PROPERTY OF THE PROPERTY O

English (30), extracts from it any information concerning kinship,
and adds this information to a family tree. Example:

input: "John, Mary's brother, went home."

effect: John and Mary are assigned a common set of parents — i.e.,

they are represented as descendants of a common node in the family

tree. The grammar is sufficient to handle a considerable portion of

natural English in recognizing family relationships. Although the

author does not consider question-answering in detail, it is clear that

the family relation information is immediately available in the tree

model and specific requests could be answered almost trivially.

input: it typical of a type of incomplete the property of the buller and property of the buller was not bear of the buller and property of the buller and the property of the buller and bear of the buller and buller and buller and the buller an

for different kinds of information. In a more general system it garded and might be possible to use the best systable model to represent information for each subject area regard trees for family relations, concitable cartesian coordinates for spatial relations, perhaps just the original text in areas for which there is no obviously batter representation; to said but that would be a confused system with treesendous organizational problems. The SIR system is based on a single model which captures and that some of the advantages of various specific models while permitting include

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uniform processing procedures and permitting the storage and retrieval processing procedures and permitting the storage and retrieval of arbitrary facts which arise in human conversation.

into the notation of symbolic logic (12): This program, written in the COMIT (34) programming language, translates certain English riddles into a logical form which may then be tested for validity by another program, written by the same author, which applies the Davis-Putnam proof procedure (13) for statements in the propositional calculus.

Example:

input: "If the butler was present, then the butler would have been seen, and if the butler was seen, then the butler would have been questioned. If the butler had been questioned, then the butler would have replied, and if the butler had replied, then the butler would have been heard. The butler was not heard. If the butler was neither seen nor heard, then the butler must have been on duty, and if the butler was on duty, then the butler must have been present. Therefore the butler was questioned."

output: [[L=M]\_ [M=N]\_ [N=P]\_ [P=Q]\_ ~Q\_ [M, ~Q]=R]\_ [R=L]]=N]

The input is typical of a type of problem which appears in elementary
logic texts. It has been pre-edited to perform certain clarifications
including removal of most pronouns and insertion of necessary marker

words such as "then." The program translates this input, by means of
dictionary references and grammatical analysis, into the model, which
is a statement in mathematical logic having the same truth value as
the original English statement. The "question" in these problems is
understood to be, "Is this argument valid (i.e., necessarily true)?",
and the answer can be obtained by applying established methods to the
logical model.

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takes advantage of a model ideatly suited become type of problem borgers to involved and advance knowledge of the only possible question; well one today considers the possibility of questions such as, swhit was the locause drive tion of the suspect who was questioned?, of maket was done to the continuation of the complicated process of translating the corpus into logical terms would not be of any aid in finding answers. Only a course small part of the information needed for intelligent behavior than to appear to the propositional calculus. As will be discussed in the propositional calculus. As will be discussed in the propositional calculus. As will be discussed in the sufficient to formative the conversational calculus calculus of not be sufficient to formative the conversational ability of the model of the quantificational calculus of not be sufficient to formative the conversational ability of the sufficient of the quantificational calculus of not be sufficient to formative the conversational ability of the sufficient of the quantificational calculus of the procedural sufficient and the sufficient of the conversational ability of the sufficient of the conversational and the sufficient of the sufficient and the sufficient of the suf

6) Bennett's computer program for word relations.(3): This was one program, written as the COMIT programming language, will accept as information and answer questions framed in a small number of fixed as years on made the small because formats. Example:

to make endinger to it.

A) Lamettal impifications broad at the matter of the interest is taken for

input: DOG IS ALWAYS MAMMAL.

MAMMAL IS ALWAYS ANIMAL.

to sected by several compacted the prometer with symmet standay before

output: MANNAL IS ALWAYS ANIMAL.

The input sentences must be in one of five formats (e.g., "X IS ALWAYS

Y," "X MAY BE Y," etc.), and only one occurrence of each format may

be held true at one time for any one item X. This input information is

translated into the model, which has associated with every item X each

corresponding item Y and an identifying number for the format which set

up the correspondence. (The model actually consists of linear strings of tagged entries, as is required by the COMIT language.) Similarly consist there is a small number of allowable question formats, each associated own with one of the input formats and resulting in a particular class of means and resulting in a particular class of means and testing the model of the contribution of the contribution of the model of the contribution of the model of the contribution of the contribution of the model of the contribution of

of SIR, is that the information kept in the model dentifies particular solkinds of semantic relations between particular words of Questions are liberal analyzed with respect to, and answered by referring to the model for the model for the model of the

- 1) Relations are identified with particular formats rather than with their intended interpretations.
- 2) Logical implications based on the meanings of the relations are ignored. (3) Analysis Drow for margory resupposes spenned (3)
  - 3) Interactions between different relations are ignored and according
- 4) Its string representation makes processing the model more associate difficult than necessary.
- tormate. Example:
  5) The user must know the form and content of the model in order to make changes to it.

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In summary, several computer question answering systems have been developed to solve special problems or illustrate approach to providing intelligent and a direct approach to providing intelligent and understanding behavior for the computer of Although various forms of the models are used in the existing systems in one represent semantic relations in an intuitive, general, and useable way. The SIR model described

corresponding from Tamilan reconstituing combe for fire Erman will in si-

in the next chapter provides the basis for a system which is more powerful than any developed thus far. The system based on this model can
store and retrieve information about arbitrary subjects, make logical
deductions, account for interactions between stored relations, resolve
certain ambiguities, and perform other tasks which are necessary
prerequisites for an understanding machine.

# Chapter III: Representations for Semantic Information

in the next chapter provides the basis for a system of the metro return

The STR model is the collection of data which the STR programs can refer to in the course of question-answering. It is a dynamic model, in the sense that new information can cause automatic additions of changes to the data. In addition, it is a semantic model, in the sense that the data are organized in a structure which represents the meanings of the English sentences upon which the model is based. The purpose of this chapter is to describe this semantic organization, which is reponsible for convenient accessibility of relevant information and therefore for efficient question-answering.

Many kinds of "semantic" models are possible. The precise form of the SIR model evolved from studies of possible word-association models and of the semantic systems of mathematical logic. Its implementation was influenced by the features of available computer programming languages. It is only capable of representing a particular group of semantic relations. These factors are discussed in the following paragraphs. Chapter VI will present a proposal for future expansion and formalization of this model and of its associated programs.

## A. Symbol-Manipulating Computer Languages (4)

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Programming the SIR system, or any other elaborate questionanswering system, would have been almost impossible if not for the
availability of symbol-manipulating computer languages. By taking care
of much of the necessary encoding and bookkeeping, these languages permit a programmer to concentrate on the more significant aspects of organ-

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is one off engigle carry models are not seen and are not as the same of the carry models and as a seen after a state of the carry manual and a seen as a see

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IPLa 252, another "Elegand of the serious of the serious symbols of the serious symbols of the serious symbols of the serious symbols of the serious of the

<sup>\*</sup> See reference (4) for definitions of list-processing terms and more detailed descriptions and comparisons of these languages.

is one of the oldest symbol manipulating languages; The basic dults of the data used in the structures composed of the symbols. An oldest program describes symbol manipulation at a very basic level, leaving level the programmer with the problems of keeping track of storage used, at as an symbols assigned, netc. On the other hand, be is quite easy in liberty build up much aborate programs out of simpler processes and to manipulate and an arbitrarily complex list structures; to same and o has an index and as a simplex of the structures; to same and o has an index and as a simplex of the structures; to same and o has an index and assigned.

to process hatural language, and was used in two of the question answering systems described above. Although COMIT is a general purpose symbol manitum pulation system; it is best suited to problems involving string and pulation; it is best suited to sprablems involving string and pulation; problems in which the data can be represented in the formand of strings of symbols without introducing and us complication into the source processing algorithms. The COMIT system provides all simple yet powerful of ormalism for describing string and pulations. This formalism can be string and processing algorithms at the comit system provides all simple yet powerful and formalism for describing atting and pulations. This formalism can be all as extremely useful for describing proceedates, such as parsing, which opers attention sentences of natural language.

Lisp; the language used in one of the above question answerers and the one chosen for programming SIR, was originally designed to be a for a semalism useful for studying the mathematical properties of functions of symbolic expressions as well as useful in a practical programming system? LISP programs consist of functions, rather than sequences of instructions

<sup>\*</sup> See reference (4) for definitions of list processing terms and more detailed descriptions and comparisons of these languages.

The state of the s

or descriptions of data forms. These functions map symbolic expressions into symbolic expressions; the basic form of a LISP symbolic expression is a binary treet which can easily be used to represent list structures when necessary. The organization of LISP programs into functions entered ables one to describe elaborate recursive tree-searching and list-way structure building operations simply and conclusive, Reasons for any other language for programming SIR include the fellowing:

- veniences such as the use of memonic symbols and the automatic maintenances of available storage.
- 2) Unitike COMIT, complex trees and Herbertunes which I frequently arise in the chosen representation for the model (see section D) Can be represented directly as Miss and Tolvador and the complex and the
- 3) The DIST formatten is particularly well sufted for describing so the recursive tree-searching procedures which are an important part of the system (see Chapter W) and addition not assume the second of the system of of the syst

in a wide various of subject areas, yet the stored information should be specificated the second to a confidence of the second

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translate from English sentences into a function form better suited for Muoda enchances galander-molaseup edit in beviovat invelope edit (ii

LISP finduture However, binde then represented the molase from the model. Neither was account and account a representation of the molase of the molase the molase finally chosen (see Chapter IV) could just as cased the problems of a hybrid system were avoided by converting everything box to the LISP language.

Vords are the basic symbols in rest cabically specially verbs and preparations, denoted adaption. Male and preparations, denoted and are specially verbs and preparation-special preparation of existing question-special systems discussed in the previous chapter demonstrates, that many different kinds of models for the

<sup>\*</sup> See reference (4) for definitions of list-processing terms and more detailed descriptions and comparisons of these languages. .assesso

representing the information in English text are possible. One can develop question answering systems which are widely in approach. At an one extreme are systems, e.g., Lindsay & Kinship program, which inhediately process the text into a form from which inside pared questions can be answered trivially, but which thereby ignore which of the information in the input. At the other extreme are systems, e.g., the symmes system, which simply store the raw text and persons all necessary computation ations after meach question is required thereby decoming subroided in complex grammatical analysis.

E) -nample, tangel letter has eldeden at majere, a test has a frequently arise in the chosen representation for the mount tree has been tion and avidable and the chosen representation for the mount tree has been supported at the recursive tree-searching procedures which are an important part of

- i) The model organization should be general though to be weeful and in a wide variety of subject areas, yet the stored information should be specific enough to be of real east store, in the question enquering of process.
- ii) The effort involved in the question sentencer iii) The effort involved in the question-answering procedure should to the procedure should be divided detyren included and the lateral should and the probability of retrieving answers from the model. We that the probability chosen (see Chapter IV) could just an imperor sanitated be probability chosen (see Chapter IV)

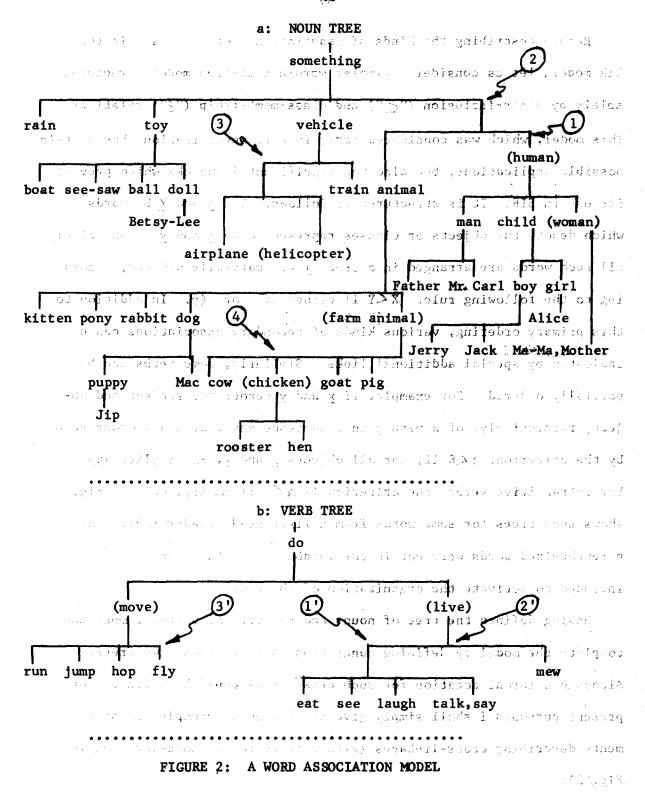
Models based upon words and word-associations are the best candidates and for meeting these requirements.

Words are the basic symbols in most natural languages. Certain words, usually verbs and prepositions, denote relationships between real about the objects. In the Six model I shall use words chemistres to represent the objects or classes denoted by the words, and specific kinds of a sacretary ations between words to represent relations between those objects or whom box actual gates about 181 to snottening to the classes.

Midail MOOM Before describing the kinds of associations actually used in the ഗുന്ദ്ചേതായെ SIR model, let us consider a simpler word-association model structured solely by class-inclusion ("C") and class-membership ("E") relations: vehicke This model, which was considered early in this envestigation, has certain (trausin) possible applications, but also has significant drawbacks which prevent ingles ofthe boat see-saw ball doll its use in SIR. It is structured as follows: Let X and Y be words was obile (weman) Betsy-Lee which denote the objects or classes represented by x and y, respectively. airplane (helicopter) All such words are arranged in a tree, i.e., partially ordered, accord-Father Mr. Carl boy girl ing to the following rule: X Y if either x Cy or x &y. In addition to (4) (Indias mast) kitten pony rabbit dog this primary ordering, various kinds of secondary associations can be Jerry Jack Harmanher indicated by special additional links. Similarly, some verbs can be Mac tow (chicken) goat ptg partially ordered. For example, if x and y denote the subject and object, respectively, of a verb q in a sentence xdy, we shall order verbs rooster hen by the criterion:  $\alpha \leq \beta$  if, for all objects x and y, x $\alpha$ y implies x $\beta$ y. For intransitive verbs, the criterion is  $\alpha < \beta$  if  $x\alpha$  implies  $x\beta$ . Fig. 2 b: VERB TESE shows such trees for some words from a first-grade reader (29). parenthesized words were not in the vocabulary of the text, but are included to motivate the organization of the tree. (live) - (63am) Having defined the tree of nounc and the tree of verbs, I must now complete the model by defining connections between these two trees. god Although a formal notation for such cross-links could be defined, for est ser ladge calk, sov present purposes I shall simply give the following examples of statements describing cross-linkages (with respect to the node-labeling in FIGURE 2: A WORD ASSOCIATION MODEL

i) Any noun below node 1 is a suitable subject for any verb below node 1'.

Fig. 2):



and a subject to the compact of the control of the

- 11) and any noun below node 2 is a suitable subject for any verb above count node 2'.
  wolls.nolinauginos gmillossa and red noiscinses bent ab-Ill and od
- iii) Only nouns below nodes 3 or 4 may be subjects for verbs below .aldiago and stawla ion year and talkenters. This subjects for verbs below node 3.

The complete model, composed of tree structures and statements about their possible connections, is a representation for the class of all possible events. In other words, it represents the computer's knowledge of the world. We now have a mechanism for testing the "coherence" or "meaningfulness" of new samples of text. As information is red into a system which uses this model, the program would simply have to insert a "thread" of special connections into the model. The thread would distinguish those events which actually happened from those which are just "conceivable" to the computer. Questions about the input state—ments could then be answered by referring to the model to see which way the thread passed. Such a model would be useful in a pragmatic system such as Abelson's (7), to test the credibility of what it is told. It could identify sources of its factual knowledge by their threads, and compare the reliabilities of the various sources.

prevent its use in a general semantic information retrieval system.

It is extremely difficut to construct a useful model of the form described, for a significant amount of information; writing a program which would add information to the model significant in the model significant to describe many useful groupings of nouns, but the introduction of a few additional relations would confuse the structural organization of the model and relations to be model and significant to describe relations would confuse the structural organization of the model and relations to be much more complicated. The verb

groupings, in order to be useful, must be carefully selected according to the ill-defined restriction that the resulting configuration allow simple and useful cross-link statements. This may not always be possible, and certainly becomes more difficult as the number of relations considered increases.

The model used in SIR is a word-association model similar in some of respects to the one just described. However, the words are linked in the ageneral manner so that no particular relations are more significant. The model is constructed, on the basis of input sentences, a completely automatically. Descriptions of the behavior of particular relations, which roughly correspond to the cross-link statements in the above system, are programmed into SIR rather than being part of the show and one of the sentences.

C. Semantics and Logic. such that the credition bear such as the control of the c

The structure of the SIR model was partly motivated by the cloud by the cloud will made to the structure of models in mathematical logic. These logical models represent the "meanings" of logical statements, and thereby help the mathematician "think" about his problems, in the same way that the SIR model will think about his problems, in the same way that the SIR model is supposed to represent the "meaning" of English input, and thereby at all supposed to represent the "meaning" of English input, and thereby at all the program obtain answers to questions. Let us take a more detailed look at logical models.

the throad passed. Inch a model would be asert in a praymatic system

The "semantics" of mathematical logic is the study of models for models of a set of individuals when the following to the domain of the logical variables), and, for each logical predicate or relation, a set of ordered n-tuples of individuals.

logical predicate or relation, a set of ordered n-tuples of individuals.

A relation is true of derivan individuals if and body if, in the said and model, the ordered in tuble of those individuals is she element of the said set corresponding to the relation. For emisple, a model for a logical system dealing with the indural ordering of the linespers algherhave as 13 its model the set of integers (as the domain of individual variables) and a set of ordered pairs of integers corresponding to the extension and a set of ordered pairs of integers corresponding to the extension of the last form and the integers are would contain all pairs (at b) and for which integers a is truly less than integer as posses, for which the same statement are businesses as the contains in a set of the contains the same statement are businesses as a second of an analysis of the same statement are businesses.

studying certain properties, such as constituently and completeness, of each the associated formal systems. They are not generally as useful as aids in proving particular theorems, or studying the possible interactions are between various relations. The BIR models organisation must be better such that to these latter problems, which are of major interest in develation oping a question-answering system no seem out so so such as a such a latter answering system no seem out so so such as a such a latter problems.

is a good starting point for a question mistering system model. A seed has however, certain model testions are necessary. Since we are interested in conversational ability in the computer; the relations in our model should represent concepts which commonly occur in human conversation, such as set-inclusion and spatial relationships, rather than abstract mathematical properties. Furthermore, unlike a Togical model, the system should have built-in provisions for determining testrictions, extensions, or inconsistencies in the model, based on properties of the

relations involved. E.g. if "C" indicates settinglusion, and if 2100 a a b and boo are both in the model to, the system should ideduce that 100 hom a conshould also be in the model (or, equivalently, that accordance is true statement), from the built-in knowledge that set ringlusion is madely transitive. Finally, for respons of computational efficiency, a subject transitive, finally, for respons of computational efficiency, a subject transitive, finally, for respons of computational efficiency, a subject transitive, for practical in formal hogic but de of prime impor- but transitive, apprachical computer systems information about relations association accessible than it would be if it consisted simply of unordered sets of n-tuples of objects. These considerations ledges to a choice of the description-list organization for the accust word association model used in SIR and described in Part & below.

Although some ideas were borrowed from logical semantic. Does not systems SIR is not directly dependent upon any formal logical serving mi mechanism. Instead, the model and the programs which utilize it, assumed were designed according to informal bouristic principles of reason—since ing, which I believe to be the most convenient open for a first. a gaige experimental system for intelligents convergation between machines and human beings. Once a working system has been developed a one of a since try to extract from it a logical basis for a more advanced. The system is the subject of Chapter VI. Short assumed an assumed an extension is the subject of Chapter VI.

D. The SIR Model, a consummission is to top a noisulant rus as doub and the

through particular relations. These associations are represented by description-list" entries. In this section I shall discuss the constants.

modes should represent concepts which commency make it besit maderial

description-list structure, the religible lead in Six, and the speedience representation on a same as to descript complex remains a can add paixs to descript converses a characters are the

the use of description lists: The model the SIR) is based largery uponouse the use of description lists. A description list as sequence of largery uponouse paired of networks, which the entire lists as sectioned with a particular object. The first element of death pair lists the make by an attribute as the pair of the fair objects, and the miscondidense of the pair less the value of that attribute for the object described a tribute attribute for the object described a tribute attribute for the object described a tribute of the number of the object described a tribute of the number of the object described a tribute for the object described a tribute of the number of the object described a tribute of the number of the object description and associated of the object of the object of the number of the object of the object of the number of the object of the object of the number of the object of the object of the number of the object of the object of the number of the object of the object of the number of the object of the object of the number of the object of the number of the object of the object of the number of the object of the object of the number of the object of the number of the object of the number of the object of the object of the number of the object of the object of the object of the number of the object of the object of the number of the object of the objec

The factuation of the acceptable of the acceptab

SOUND, MEW, COLOR, (BLACK, WHITE, YELLOW, BROWN); PROGRESS; 14, 10.

Note that, since the color of cats is not unique, the value associated with COLOR is a Pret of possible cet colors. Total parentheses indicates that the mentire list of colors is a single element labour of the description list. The mentire list of colors is a single element labour of the description list.

of tan fliustrate the way description-flists may be used by considering their place in the Tri (25) programming system. By convention, an every IPE data list has an associated description-fist. The attributes on IPL description; lists are IPL symbols, and the values are symbols which may name arbitrarily complex IPL list atructures, Basic IPL argord operations can add pairs to description-lists; others retrieve the second slement of a pair (a value) sponthal description; list, as even; the first element (the attribute) and the same of the main date list. An attribute can only specure operations any specialist in large ed. IThus, and other of the attributes on a description; list land other order of the attributes on a description; list in large ed. IThus, and description; list speciations simulate an associative memory containing que arbitrary descriptive information for the described object. Solve and all the large examples are used in it much the same ways as IPL description; lists dilly LISP, the described list objects are individual words or watoming appropriation; the the same ways as IPL description; lists dilly LISP, the described list objects are individual words or watoming appropriation; the lists.

objects are individual words or "atomic as model, " the description objects are individual words or "atomic as models," the ther the additional objects are individual words or "atomic as models, and the sacription of the allowing the was of flags as attributed of value pairs. Although originally provided to facilitate the internal operations of the alignment, property-lists and according to the lists and according to the programmer. The model and according to the programmer. The model and according to the accor

6

model is to assist the computer in understanding and communicating with a person in English sentences. SIR works only with simple of the consist of words which denote real objects or classes of objects and words which express particular relationships between gain the objects and classes. If one considers the objects and classes

Note that, since the cotor of cats is not unique, the value apportated

as the individual elements in a formal system, then these relationships between objects and classes are analogous to the relations of format and logic (described in Cabove). "Understanding the meaning" of a sen-more tence is interpreted as the process of recognizing the objects in the sentence and of placing them in a specified relation to one another.

The proper relation to use is frequently determined by the verbs and prepositions in the sentence, and the way in which to place the objects into the relation is determined by the form of the sentence. For example, the verb wish usually determines a set relation. The form

In the computer representation the basic objects, as well as then names of relations, are simply words. The intended interpretation of this representation is as follows: Suppose word x is associated in the model with word y by means of relation k. Then this represents a statement which "means" that the object or class denoted by x is associated with the object or class denoted by x is associated with the object or class denoted by y by means of the relation named R.

2

The procedure for developing the form of the model and the commend associated storage and retrieval programs was approximately as follows:

A single relation -- set inclusion -- was chosen because it is an easy concept to recognize from English text and is also (intuitively) important to the "meaning" of simple sentences. An internal computer representation was then found which adequately represented the relational information, seemed general enough to model many other kinds of relative tions, and also had connectivity and accessibility properties which make it useful for question-answering. Programs were then developed for

recognizing sentences which deal with the given relation by their syntactic forms (see Chapter IV); selecting relevant word tokens from the sentences; and adding to, modifying, or searching the model according to the results of the recognition process. The search programs are designed to "know" the peculiar properties of the relation being searched, e.g., transitivity or reflexivity. Therefore a special set of search programs had to be written for each relation. Each time a new concept or relation was added to the system, the above steps were repeated. That is, the basic model structure was generalized, if necessary; new syntactic recognition forms were introduced, and existing ones modified if any ambiguities had been introduced; and search and response programs for the new relation were written. Search programs designed for relations already available in the system were modified when the old and new relations "interacted"\*

The relations included in SIR were chosen because they demonstrate various aspects of the information normally conveyed in human conversation. They were introduced in the following order and for the reasons stated:

- a) Set-inclusion, because it is one of the most basic relations of which people are aware.
  - b) Part-whole relationship, because, although it is significantly

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<sup>\* &</sup>quot;Interactions" between relations, and the structure of a modified system which is easier to expand, are discussed in Chapter VI.

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Since in general relations are not appaced to a charlon R most in different from, it interacts strongly with the set-inclusion relation from the set-inclusion relation  $R_1$  and  $R_2$  so that if relation  $R_1$  and  $R_2$  so that if relation  $R_2$  and  $R_3$  so that  $R_4$  are  $R_4$  (in logic terms, if  $R_4$ ), then one can say that between  $R_4$  and  $R_4$  (in logic terms, if  $R_4$ ), then one can say that set of the se

c) Numeric quantity associated with the part-whole relation,

to y. One may think of KI and KZ as mappings from individuals into -qlrosed laises to staten restrict restrictions at its solution sets such that  $\langle x,y \rangle \in \mathbb{R}$  if and only if  $y \in KL(x)$  and  $x \in KZ(y)$ . For noisempoint lanoisaler this goals beings ed the noisempoint evit

example, if K is the set-inclusion relation, Rl is the subset relucion - tes of betaler ylesols at it esuaped quitaredmem-tes (b

and A2 the superset relation. R1 and R2 may be neaded by the symbols sized classifier and superset in general, the symbols nameng R1 and R2 are used superset. In general, the symbols nameng R1 and R2 are used superset.

as attributes on the property lists of x and y, despectively. Note that needs the characteristics of the character

if R is a symmetric relation then only one mapping which may itself be a significant as at a significant and a significant sig

named R, is decessary; for  $y \notin R(x)$  implies  $x \notin R(y)$  and vice-versa. .1sbom gairseqqa-larutan erom ,therein

if one and only one object can be in relation 21 to any word xo

gnitaixe the walue of artribute RI of x can be simply the name of that they same of artribute RI of x can be simply the name of that dray same and yd beiliosque ai yllney and the same along that a type-1 link exists from x to y in this case I say that a type-1 link exists from x to y in themiseas no too too the stribute in themiseas of) the attribute in the example of the use collewing (er. by means of) the attribute in a sample of the use saidlewing (er. by means of) the attribute in a saidle saidle

of typerl links as in spatial relations, oners only one objet can be

"just-to-to-to-to-to and in staged of the spaces to are the "Bom and the right of the chair," them the attribute-value pair (JRIGHT.)

just to the right of the chair," them the attribute-value pair (JRIGHT.)

words which denote real objects and classes. If an English statement to the property-list of CHAIK, and the inverse relation gaintesses as margor noitingoor more constructed by the sentence-form recognition program as interpreted by the sentence-form recognition by adding the pair (JRIGHT, CLAIR) to the property-list of the trelation A holds between objects or classes and the relationship is represented by placing attribute-value pairs of the property-list of both x and can also between x and z, type-i finds the property-list of both x and y. There can saly be one value corresponding the action, and the value of the attribute and given property list. However, this value may he related to the described object by mean of the specified relation.

Since in general relations are not symmetric, relation R must be different From, it interacts atrongly with the sentacination relation factored into two relations  $\underline{R1}$  and  $\underline{R2}$  so that if relation  $\underline{R}$  holds and has several common properties with it persons in the several common properties with its persons as several common properties. between x and y (in logic terms, if  $(x,y) \in \mathbb{R}$ ), then one can say that approutines. y stands in relation R1 to x and x stands in the inverse relation R2 to y. One may think of R1 and R2 as mappings from individuals into - grapech leaders to species and reduced models were a for all all operations. sets such that  $(x,y) \in \mathbb{R}$  if and only if  $y \in \mathbb{R}1(x)$  and  $x \in \mathbb{R}2(y)$ . For well-small indicates along with relationship must be carried along with relationship. example, if R is the set-inclusion relation, R is the subset relation Set-membership, because it is closely related to and R2 the superset relation. R1 and R2 may be named by the symbols about 60 sections of order attention and colerates. SUBSET and SUPERSET. In general, the symbols naming R1 and R2 are used .3528650 as liew as as attributes on the property lists of  $\underline{x}$  and  $\underline{y}$ , respectively. Note that smooth and see of constable faltage adjacet left. (a if  $\underline{R}$  is a symmetric relation then only one mapping, which may itself be selected works for a different kind of relation for which restricted by named  $\underline{R}$ , is necessary; for  $y \in R(x)$  implies  $x \in R(y)$  and vice-versa. different, mere natural-appearing model. If one and only one object can be in relation R1 to any word x, guite our from the our state of the out to our transfer out to our transfer out to out the out to o then the value of attribute R1 of x can be simply the mean of that part-whole relation. and yet frequently is specified by the same very object. In this case I say that a type-1 link exists from x to y("to bave"). It is therefore a sulfable subject in a continuent in following (or, by means of) the attribute R1. An example of the use resolving ambiguities. of type-1 links is in spatial relations, where only one object can be

"just-to-the-right" of another. If the system learns that "The lamp is only one can discooled placed and reconstructed learns to the right of the chair," then the attribute-value pair (JRIGHT, drawdels wallyon as it is essent and stooled for establishments and the inverse relation subjusted to the property-list of CHAIR, and the inverse relation and the inverse as essential at it indicated by adding the pair (JLEFT, CHAIR) to the property-list of that it has a manufactor of stooled between abjects of another stooled between abjects of another stooled by a trial another stooled by a

If R holds between x and y and also between x and z, type-1 links are inadequate, since there can only be one value corresponding to a managed to the distribute of an establishment of the attribute on a given property list. However, this value may be mediated to the end to shade the attribute of the end to shade the corresponding to given attribute on a given property list. However, this value may be mediated to this end to shade by the shade to the end to shade the corresponding to the end to shade the corresponding to the end to th

a list of object-names instead of just a single object-name. In particular, we can make the value of Rl a list of the objects related to x estimated to a strong and the second strong that will people the large that the second strong that the second relation relation we may learn by relation R. For example, in the set-inclusion relation we may learn large of the Sold videous and the second strong that second strong the second strong that the second strong

Prote of restinger to descriptive information pertinent to a particular

Occasionally descriptive information pertinent to a particular

stagistication approach of reported in inclination of the state of the person of the state of the state of the state of a relation must be represented, in addition to the occurrence of a relation must be represented, in addition to the large of the state of

on each sub-property-list whose type-l value is the principal object on the list. For example, after the system learns that "A person has two hands" and also "A finger is part of a person," the property-list no ence past ten to fifteen years much research has been done one one the post ten to fifteen years much research has been done of PERSON would contain the attribute-value pair:

.((REDNIT, EMAN TELLY) (2, REMNIN, COMMING English, for automatic .(((REDNIT, EMAN TELLY)), TRAYBUZ)

processing by computer. In virtually every case, the form of the ori-erq ent era samil E-equivalent of the virtual of the computer.

ginal text is restricted or pre-processed is some way to make it more dural text is restricted or pre-processed.

amenable to currenatio provisition. Some of those studies were montioned

in Chapter II in connection while existing quartion overlay systems.

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Chapter IV: SIR Treatment of Restricted Natural Language cular, we can make the value of Ri a list of the objects to entry SIR must communicate with people: therefore the input and response by relation g. For example, in the ser-inclusion relation or may itself languages of the SIR system should both be reasonably close to natural tadependently that every boy is a person, every girl is a person, every girl is a person. English. Since SIR utilizes a relational model, we are faced with the every MIT-student is a person. The value of the attribute Single on the larutan.morf::noitamrofni lanoitalar gnitsartxa fo maldorq tlusiffib property-tist of PERSON would then be the list (BOY, SIME, MIT-STIDENT). language text. This type of linkage is called a type-2 link I am primarily interested in the ability of a computer to store Occasionally descriptive information pertinent to a computer to store and utilize relational information in order to produce intelligent occurrence of a relation mast be represented. In addition to the larutan gnimrofanari to meldorq sitsingnil ed dguodlA .roivaded basic fact that the relation exists. For example, the person of two language input into a usable form will have to be solved before we bands" implies not only that a band is part of colly person, interior obtain a general semantic information retrieval system, it is indethat in the case of "hands" there are exactly the such party. pendent of the representation and retrieval problems and therefore is relation can is handled by using type-3 links, where the value of considered beyond the scope of this paper.

-villed a limit of dead, each of the scopial a state of the scope est. The first item on such sub-property-lists is the Flog PLOT. which indicates that a property-list follows. MANE is an entribute .tuqtuo bns tuqni sail-dailgn3 sldsbnstsrabnu gnizilitu llita
on each sub-property-list whose type-l value is the prisonal object on the list. For example, ifter the system learns that "A Jorson has Background two hands" and also "A linger is pure of a sersell," the energy of In the past ten to fifteen years much research has been done on raise outstanding attribute-value outstanding the straightform. the structure of natural languages, including English, for automatic (SUBPART, ((PLIST, NAME, PAND, NUMBER, 2) (SULST, NAME, FLAND, SULST, NAME, F processing by computer. In virtually every case, the form of the oring the interest of generality and uniformity type-3 like are processed in the interest of generality and uniformity type-3 like are processed in the process of the ginal text is restricted or pre-processed in some way to make it more dominant mechanism for structuring the mode. amenable to automatic processing. Some of these studies were mentioned in Chapter II in connection with existing question-answering systems.

A recent paper by Bobrow (3) surveys various approaches and cata- property logues existing computer programs which automatically parse English deligned text.

The object of most of these systems is to identify the classical result grammatical structures of the sentences for purposes of linguistic and the sentences for purposes of linguistic and the sentences for purposes of linguistic and analysis, mechanical translation, but informations retrieval. The large in some dictionaries of parts of speech and grammatical rules are generally included employed, and usually no consideration is given to the meanings (in some any acceptable sense of the term meanings) of the words and phrases are involved.

A recent benefition is the work at the national moreau of Standard more dards desired with a spicified language language recent (1). There the object into is to determine whether a given English statement (1). You determine whether a given English statement (1). You determine be made a given English statement (1). You determine be made a given English statement (1). You determine be made about geometrical relationships in a given picture; therefore the bear made "meaning" of the sentence is a critical. The procedure need is west that a same late the English sentence into a logical statement involving geometric durch predicates, and then to test the truth of the logical statement by the predicates would not determining whether the relations specified by the predicates hold not be me evitoes for the given picture.

In the SIR search and retrieval programs I am concerned with a problem similar to that of the picture language machine: "namely, " translating from English to a relational statement, and then deter is mining how the relational statement affects the model. However, dans lient the SIR model is a data structure automatically built up on the basis of the input relational statements, rather than an independently provided to you

"picture." In the NBS system, the process of translating from the NBS system, the process of translating from the name of the process of translating from the name of the name English to the logical statement involves using a complete phrasestructure grammar for a fragment of English associated with picture descriptions This seems like an extravagant approach, although it am may turn out to be the one best capable of generalization. In the present version of SIR I am not concerned with contracting a formal ancivers, mechanical translation, of involvation are true with contracting a formation and the contraction of the co logical statement of the relations recognized from the English sentence. Instead, the recognition programs directly invoke the appropriate storage or retrieval programs to deal with the relations acceptable and acceptable with the relations recognized. I call the process of extracting relational information from English text "semantic parsing." The NBS work described above A points to one rather expensive approach for obtaining this relational cards lands information. 32 Charney (8) has studied the relation between sentence of all form and word meanings. Reichenbach (34) and Fries (16) also discuss the semantic parsing problem, and other approaches will unlate the hope developed by linguists in the near future. It seems late the hope developed with a first of the hope developed by late the hope developed by significant, although somewhat surprising, that the simple formatmatching approach used in SIR, and discussed in part B below is as matching approach used in SIR, and discussed in part B below is as matching approach used in SIR, and discussed in part B below is as effective as it is. for the given picture.

B. Input Sentence Recognition profits and profits and sentence recognition profits and sentence recognition and sentence

SIR solves the semantic parsing problem by recognizing only a small number of sentence forms, each of which corresponds in specific ways to particular relations. The allowable input language is defined and by a list of rules, each of which recognizes and operates upon a particular.

En the SIR search are retrieved thoughtes I was compared with a

55

the value of any of these function evaluations is the special LISP cular form of English sentence. Each sentence presented to SIR is symbol "NIL" the substring is considered unsuitable and the entire tested by each rule in the list. The first rule applicable to the rule is rejected. Otherwise, the system composes a list of the sentence determines the action taken by the system and immediately results of the applicability tests and communicates this list to the invokes a program to perform the action. If no rule is applicable, last part of the rule, the "action" list. the sentence is ignored, except that the system makes an appropriate The first element of the action list is the name of a function response (see Section C). A new rule may be added to the system, and which will act on the model to perform the operation required by the thus the class of recognizable sentences may be enlarged, by executing English sentences oceate a link, test whether a particular relation the LISP function "addrule[x]" where x is the rule to be added. Let holds by checking the existence of certain chains of links, or extract us consider the use of these rules in detail. certain information from the model. The remaining elements of the : stubsporg gain tament (1 action list are functions which, when applied to the list resulting The four components of a rule are a format, a list of the varifrom the applicability tests, produce arguments for the main action ables appearing in the format, a list of applicability tests, and an "action" list specifying the actions to be taken if the sentence satis-For example, the semantic parsing of the sentence, "(A BOT IS fies all the tests. The format is simply a string of symbols which may A PERSON)" would be performed by a rule such as be words. The list of variables contains those symbols which appear ((X IS A Y) (X Y) (ART ART) (SEFR CAR CADE)) in the format which should be treated as variables. All other symbols The formet "(X IS A Y)" is indeed similar to dis sentence "(A DOY IS in the format are constants. The first step in trying to apply a rule  $\Lambda$  PERSON)" because the constants "IS" and "all appear in both is the to a sentence is a "similarity test" between the sentence and the forsame order. Therefore the variable X is associated with the scring mat of the rule to see whether the constants in the format all appear, "A BOY" and Y with "A PERSON." "ART" is the name of a tunction which in the same order, in the sentence. If they don't, the rule is rejected. tests whether its argument is a string of two symbols, the first of If the sentence is similar to the format, the variables in the format which is an indefinire article. If so, the value of "ART" is the are indentified with their corresponding substrings in the sentence. second symbol in the string. Otherwise, the value of "ART" is "NIL." The applicability tests are then applied, one to each substring In onis case, the same applicability test teaction, "ART," is dased-for matched by a variable. Each of these tests is the evaluation of a both matched substrings "A BOY" and "A PERSON." in hoth cases their specified function of one argument, the corresponding substring. If

the value of any of these function evaluations is the special LISP cular form of English sentence. Back sentence presented to bik i. symbol "NIL" the substring is considered unsuitable and the entire tested by each rule in the list. The first rule applicable to the rule is rejected. Otherwise, the system composes a list of the sentence decembles the action taken by the system and emocifically results of the applicability tests and communicates this list to the invokes a program to perform the action. If no rule is applicable, last part of the rule, the "action" list. the sentence is ignored, except that the system maker an appropriet The first element of the action list is the name of a function response (ace Section C). A new rate was the added to take elected the which will act on the model to perform the operation required by the thus the class of recognizable sentences may be entabled by execution English sentence: create a link, test whether: a particular relation the DISF function "addraie[x]" where x is the rule to be added. Let holds by checking the existence of certain chains of links, or extract us consider the use of these rules in details certain information from the model. The remaining elements of the :310593019 Related the content of the certain information from the model. (1 action list are functions which, when applied to the list resulting The four components of a rule are a format, a sist of the Varifrom the applicability tests, produce arguments for the main action ables appearing in the format, a list of applicability tests, and an function. "action" list specifying the actions to be taken the sentence satisfi-For example, the semantic parsing of the sentence, "(A BOY IS fres all the tests. The format is spouly a string of symbols which may A PERSON)" would be performed by a rule such as be words. The list of variables contains those symbols waire appear ((X IS A Y) (X Y) (ART ART) (SETR CAR CADR)) in the format which should be treated as variables. All other cymbols The format "(X IS A Y)" is indeed similar to the sentence "(A BOY IS in the format are constants. The first step in theirs to apply a rule A PERSON)" because the constants "IS" and "A" appear in both in the to a sentence is a "similarity test" between one sentence and the torsame order. Therefore the variable X is associated with the string mat of the rule to see whether the constants in the found oil appear. "A BOY" and  $\underline{Y}$  with "A PERSON." "ART" is the name of a function which in the same order, in the sentence. If they son't, the role is rejected tests whether its argument is a string of two symbols, the first of If the centence is similar to the format, the variables on the formawhich is an indefinite article. If so, the value of "ART" is the are incentified with their corresponding substituees in sectence. second symbol in the string. Otherwise, the value of "ART" is "NIL." The applicability test, are then applied, end to cach substitue In this case, the same applicability test function, "ART," is used for satthen by a variable. Each of these rests to the svalourion of a both matched substrings "A BOY" and "A PERSON." In both cases the specified function of one argument, the contentables a butting. If

and semantic ambiguity results of the test are positive, so the values of the two evaluations Format ambiguity is programming device redict that a format of "ART" are "BOY" and "PERSON," respectively. The system then composes uity. It occurs when a single format (and rule) is used in order to "noitas" at ot absolve of part of the "(MOSASY (YOG)" souls seek in order to be necessary to uniquely determine the required retion. E.g., the the existence of a set-inclusion relation between its two arguments. semience "Every boy is a person" specifies that the set "boy" is "CAR" and "CADR" are functions which obtain the arguments for "SETR" included in the set "person," while "The boy is a person" specifies by extracting the first and second elements, respectively, from the that some particular element of the set "boy" is also an element of the ; vol yet respect that since the set of the set o set "person," These two types of sentences could be uniquely recog PERSON]" is executed, the model will contain the relational information nized by the formats, "Every x is a y" and "The x is a y." Instend, ".(MOSREY A SI YOS A)", sometimes and mort betatas alum and haidw SIR uses a single format of the form, "z is a  $\chi$ ." In the rule con---cos evitaralsab neswted daingnitaib ton asob emedia notingoser. taining this format, the "action" function cannot be one which directly -estrop bas esams as year cannot be seen that such as year. creates either a set-inclusion link, corresponding to the first of the anoithmed noiths eat to atoethe eat, earned to anoithm anithmed animals and the same and the series and the series are the series above interpretations, or a set-membership link, corresponding to the -aralash to atosts and the the state of the state of the set-membership in the state of the set-membership in the set-membership second interpretation. Instead, the applicability test is the "classify" yillidabilqqa as ilew as , anoitamid noitas IIA .anoitanut earnes-evit function which transmits to the action function an indicator o. the tests, are programs which must be provided to the system along with nature of the article in the string match of by variable g, is well as each new rule.

A more incorresting case is that of semantic ambiguit, and which

the ambiguity in desired action is due to the meanings of the words to conserve delignation from the sequence to conserve delignation from ambiguity cannot be resolved by using more-detailed formats. The example implemented in SIR involves the verb "to have," to the example implemented in SIR involves the verb "to have," to the day of the case with many of the conserve the conser

and semantic ambiguity.

- sociated to with the control of the sociation o

Format ambiguity is a programming device rather than a true applied of "ANE" are "SOY" and "PERSON," respectively. The solution of មួយសមុសមាន អាក្សាវ ១១៨ស៊ីកូន ស៊ីម៉ា uity. It occurs when a single format (and rule) is used in order to the list of these values "(BOY, PERSON)", and proceeds to these values. save space and processing effort, even though several formats would ins . Here "SETR" is the STR function which crists links indiciting be necessary to uniquely determine the required action. E.g., the the estatence of a set-inclusion relation between it two arguments. sentence "Every boy is a person" specifies that the set "boy" is "GADE" are functions which obtain the arguments for "SETRE" included in the set "person," while "The boy is a person" specifies by extending the Rifst and second elements, respectively, from the that some particular element of the set "boy" is also an element of the value list "(BOY, PERSON)." After this time function "seer [DOY; set "person." These two types of sentences could be uniquely recog-PERSON!" is executed, the model will contain the relational followation mized by the formats, "Every x is a y" and "The x is a y." Instead, which the cetracted from the sentence, "(A BOY IS A PERSON) SIR uses a single format of the form, "z is a z" In the rule contact the recognition scheme does not distinguish between decimalism scheme taining this format, the "action" function cannot be one which directly tences and questions; they each have their own formats and correscreates either a set-inclusion link, corresponding to the first of the pending aution fuctions. Of course, the effects of the serien functions above interpretations, or a set-membership link, corresponding to the for coestains are usually quite defferent from the effects of declarasecond interpretation. Instead, the applicability test is the "classify" tive-sentence functions. All action functions, as well as applicability function which transmits to the action function an indicator of the tests, are programs which must be provided to the cystem along with nature of the article in the string matched by variable z, as well as cach ner tuly the noun in the string. The action function then used is a "select" the role of the present over the role of all the roles and as a listing of all the roles and as a listing of all the roles are larger. type of function which resolves the format ambiguity by examining the sion of Sig. The symbol "Q" is to be read as a question-mark. indicator supplied by "classify" and then invoking the correct action a desagnate of the "classify" function is explained to be also b as a subroutine.

A more interesting case is that of semantic ambiguity, in which

the antical properties and to the meanings of the words

2) Antiquities: The above translation from English sentence to

ballash-erom gnisu yd bevloser ed tonns ytiugidma na huz. bevlovni

ction function can work only if a desired action is uniquely determined by each format. This is not really the ease with many of the

formals used for one of two reasons, which I call from t ambiguity

```
I(X IS *) (X *) (CLASSIFY CLASSIFY) (SETR-SELECT CAR CADR))

(IIS X Q) (X) (DECOMPOSE) (SETRJ-SELECT CAR CADR))

(IX DWNS Y) (X Y) (CLASSIFY CLASSIFY) (DWN-SELECT CADR CAR))

(IX DWNS Y) (X Y) (CLASSIFY CLASSIFY) (DWN-SELECT CADR CAR))

(IX DWNS Y) (X Y) (CLASSIFY CLASSIFY) (DWN-SELECT CADR CAR))

(IX DWN MANY Y DOES X OWN Q) (Y X) (SING CLASSIFY) (OWN-SELECT CAR CADR))

(IX DWN MANY Y DOES X OWN Q) (Y X Y) (CLASSIFY A CLASSIFY)

(PART OF Z) (X Y Z) (CLASSIFY A CLASSIFY)

(PART OF Z) (X Y) (CLASSIFY IDEN-1)

(PART OF Z) (X Y) (CLASSIFY IDEN-1)

(PART ON X) (Y X) (NUM-Y CLASSIFY) (PART ON-SELECT CADR CAR))

(ITHERE 1S ONE Y ON X) (Y X) (NUM-Y CLASSIFY) (PART ON-SELECT CADR CAR))

(ITHERE 1S ONE Y ON X) (Y X) (ILAMBDA (J) (CLASSIFY (ALAST J)))

(CLASSIFY) (PART ON X Q) (Y TH X) (SING THERE - CLASSIFY)

(PART ON Y ARE THON X Q) (Y TH X) (SING THERE - CLASSIFY)

(PART ON Y ARE PARTS OF X Q) (Y X) (SING CLASSIFY)

(PART ON Y Y ARE PARTS OF X Q) (Y X) (SING CLASSIFY)

(IX DASA Y) (X Y) (CLASSIFY NUM-Y) (HASN-RESOLVE CADR CAR))

(IX DASA Y) (X Y) (CLASSIFY NUM-Y) (HASN-RESOLVE CADR CAR))

(IX DASA Y) (X Y) (CLASSIFY NUM-Y) (HASN-RESOLVE CADR CAR))

(IX DASA TO THE RIGHT OF Y) (X Y) (CLASSIFY CLASSIFY)

(JRIGHT-SELECT CAR CADR))

(IX IS TO THE LEFT OF Y) (X Y) (CLASSIFY CLASSIFY)

(JRIGHT-SELECT CAR CAP)

(IX IS TO THE LEFT OF Y) (X Y) (CLASSIFY CLASSIFY)

(JRIGHT-SELECT CAR CAPR)

(IX IS TO THE LEFT OF Y) (X Y) (CLASSIFY CLASSIFY)

(JRIGHT-SELECT CAR CAPR)

(IX IS TO THE RIGHT OF Y) (X Y) (CLASSIFY CLASSIFY)

(JRIGHT-SELECT CAR CAPR)

(IX IS TO THE LEFT OF Y) (X Y) (CLASSIFY CLASSIFY)

(JRIGHT-SELECT CAR CAPR)

(IX IS TO THE RIGHT OF Y Q) (X Y) (CLASSIFY CLASSIFY)

(JRIGHT-SELECT CAR CAPR)

(IX IS TO THE LEFT OF Y Q) (X Y) (CLASSIFY CLASSIFY)

(JRIGHT-SELECT CAR CAPR)

(IX IS TO THE RIGHT OF Y Q) (X Y) (CLASSIFY CLASSIFY)

(JRIGHT-SELECT CAR CAPR)

(IX IS TO THE LEFT OF Y Q) (X Y) (CLASSIFY CLASSIFY)

(IX IS TO THE LEFT OF Y Q) (X Y) (CLASSIFY CLASSIFY)

(IX IS TO THE LEFT OF Y Q) (X Y) (CLASSIFY CLASSIFY)

(IX IS TO
```

#### FIGURE 3: SENTENCE RECOGNITION RULES

which may mean either "to have attached as parts" or "to own," e.g.,

"John has ten fingers" vs. "John has three marbles." In a case of

semantic ambiguity the "action" function is a "resolve" type function

which once again has the task of resolving the ambiguity and selecting

the appropriate subroutine, rather than performing any action on the

model directly. However, the subjective contact be resolved on the

model directly. However, the subjective contact be resolved on the

sais of any information evaluable of the contact be resolved in the ambiguity resolution depends upon the contact to the model

which were created on the basis of provious sentences.

Section VB of this paper: contains some contact be resolved in discussion of the

processes used, and further discussion of the contact be resolved in the contact be some contact by the contact be contact by the con

# C. Output: Formation and Importance of Responses

As with the input language, SIR avoids the model and the ability of the present system to produce intelligible conversation.

TALENT CONSERVE TO THE TALENT THE

FIRE REPORTS AND ALL TO THE PROPERTY OF THE PR

Some of the responses are complete prepared statements, such as are frequiently used as diagnostic comments in modern programming systems; e.g., the comment line above statement is not recognized by the present system," which is printed if no rule is found to be applicable to the input sentence. Other responses must be completed by the

programs which use them before being printed; e.g., the form, "I don't know whether \*\* is part of \*\*," which is printed, after the \*\*'s are appropriately replaced, in response to certain questions about part-whole relations.

One principle used in programming this system was that SIR should always make easily understandable reports of its actions. In particular, it should never fail to act on a new input sentence without presenting a reasonable explanation for its failure. Implementing this principle turned out to be easier than expected, for there always seemed to be only a small number of possible reasons for the failure of any one search procedure, and thus it was only necessary to provide a few response formats (and programs to use them). These responses, in turn, not only improved the conversational ability and thus the apparent intelligence of the system, but also greatly aided in debugging. SIR, in effect, frequently told me what it was doing wrong.

The conversation shown in Fig. 1 was produced by operating in an abbreviated-response mode in which SIR only prints directly relevant responses. The program can also operate in a mode in which SIR provides a running commentary of its activities, identifying functions used and commenting on every link created. Although less readable, this full-response mode was a significant program debugging aid. Fig. 4 shows the output for the dialogue of Fig. 1 in the alternate full-response mode.

医中央性 医乙酰磺酸磺胺磺胺 医大口 医结束结束的复数经免疫或精神 法法律政策的 医上面的 医电子工术

```
(THE NEXT SENTENCE IS . .)
(EVERY BOY IS A PERSON)
                                                                                                                                                                                                                                                                                                                                                                                                Ţ-4
                                                                                                                            (THE FUNCTION USED IS . .)
                                                                                                                             ((GENERIC . BOY) (GENERIC . PERSON))
                                                                                                          THE REPLY ... I CEREMIC FASSION FOR STATE OF COLOR SEMENTAL SENT ASSOCIATED AND SELECTION OF SEL
                Leggya \mathbf{T}^{O}
                                                                                                                             IBUY PERSUN)
                                                                                                                         (ITS NEPLY . .)

(E) DIDENTIFIED SUPERSET RELATION DEFINED/FINENS ON AND SOME STEEL STEEL THE THE STEEL WORLD

IT UNDERSTAND THE SUBSET RELATION DETWEEN BOY AND PERSON)
                                  ato elek
                     eppropriately replaced, in response to certainsemental authors part-
                                                                                                                        THE FUNCTION USED IS..)

TREPLACE TO STREET (GENERIC - HAND) (GENERIC - BIRDET - STREET (GENERIC - BIRDET - STREET (GENERIC - BIRDET - BIR
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 whole relacions.
                           West State
                                  (ITS KEPLY - -)

1.1973 (II UNDERSTAND THE BUSINGTARF-BACH INDEAPTEN BETWEEN JURGER AND INDEX) VILES 1 9 450 878W16

II UNDERSTAND THE SUPERPART-OF-EACH RELATION BETWEEN HAND AND FINGER)
                                              cular, it should sever fail to are on a new Large shushes transcript to con-
                                          (THE FUNCTION USED IS ...) Repair to the function used is ...) Repair ( ) Proceeding to proceeding ( ) Proceded ( ) Proced
ovewir.
                                                                                                                        (THE NEXT SENTENCE IS . .)
(THERE ARE THO HANDS UN EACH PERSON)
13 TO 1 REDERED DIGERROO TO TO FORM I FOR B VIGO DE DO TO FORM I FORM I VIGO DE DE DOMENO COMPANS (THE FUNCTION USED IS . .)
                     971.1361 G
                                                                                                                             PARTRN-SELECT
                                turn not only improved the corversminimal and laber value of the
                                                                                                                            (THE FUNCTION USED IS . .)
                                                                                                                      apparent intelligence of the system, but also one about also
          -gride# of
                                                   ging. Sig. in effect, frequently told me what i was doing wrong
         (.. si sonienes that the motion of the motio
                                           Vant cesponees. The program can also operate in aliminate its which fix (who which fix) which fix (who can stand the contrast the contrast of the contrast contrast is contrasted to the contrast contrast contrasted to the contrast contrasted to the contrasted to th
  recybles a runneds commentary of its activities, identifying furnitions (... 2) agains TXSM and (... 2) agains TXSM agains TXS
                                   ased and commenting on every link created. (Althanaschumbassum and and
                                                                                                                         HAVE-RESOLVE
(FINGER (UNIQUE . JOHN))
                                                                                                             this full-response mode was a segminicant program debugging (... vigin ant) (track as ash) sham and amuza i tue ** suduplena is appending the stand one deam negates noitaish has-no-trackshed and now it is closed for the dislogue of Fig. ((e) one and responsible and responsible of the contract of the standard one and the contract of the standard one and the standar
         夏利斯
                                              + 1 1321
                                                                                                                            (THE NEXT SENTENCE IS . .)
(EVERY HAND HAS 5 FINGERS)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         .shom sampdays
                                                                                                                            (THE FUNCTION USED IS . .)
                                                                                                                            (THE FUNCTION USED 15 . .)
HASN-RESOLVE
((5 . FINGER) (GENERIC . HAND))
(THE REPLY . .)
                                                                                                                             TIME REPLY . .)
(THE ABOVE SENTENCE IS AMBIGUOUS .. BUT I ASSUME (HAS) HEANS (HAS AS PARTS))
```

FIGURE 4: SAMPLE CONVERSATION IN FULL-RESPONSE MODE

```
(I KNOW THE SUPERPART-OF-EACH RELATION BETWEEN HAND AND FINGER)
(I REALIZE THE NUMBER RELATION BETWEEN 5 AND (PLIST NAME HAND))
(I KNOW THE SUBPART-OF-EACH RELATION BETWEEN FINGER AND HAND)
(I REALIZE THE NUMBER RELATION BETWEEN 5 AND (PLIST NAME FINGER))
(THE NEXT SENTENCE IS . .)
(HOW MANY FINGERS DOES JOHN HAVE U)
(THE FUNCTION USED IS . .)
HAVE-RESOLVE
HAVE-RESOLVE

(FINGER (UNIQUE . JOHN))

(THE REPLY . .)

(THE ABOVE SENTENCE IS AMBIGUOUS ** BUT I ASSUME (HAS) MEANS (HAS AS PARTS))

(I KNOW THE SUPERPART-OF-EACH RELATION BETWEEN HAND AND FINGER)

(I KNOW THE SUPERPART-OF-EACH RELATION BETWEEN PERSON AND HAND)

(THE ANSWER IS 10)
(THE NEXT SENTENCE IS . .)
(HOW MANY AUTOMOBILES DOES JOHN HAVE Q)
(THE FUNCTION USED IS . .)
HAVE-RESOLVE
(THE REPLY . .)
(THE ABOVE SENTENCE IS AMBIGUOUS .. PLEASE RE-PHRASE IT)
(THE NEXT SENTENCE IS . .)
(WHO IS PRESIDENT OF THE UNITED STATES Q)
(STATEMENT FORM NOT RECOGNIZED)
(THE NEXT SENTENCE IS . .)
(THE BOY IS JUST TO THE LEFT OF THE TABLE)
(THE FUNCTION USED IS . .)
JRIGHT-SELECT
((SPECIFIC - RABLE) (SPECIFIC - BOY))
(THE REPLY - -)
(THE SUB-FUNCTION USED IS - -)
 JRIGHT
JRIGHT
(TABLE BOY)
(ITS REPLY . .)
(G02840 IS A TABLE)
(I UNDERSTAND THE ELEMENTS RELATION BETWEEN GO2840 AND TABLE)
(I UNDERSTAND THE MEMBER NELATION BETWEEN TABLE AND GO2840)
(I REALIZE THE JRIGHT RELATION BETWEEN TABLE AND BOY)
(I REALIZE THE JLEFT RELATION BETWEEN BOY AND TABLE)
 (THE NEXT SENTENCE IS . .)
(THE LAMP IS JUST TO THE LEFT OF THE TABLE)
 (THE FUNCTION USED IS . .)

JRIGHT-SELECT
((SPECIFIC . TABLE) (SPECIFIC . LAMP))
(THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)

JRIGHT
 JRIGHT
(TABLE LAMP)
(ITS REPLY . .)
(GO264) IS A LAMP)
(I UNDERSTAND THE ELEMENTS RELATION BETWEEN GO2841 AND LAMP)
(I UNDERSTAND THE MEMBER RELATION BETWEEN LAMP AND GO2841)
(THE ABOVE STATEMENT IS IMPOSSIBLE)
 ITHE MEXT SENTENCE IS . .)
ITHE TABLE IS TO THE RIGHT OF THE CHAIR)
ITHE FUNCTION USED IS . .)
RIGHT-SELECT
(ISPECIFIC . TABLE) (SPECIFIC . CHAIR))
ITHE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
RIGHT
(TABLE CHAIR)
(ITS REPLY . .)
(GUZ842 IS A CHAIR)
(I UNDERSTAND THE ELEMENTS RELATION BETWEEN GOZ842 AND CHAIR)
(I UNDERSTAND THE MEMBER RELATION BETWEEN CHAIR AND GOZ842)
(I UNDERSTAND THE MEMBER RELATION BETWEEN TABLE AND CHAIR)
(I UNDERSTAND THE RIGHT RELATION BETWEEN TABLE AND CHAIR)
(I UNDERSTAND THE RIGHT RELATION BETWEEN CHAIR AND TABLE)
 (THE FUNCTION USED IS . .)
 (THE NEXT SENTENCE IS . .)
(WHAT IS THE RELATIVE POSITION OF A PERSON Q)
 (THE FUNCTION USED IS . .)
 (THE FUNCTION USED IS ..)
LOC-SELECT
((GENERIC . PERSON))
(THE REPLY ..)
(THE SUB-FUNCTION USED IS ..)
LOCATEG
(PERSON)
 (ITS REPLY - | )
(THE LEFT-TO-RIGHT ORDER IS AS FOLLOWS)
(CHAIR (BOY TABLE))
```

### Chapter V: Behavior and Operation of SIR

In this chapter I shall elected and the standard logical symbols will be used when a conversation. These examples can frequently best be presented with the aid of logical notation, so formal symbols will be used when necessary. Explanations of the standard logical symbols will be used when Appendix I.

्राच्या करणा है। इस इंग्लिस के मान्या करणा है। इस अनुसार के मान्या है कि एक स्थापन करणा है। Some knowledge of the LISP (21) programming language might be of aid in understanding the following pages. However, it should be sufficient for the reader to know the "fcn[a;b]" indicares that the function named "fcn" is to be applied for the symbols or symbolic expressions named "a" and "b" as arguments. This function of these arguments will have a value which is itself a symbolic expression, although the evaluation process may have side effects such as changing the model structure or printing comments with In a more conventional programming terms, one may think of "fcn" as naming a subroutine, and TRINGS OF SU SHOLD DE SEE START INTO "fcn[a;b]" representing the execution of the subroutine with "a" and ganesen . Deeradinest frankt. "b" as input data. The creation of a single symbol to expression called the value is the principal result of the execution. This र्यात व्यवस्थातः व्यवस्थातः स्थापन्तः । इति श्रीकारः सम्बद्धाः सम्बद्धाः । १९८१ विकासः सम्बद्धाः स्थापन्तः । value of a function, which is a symbolic expression resulting from a computation, should not be confused with the value of an attribute, which is the entry following the attribute on a property-list.

#### A. Relations and Functions.

Each part of Fig. 5 is a conversation between a person and SIR,

মতানাম ক্ষাব্য (ক্ষাব্য ক্ষাত্ৰ ক্ষাত্ৰ ক্ষাত্ৰ ক্ষাত্ৰ ক্ষাত্ৰ কৰে। বিমানক ক্ষাত্ৰ বিভাগৰ ক্ষাত্ৰ ক্ষাত্ৰ ক্ষাত্ৰ কৰে। The state of the s

Section IV.C. Each example illustrates the was of a different group of relations and their associated LISP functions in the SIR system. With minor exceptions the examples are cumulative, i.e. later ones freely use functions introduced earlier but not conversely. These conversations are presented again as Appendix III in the full-response mode which identifies the functions used. In Fig. 5, the symbol "\*\*\*."

prefixes the input sentences; all other remarks are SIR responses.

The remainder of this section presents descriptions of all the significant functions mentioned in Appendix III in the order in which they are needed for the conversations. The functions are presented in groups which correspond to the various parts of Fig. 5, and which are identified by the principal attribute-links manipulated by the functions in the group.

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method, and a procedure. The purpose is the brief statement of the effect the function is designed to have. The method is an intuitive description of how the purpose should be achieved, and is usually presented in a mixture of English and logical notation for maximum clarity.

Finally, the procedure is a description of how the method is implemented, and may be considered a rough flow-chart of the actual program.

Notice that the relational structure of the model is the key internal feature of SIR which enables the procedures to implement the methods in a direct and efficient manner. These methods, in turn, determine the degree of SIR's ability to store facts and answer questions. Chapter VI will discuss how SIR's model, methods, and procedures could be generalized to produce a more powerful semantic information retrieval system.

```
Suction IV. w. Rach example illustrates then commissed til rem grade of
            celariogr and their associated librated at adequater, ways so their acceptances and their acceptances.
                       (1 UNDERSTAND)
      12 de la 184. Cant dine de la example of a PERSON)
                       ( | UNDERSTAND)
                                         und insotrace introduced earlier but not serverseiv.
      чыстыуды» ваче?Т
                                    IS A KEYPUNCH-OPERATOR A PERSON Q1
          tions are presented again as Appendix Til is the Lull-resp<sup>ond</sup>ic wate
                                                                                                     c. EOUIVALENCE
           witch Edensifies the fare clone used. The Fig. 5, the symbols of
                                                                                    (cores is a man)
            Japanderna Ala Mess Asimanar volisa
                       SOME TIMES
                                                                                                   JACK IS A DOPE)
                                                                                    out seems that to represent the
  PERSONAL PROPERTY AND STATE OF ALL CINE SILVE
            atelean, der Liot Mondiffened Th Appendix lil in che arder in which
                                                                                       ( UNDERSTAND)
                                                                       Concorded for the conversations.
   of bomosate his and imulation
      enter object or respond to the various parts of Fig. and and which ere
sparitual by amergrant par tribute links manyour sied by the functions
                                   AN IBR-7094 IS A COMPUTER)
                                                                                                    JUMM IS THE MAN!
                                                                                                                             in the aroug.
                      ( UNDERSTAND)
           Lach lunctering description consists of them parts; a purpose, a
maniges, and is propagate at The numbers is named the structure of the effect
                                                                                       (1 UNGERSTAND)
                                                                                   the function is designed to have.
     The metand is an intellive descrip-
                                  EVERY MIT-STUDENT IS A BRIGHT-PERSON)
         ction of how the parpose should be achieved, and an asserting-mydbashrep
                in a maximum of the state of th
            Finally, the procedure is a description of how are ened is tapple-
                      ( I UNDERSTAND)
    acated, and may at considered a rough florechard of the action program.
         Nutice that the relational structure of the model is the adjunctors
                                                       feature and which enables the procedures co
          aboutson
                                             FIGURE 5: SELECTED CONVERSATIONS
 in a direct and efficient manner. These methods, is turn, do comine the
  degree of SER's ability to store facts act and a temperature.
    with discuss how SIR's model, methods, and pronounces done be denoted-
      implient lively les de l'heroist plinkeus luftewee sions s'equicat of bank
```

### d. OWNERSHIP, GENERAL

EVERY FIREMAN OWNS A PAIR-OF-RED-SUSPENDERS) ( UNDERSTAND) DOES A PAIR-UF-RED-SUSPENDERS UNN A PAIR-OF-RED-SUSPENDERS w) INU .. THEY ARE THE SAME) DOES A DOCTOR OWN A PAIR-OF-RED-SUSPENDERS WI (INSUFFICIENT INFORMATION) A FIRECHIEF IS A FIREMAN) ( L UNDERSTAND) ( \* • • . DOES A FIRECHIEF OWN A PAIR-OF-RED-SUSPENDERS Q) YFS e. OWNERSHIP, SPECIFIC (\*\*\*. ALFRED DWNS A LOG-LOG-DECITRIG) (I UNDERSTAND) A LOG-LOG-DECITRIG IS A SEIDE-RULE) ( I UNDERSTAND) ( \* \* \* . DOES ALFRED UNN A SLIDE-RULE Q) YES EVERY ENGINEERING-STUDENT OWNS A SLIDE-RULE) (I UNDERSTAND) (\*\*\*. VERNON IS A TECH-MAN1 ( UNDERSTAND) A TECH-MAN IS AN ENGINEERING-STUDENT) ( UNDERSTAND) (\*\*\*. DOES VERNON OWN A SLIDE-RULE Q) YES { \* \* \* . DUES AN ENGINEERING-STUDENT OWN THE LOG-LOG-DECITRIG Q) (G02840 IS A LOG-LOG-DECITRIG) (INSUFFICIENT INFORMATION) ALFRED IS A TECH-MAN) [ UNDERSTAND) .... DUES AN ENGINEERING-STUDENT DWN THE LOG-LOG-DECITRIG Q)

## FIGURE 5 (Cont.)

YES

## (\*\*\*. A VAN-DYKE IS PART UF FERREN) (I UNDERSTAND) A VAN-DYKE IS A BEARD! (I UNDERSTAND) IS A BEARD PART OF FERREN Q) YES A CRT IS A DISPLAY-DEVICE) (I UNDERSTAND) A CRT IS PART OF THE PDP-1) (GO2840 IS A PDP-1) (I UNDERSTAND) (\*\*\*. IS A NOSTRIL PART OF A PROFESSOR WI SAM IS THE PDP-11 (1 UNDERSTAND) A SCREEN IS PART OF EVERY DISPLAY-DEVICE) (1 UNDERSTAND) IS A SCREEN PART OF SAM Q) THE TENTH OF A LIVING-CREATURE Q1 A BEARD IS PART UF A BEAINIK) (I UNDERSTAND) (\*\*\*. IS A LIVING-CREATURE PART OF A NOSE Q) (\*\*\*. EVERY COFFEE-HOUSE-CUSTOMER IS A BEATNIK) (NO , NOSE IS SOMETIMES PART OF LIVING-CREATURE) (1 UNDERSTAND) BUZZ IS A COFFEE-HOUSE-CUSTOMER) (I UNDERSTAND) ( \*\*\* . IS A BEARD PART OF BUZZ Q) YES

g. PART-WHOLE, SPECIFIC

FIGURE 5 (Cont.)

f. PART-WHOLE, GENERAL

A NOSE IS PART OF A PERSON)

A PROFESSOR IS A TEACHER)

A TEACHER IS A PERSUNI

(\*\*\*. IS A NOSE PART OF A NOSE Q) (NO , PART MEANS PROPER SUBPART)

(\*\*\*. A PERSON IS A LIVING-CREATURE)

A NOSTRIL IS A PART OF A NUSE)

[ \* \* \* <u>.</u>

( UNDERSTAND)

(I UNDERSTAND)

( UNDERSTAND)

(I UNDERSTAND)

( I UNDERSTAND)

SOMETIMES

YES

#### h. NUMBER

```
( * * * .
         A BOY IS A PERSON)
( | UNDERSTAND)
           JOHN IS A BOY!
( UNDERSTAND)
           A FINGER IS PART OF A HAND)
(I UNDERSTAND)
           HOW MANY FINGERS DOES JOHN HAVE Q1
(THE ABOVE SENTENCE IS AMBIGUOUS ** BUT I ASSUME (HAS) MEANS (HAS AS PARTS))
(1 DON'T KNOW WHETHER FINGER IS PART OF JOHN)
           THERE IS ONE HAND ON EACH ARM)
(I UNDERSTAND)
           THERE ARE TWO ARMS ON A PERSON)
( L UNDERSTAND)
           HOW MANY FINGERS DOES JOHN HAVE Q1
(THE ABOVE SENTENCE IS AMBIGUOUS ** BUT I ASSUME (HAS) MEANS (HAS AS PARTS)) ((HOW MANY FINGER PER HAND Q))
           A HAND HAS 5 FINGERS)
(***.
(THE ABOVE SENTENCE IS AMBIGUOUS \bullet \bullet BUT [ ASSUME (HAS) MEANS (HAS AS PARTS)) II UNDERSTAND)
           HOW MANY FINGERS DOES JOHN HAVE Q)
(THE ABOVE SENTENCE IS AMBIGUOUS \bullet \bullet BUT I ASSUME (HAS) MEANS (HAS AS PARTS)) (THE ANSWER IS 10)
```

FIGURE 5 (Cont.)

#### i. LEFT-TO-RIGHT POSITION

```
THE TELEPHONE IS JUST TO THE RIGHT OF THE BOOK!
(GO2840 IS A TELEPHONE)
(GO2841 IS A 800K)
(L UNDERSTAND)
                            THE TELEPHONE IS JUST TO THE LEFT OF THE PAD)
(GO2842 IS A PAD)
                                                                                                                                      医乳膜线 计
                                    IS THE PAD JUST TO THE RIGHT OF THE BOOK Q) _{\rm 100 MeV} and _{\rm 100 MeV}
NO
                                    IS THE BOOK TO THE LEFT OF THE PAD Q)
                                                                                                                                                                                                                12.65 + 23 BMG-E
YLS
                                    THE PAD IS TO THE RIGHT OF THE TELEPHONE) TO SEE THE PAD IS TO THE RIGHT OF THE TELEPHONE)
(THE ABOVE STATEMENT IS ALREADY KNOWN)
                                    THE PAD IS TO THE LEFT OF THE TELEPHONES
THE ABOVE STATEMENT IS IMPOSSIBLE Form: An impossible form of the property of the transfer of the control of th
                                  THE ASH-TRAY IS TO THE LEFT OF STREETINGS ME GRAD STREET COLUMN
(GO2843 IS A ASH-TRAY)
                             THE PENCIL IS TO THE LEFT OF THE PAD)
                                                                                                                               THE REAL PROPERTY SECTION OF THE HEAVY TO SECTION
E---- THE PAPER IS BUT THE PAPER IS BUT THE RESIDENCE OF STREET THE PAPER IS STREET OF STREET OF STREET OF STREET
 (G02845 IS A PAPER)
  [ UNDERSTAND]
                                                                                                                                                                                   ் நில்களை இது இந்த வூண்ணு இ
                                      WHERE IS THE PAD Q1
                                                                                                                                                                                         (JUST TO THE RIGHT OF THE TREEPHONE'S . . (PENCIL)
                           WHAT IS THE POSITION OF THE PAR QUESTS 2 200 2 9 3000 2 70 ALL MED
 (THE LEPT-TO-RESET OFFICE TS MS POLICIONS) TO THE STATE OF A STATE
                                      THE BOOK IS JUST TO THE RIGHT OF THE ASH-TRAY)
  ( UNDERSTAND)
                                      WHAT IS THE POSITION OF THE PAD Q1
  (THE LEFT-TO-RIGHT URDER IS AS FOLLOWS)
{PENCIL (ASH-TRAY BOOK TELEPHONE PAD) PAPER)
                                      A TELEPHONE IS AN AUDIO-TRANSDUCER)
  ( UNDERSTAND)
                                      A DIAPHRAGM IS PART OF AN AUDIO-TRANSDUCER!
  (I UNDERSTAND)
                                                                                                        FIGURE 5 (Numb)
                                      WHERE IS A DIAPHRAGE Q1
  (JUST TO THE LEFT OF THE PAD)
(JUST TO THE RIGHT OF THE BOOK)
(SOMEWHERE TO THE LEFT OF THE FOLLOWING . . (PAPER))
```

FIGURE 5 (Cont.)

### er Nagel da Operation of functions: THE "(FETSI RAME 9)" to the sum of the THE WHILE EAST MARK X)" TO THE VOICE OF THE STATE OF THE a) Attributes: SUBSET, SUPERSET Fernord "(I Chiperstant)" 1. setr[x;y] Trixipulled 12 To specify in the model that set x is included in set y. 9 198 odd to todmom a at x settled at as vigor of the order method: Create a type-3 link between x and y which indicates setinclusion. inclusion. Align of which and the equivalent we give in the gold collected and the election of the procedure 12 10 Aprilian Common Add (PEIST NAME x)" to the value if at of attribute "SUBSET" [[[[[y] sed to rodsom r 2. y fee lo radieam kur of y. b. Add "(PLIST NAME y)" to the value list of attribute "SUPERSET" of x. c. Responden(I UNDERSTAND) usbernoo sheet and lo sval a neam "TERMIN" educations and relication it y is on the list, respond "Thy' 2. setrq[x;y] cas surger. . two maps a construction of the section purpose: To reply as to whether an arbitrary element of set x is an element of set y. To become more than (a) again the set of the s se al escures "Egy" a lides (yes ll) y cr "de l'escure method: A member of x is considered to be a member of y if the sets x and y are identical; or if there is a chain of explicit set-inclusion links proving that x is a subset of y, 1.e., if there exists a possibly empty) sequence of sets v.w. . . such that A member of x is "sometimes" in x if there is a chain of explicit setnclusion links proving that y is a subset of x. energy of x conversed that the unique element of x conversed which indicreas ser-membership. If A has more energiance of ement, do no still british and the control of the still be seen and the service of the a. If x=y, respond "YES". b. If there is a path from x to y through type-3 links following the attribute "SUPERSET", respond "YES". c. If there is a path from y to x through type 3 links following the attribute "SUPERSET", respond "SOMETIMES" and IN The state of the d. Otherwise, respond "(INSUFFICIENT INFORMATION)" Salwrells is specifical

b) Attributes: MEMBER, ELEMENTS comede augine and maintable of terrograp

1. setts[x;y] and x it seems or boil shows a solution and x it stocks a part of the set y.

purpose: To specify in the model that x:is a member of the set y.

method: Create a type-3 link between x and y which indicates set requestion.

```
procedure:
                                                                                                  c of functions:
                  Add "(PLIST NAME y)" to the value list of attribute "MEMBER"
of x.
                  Add "(PLIST NAME x)" to the value list of attribute "ELEMENTS"
of y.
                                                                                    a) Attronuces Subject Superser
           c. Respond "(I UNDERSTAND)".
                                                                                                                      lygxindua 🗀 t
           2. setrsq[x;y]
purpose: To apecify in the model that x is included in set y purpose: To reply as to whether \underline{x} redemma so \underline{x} represents the set \underline{y}.
-tes cetacibri deink y bas x neeween Xa) [ & eqy: & cotacibri deink y branched: Reply "YES" if the folling is true:
           (\exists u)[[u=x \lor [\underline{u} \text{ is equivalent}^* \text{ to } \underline{x}]] \land
                        [[there is a link indicating that \underline{\mathbf{u}} is a member of \mathbf{y}]\mathbf{V}_{\mathrm{orb}}
           [(3z)][|there, is, a, link indicating that u is, an manberrof) zla
                       [any member of set z is a member of set y]]]]]
      b. and "(PLIST NAME v)" to the value list of attribute "SUPERTET"
procedure:
           a. Make a list of the items connected to make a type 30 link
following the attribute "MEMBER".
           b. If y is on the list, respond "YES".
           c. If, for any member z of the list, setrsq[z;y]=YES, respond
"YES".
               purpose: To reply as to whether an arbitrary element of set x is clement megis does we do be a set x is clement megis does with a set x is
equivalent* to x (if any) until a "YES" response is made.
           method a member of (MOIJAMAGINE THIS DISTRIBUTED SEPTIMENT OF TWINGE BOLD SEPTIMENT OF THE SECTION OF THE SECTI
                  x and y see identical: or if there is a chain of explicit setting links proving that x is a subset of y, i.g. if there wistsagina
purpose: To specify in the model that the unique element (if any) of
the set x is also an element of the set x. n) "semi secons" at g to a semi ment
method: Create a type-3 link from the unique element of x to y which
indicates set-membership. If \underline{\mathbf{x}} has more than one element, do not set \underline{\mathbf{x}}
any link.
                                                                                            a. If x-y, reapond "YES".
b. If there is a path from x to y through type-3 links following procedure:
                                                                          the attract of "NdF ERSET" respond "VES"
          a. Compute u = apecify x into y or y move case at arone is so
         the attribute "Superser", reseand "SOMETIMES and attribute of
                  d. Otherwise respond "(INS) FF of Will after Mind was saiwa at 10
          4. specify[x]
purpose: To determine the unique element, if any, of the set x 100 130 (d
method: If x has one element, find its name. If x has no elements,
create one and give it a name. If x has more than one element, ask
purpone. To specify in the model that X is a member of the pan and that
  See part; (c) for an explanation of "equivalent". See part: (c) for an explanation of "equivalent".
```

Thinks, the feet our letters by

The articloudes (Weeph. Event. 1998 1998) The countries of the procedure: a: Get the value list of the attribute "ELEMENTS" of the state of t execute setus[u;x], and return, uses the value of specify[x] as the value of seconds c. If there is just one element named on the list 100 riff sin the elements are equivalent, return the name of the first element as the value of apecify that he made a necessary but a secure of the control of the cont names of the elements, and return "NIL" as the value of specify[x]. 5. setralgiv;y) to some outco and out of TMAN TRILIA;" bbs "MANAGRA RY - ERCH!" OF K. purpose: To reply santo whether the unique elements forany of the set x, is a member of the set y. "POSSESS-BY-EACH" of y. c. despend "(I UWDERSTAND)" method: Determine the element referred to and apply setreq. IV:XIDEG 5 procedure: a. a. Compute augo specify[x]. gradio en baddado en viges di loscopios b. If u = NIL, terminate. Some stander of ser K. c. Execute setrsq[u;y]. merical the answer is "YES" if x A y to the Alig in seadon a a vilve- i(sf) The transport of the content of the section of the content of the ..esphoound 1. equiv[x;y] respond "(NO me That ARE The SAME)" [y;x]viupe b. Creace the list & containing y and all says purpose: To specify in the model that x and ware equivalented along a si "SHEERRET". method: Create a type-2 link between a and y which indicates equivalence. the autribute "POSSESS-BY-EACH", respond "YES" procedure: o. Otherwise respond "(INSUPPICTERT INFORMATEORIS. a. Add x to the value list of attribute "EQUIV" of y. b. Add y to the value list of attribute "EQUIV" of x. c. Respond "(I UNDERSTAND)". v) wites and ear OWMED | POSSESS 2. equiv1[x;y] ly a lugación of

purpose: To specify in the model that x is equivalent to the unique element of the set y where a range gradual labor of the set y where a range gradual labor of the set of the

4.4

a. Compute u = specify[y].

"attack a figure and a specify and a specific and a spe

c. Execute equiv(x;u).

b. Add. "(Fulst water y)" to the value fisc of threshops. 'Wasser's to the value fisc of threshops.'

c. Respond "(I PRESERSTAND)".

procedure:

the same of

. [ម្នាស់ នេះសម្ពេច មា ស ១០០១,១០៨ ខែ ខេត្

### d) Attributes: OWNED-BY-EACH, POSSESS-BY-EACH

1. ownrex; y | 12 | MCCCLEV soudtrains and to vali selev ad 140 . A all a)" brougest, a locate men a absent jail on at another of the purpose: Totapecify the the model that every member of set; y owns absent some member of set; that we because the model at a sould it in a select at a sould be a selected at a select at a sould be a selected at a select a select at a select a select a select at a select a select

a. Add "(PLIST NAME y)" to the value list of attribute "OWNED-BY-EACH" of x.

358bed3Add "(PEIST NAME ) B COPERE value flatwof aftribute of the or of "POSSESS-BY-EACH" of y.

c. Respond "(I UNDERSTAND)".

\_parges vivat boo of hearster normeds and northered are food

ownrq[x;y]

purpose: To reply as to whether an arbitrary member of set  $\underline{x}$ , some member of set  $\underline{x}$ .

method: The answer is "YES" if  $x \neq y$ , and  $(\exists z)[y=z \lor [y \text{ is a subset of } z]] \land [$ 

[there exists the appropriate ownership link between x and z]]

procedure:

a: If x=y, respond "(NO \*\* THEY ARE THE SAME)". Proposed

b. Create the list & containing y and all sets u for which there is a path from y to we through type 3 14nks following the attribute "surgard "SUPERSET".

the attribute "POSSESS-BY-EACH", respond "YES".

d. Otherwise respond "(INSUFFICIENT INFORMATION)".

in a dar g to the value list of attribute "EQUIV" of y.

b. Add y to the value list of stribute "EQUIV" of y.

c. Report "it and ENSTAND)".

### e) Attributes: OWNED, POSSESS

1. ownrgu[x;y]

purpose: To specify in the model that y owns a member of the set x ...

method: Create a type-Julink between x and y which indicates the intended ownership relation.

procedure:

- a. Add "(PLIST NAME x)" to the value Tist of attribute "POSSESS" of y.
  - b. Add "(PLIST NAME y)" to the value list of attribute "OWNED" of x. c. Respond "(I UNDERSTAND)".

and the sources of the property of the property of the source of the sou

### ownrguq[x;y]

purpose: To reply as to whether y owns a member of set x.

method: The reply is "YES" if there is a link indicating that y owns a member of x or of some subset of x; or if

\(\lambda\) \(\lam there is a link indicating that every member of set u owns a member of set x]]]

### procedure:

- a. If there is a link indicating an x is owned by x, respond "YES".
- b. Consider each set z for which there is a fink indicating that y owns a member of z. If, for any z, setro[z;x]=YES, respond "YES"
- c. Consider each set z such that there is a link indicating y is an element of z.
- d. For each  $\underline{z}$ , construct a list  $\underline{\ell}$  containing every set  $\underline{u}$  for which setrq[z;u]=YES.
- e. Compute m = the list of all sets y such that there is a type-3 link from x to v following the attribute "OwnED-ny-EACH".
- f. If, for some z, the intersection of  $\ell$  and m is non-empty, respond "YES".
  - g. Otherwise, respond "(INSUFFICIENT INFORMATION)".

# 3. 16 compressed in the substitution of the su

purpose: To reply as to whether the unique element of the set x is owned by some element of the set y. santi to need of a local life.

method: Determine that a unique element of x exists. Then, the reply is "YES" if

(3z)[[there is a link indicating that a member of set x is owned by 3/  $(\exists v)[[v=zV[\underline{v} \text{ is equivalent to } \underline{z}]] \wedge =$ (Jw)[[there is a link indicating that y is an element of who [there are links indicating that wis a subset of \*]]]]

Senarate chare sous w which an a carchad

- procedure:

  a. Compute u = epecify[x]

  b. If u = NIL, terminate.

  View pages a succession of the process of the b. If u = NIL, terminate.

  c. Generate the individuals w which are linked to x as type-3 values of the attribute "OWNED":

  d. For each w, generate the sets z which w, and any individual
- e. If, for some z, setro[z;y] = YES, respond YES".
  - f. Otherwise respond ! (INSUFFICIENT INFORMATION)".

```
f) Attributes: SUPERPART-OF-EACH, SUBPART-OF-EACH
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    2. ourrands;yl
                                                          1. partr[x;y]. The first arms a series y then of y in y and y in y in y in y.
       purpose: To specify in the model that every element of set x is part of some element of set y.
                                                                                                                                                                                                                                                                                                                                                       member of a cr of some subset of kintil
       method: Create a type-3 link between x and y which indicates the part-
whole relation between their members: [[[x] ]] satisfies to sedmen a saw
        procedure:
                                                       if there is a link indicating on x is water that a william water the telephone in x is a water that a water the contract in x is a water that a water the contract in x is a water that a water the contract in x is a water that a water that a water than 
       b. Consider to sail the sail to 
                               d. For each at construct a list & contains every; year
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       sourd stal PES
      purpose: To reply as to whether an arbitrary rember of set x is a part of some member of set y is a part of some member of set y is a part of some zone in a non-ample of x is non-ample o
      method: No element may be part of itself. Reply "YES" if Characters (Bw)[[there is a chain of links indicating that an arbitrary
                                                         member of set x is part of some member of w \ [[y=w V
                                                                                                                    [[there is a chain of links indicating that y is a subset
      Reply "SOMETIMES" of to receed elegate of the rent of the control of the rest 
                                                         (3w)[[there is a chain of links indicating that an arbitrary benevo at
                                                        member of set x is part of some member of w
                                                        [there is a chain of links indicating that wis a subset of y]].
(Jw) [(there is a link indicating that y is an element stubsorq
                                                        a. If x-y, respond "(no, they are the same) at see sucht
                                                         b. Generate those sets w which can be reached from x through
       a chain of type-3 links following the attribute "SUPERPART-OF-EACH" BEST OF EACH TO BE STORE OF THE STORE OF 
                                                        c. If, for some w, setrq[y;w] = YES or SUBTIMES, respond or "SOMETIMES" respectively established the statement of the set of the set
   "YES" or "SOMETIMES", respectively.

d. If the response for partially way to the respond "(NO, y IS PART OF x)" or "(NO, y IS CART OF x)" or "(NO, y I
                                                        equivalent to w, is "(NOTTAMOUNT TRAIDITAURI)" broques asiwrend O. e. If, for some Z, setrol Z; y = YES, respond YES.
```

f. Otherwise respond "(INSUFFICIENT INFORMATION)"

g) Attributes: SUBPART, SUPERPART "HERT, profesa Chaus freuen i Filberan, ing

n n**4:0 partrgu[xfy]** so sasias o sitte sussiti sata mengapakan kendista sa Ruakkenti gunadan 1920 pantinta sa yiti ian tatiot annii tenggun sa sissit suga

purpose: To specify in the model that some element of set x is a part of the individual y. 6138 to x tall add of grown and construction to a part of the individual y. 6138 to x tall add of grown and the individual individual years and the second of the individual individual years and the second of the individual individual years and the second of the individual individual individual years and the second of the the

method: Create a type-3 link between x and y which indicates the selection appropriate part-whole relations may distall a season and subject to the selection of the selection o

procedure: because a strong son passes at a got both g you set and any

- a. Add "(PLIST NAME x)" to the value list of attribute "SUBPART" of y.
- b. Add "(PLIST NAME y)" to the value list of stribute
  - c: Varespond (Tiunderstand) . Lend lates said (Libers and Cales said to see such set to it part with autique elements if seal of set

2. partrgs[x;y] to have the value of a discussion appears and official to the following the contract of the co purpose: To specify in the model that some element of set x is a part of the unfque element, ff anypiof the set years and to inchive out

method: Determine z, the unique element of y. Then specify that some element of x is part of z.

procedure:

- a. Compute z = specify[y].
- b. orfizio NIE Williamete in the to bell outsy and can bba the
- c: Else, compute partigu[x; 2] . 22 2 20 20 TMA982933 .... To reduce
- 3: partrguq[x;y]

purpose: To reply as to whether some element of set x is part of the individual y. To come a section of the individual y. Ly year de Interest campa de

method: A member of x is a part of y if 

[(]w)[[there is a link indicating that an element of we have a subpart of make and some subpart Asta support of ula satisfication

[[w-xV[there are links indicating that w is a subset of x] V Aly to in [3] [There are links indicating that every element of z

[w=z VI there are links indicating that w is a subset of z]]] [W

[w=z VI there are links indicating that w is a subset of z]]] [Qz) [[u is an element of set a subset of z]]] [W

Constance All English Back

C. M. POLCE "(I WINESPEND)".

Compace a supporting man

ន ស្រែសៀមអ្នកសារជាមិន នេះ

detailageration &

(Av) there are links indicating that z is a subset of v]]]]]]]

procedure:

a. Generate those nodes w which can be reached from y, or from any node equivalent to y, by a chain of types? Hake following the attribute "SUBPART." attribute "SUBPART." 1. This often apply perto [hopping this y have point FIDE by
self-a for finishing point possession for the formal and for his contraction for the finishing point of the finishing p

- b. If, for any w, setrq[w;x]=YES, respond "YES".
- c. Otherwise, generate those nodes z which can be reached from x by a chain of type-3 links following the attribute "SUPERFART-OF-EACH".
  - d. If, for any z and any we setrolwiz =YES respond "YES".
- e. Otherwise, compute the list of sets for which there is a type-3 link from y, or any node equivalent to y, following the
- f. Generate the nodes v which can be reached by a chain of recovery type-3 links from x following the attribute, "SUPERPART-OF-EACH".
  - If, for any  $\underline{v}$  and any  $\underline{u}$  in  $\underline{\ell}$ , setrq[ $\underline{u}$ ; $\underline{v}$ ]=YES, respond "YES".
  - h. Otherwise, respond "(INSUFFICIENT INFORMATION)" BLA
  - 4. partras[x;y] to gain or the odd of "to gman feliga" .5a in

purpose: To specify in the model that the unique element if any, of set x is part of the unique element, if any, of set y.

method: Identify the unique elements  $\underline{u}$  and  $\underline{v}$  of sets  $\underline{x}$  and  $\underline{y}$ , respectively. Specify that some element of set x is part of the secure individual v. Then create a type-2 link from the appropriate type-3 link from x to u, specifying which element of x is involved.

១១២៦១១១១១

Tris Instruction of

methods. Difference z, the unique element of political checiff that procedure:

- dosq ai x in duscets seva a. Compute v=specify[b], and u=specify[a].
  - b. If u or v = NIL, terminate.

c. Execute partrgu[x;v].

- d. Add u to the value list of attribute "File ENTS" on that member of the "SUPERPART" value list of x which refers to your
  - e. Respond "(I UNDERSTAND)".
  - 5. partrsgq[x;y]

purpose: To reply as to whether the unique element of set x is part of of some element of set y.

method: The answer is "YES" if there exists a unique element z of (bere is a link indicat

(3w)[[there is a link indicating that some x is part of w] (By) [ there is a link indicating that u is an element of v] [[y=v]V [there are links indicating that y is a subset of v]V is part of some glally and some significant and some glally and some significant and some sig [there are links indicating that w is a subset of q]]]]]]

procedure:

- a. Compute z = specify[x].
- b. If z = NIL, terminate. and this was select agent attracted as configurate those modes w which can be reached from x, by a shan was type-3 link following the attribute "SUPERPART".

- d. For each w compute the list  $\underline{\boldsymbol{\ell}}$  of those sets which w, or any set equivalent to w, is member of mileston and a second fill (ch)
  - e. If your in grampond wasser a servent of the wind
  - f. If, for any vel, setro(y;v) = YES, respond "YES".
- Visco Otherwise, generate those notice q which can be reached from y by a type 3 link following the attribute (SUPERPART-OF-EACH)

ray plater i jakoliko raken irondar eta irolaren 18 meta berra 18 **me**ta **19 me**ta 19 meta 19 meta 19 meta 19 meta

- h. If y for any go setting v; alim YES, respond l'YES! (1) (vc)
- i. Otherwise respond "(INSUFFICIENT INFORMATION)". is at grain metholibet adett to bladus at stutt

# h) Attribute: NUMBER: Properties of the Aller Properties of the Attribute: NUMBER: Properties of the Attribute: Properties of the At

purpose: To specify in the model that there are n elements of the set x which are parts of every element of set y. bened va. Louis Stane Prix Geralian la violence as well to the

method: Create a type-3 link between x and y specifying that an a common method: element of x is part of some element of A Creste type-1 links associating the number n with that type 3 links and all disease and all TO SHATE OF BEHAVIOR WHELESTED FOR

### procedure: 4AM988232

- **schilure:** ANTARCET . such about promocive of the common of the confidence of a common of
- b. Add"(((NUMBER m))" to both the list; which was added to the value" list of attribute "SUBPART-OF-EACH" of by and the list which was added to the value list of attribute "SUPERPART-OF-EACH" OF ETWOMA TOTOM Dougles of
  - 2. partrnu[x;y;n]

purpose: To specify in the model that there are n elements of set x which are parts of individual y. 

method: Create a type-3 link between  $\underline{\mathbf{x}}$  and  $\underline{\mathbf{y}}$  which indicates that some elements of set x is part of yl Create type-1 links associating - 1085 the number n with that type+3 link. welfor soft le felgin and on the control

in the contract of the property of the section of the section of the section of

ovologija se se se predenje produkate storija i traja i storija potenija i se i se se in se in se in se in se To storija i se opravlja objektiva i se produkate in te se in se se se se se operava se objektiva i se se se o

### procedure:

- a: Execute partrau[x;y] ted ad as twoma as garden and a so jet which and by Addiff(Nthmers n) to both the lists which was added to the and see the the value list of attribute "SUBPART" of y, and the list which was added to the value list of attribute "SUPERPART" of x.
- 3. partrnuq[x;y]and so a liver to the image of the observed control of the contro purpose: to reply as to how many elements of the set x are parts of the individual y.s. Free and as all glosses announced from the second second

efficience for the common for the company of the second section of the contract of the common for the common fo

4. For each a compute the list \$ of those s of one on, and anthon (Ju)[[there is a link indicating that an element of we is part of whe [[u=x]V(]v)[[there is a chestry of hilder in the time that ... f. If, for any of I, self-lywell refrequestion are not us

many (there is an enchain of diskended out in the same a subset of villi) y by altytes It themself on in the test and cather and cather and cather at earth ]] (uE) (3v)[[there is a chain any links lipsicating the trat v ds a 1. Otherwise respond "(INSUPFICIAMI) (LENgueraya) traq

[there is a chain of links indicating that x is a a minimum. subset of v]]],

then the answer is the product of the values of the type-1 links following the attribute "NUMBER", associated with each type datank used in A (a proving the required part relation. If any such "NUMBER" attribute is missing, the reply should explicitly request it. If the party whole relation cannot be established, the reply indicates that fact.

purpose: To specify in the model that chere are n elements of the procedure: set a which are parts of every element of the

- a. Follow the procedure of partrguq[x;y] until links are found which warrents at "YES" vesponse on Saversalist and sldgrequired links of issue which follow the attribute "NIBPARTEGORISH PERSART-OF-BACK" at a financial
- associating the number a withresser to build add not be in the second in "(I DON\*T KNOW WHETHER x IS PART OF y)".
- c. For each element  $\alpha$  of  $\ell$ , where  $\alpha$  specifies a "SUPERPART-OF-FACEL" link from u to v, get the value of the attribute "YIMBER" of G. X. If so for some Oby no such system existed respond ( MOSH MANY (M. 2004 X) "bbb . d
- disc computation—ithe product of the munbers—phraducation is sail. to the value list of attribute "SUPERPART-OF-EARCH at Rawsum aff) bnogas

2. psytroujk;v;ni

purpose. The specify in the modfillet, TEST, trail of the set that the set of x which are parts of individually

1. jright[x;y]

method: Greate r type-3 link between a and y which indicates the c purposetic Toospecify in the models that the unique elements of o setox is asset located just to the right of the unique, alements of satisfy. dither a reclassified

method: Check whether the statement is consistent with existing know 2019 ledge; i.e., that nothing is known to be between agands y and that yo is not known to be the the rightwofers off Atods not commissent bromplain. Otherwisesworeage satyped dink, indicating the positions likelation. loo end added in the veloc list of attribute "SUPERCART" of

procedure: . I a. If specify[x] or specify[y] = NIL, terminatequal pharaless . (

b. If there is already a type-1 link from y to x following the attribute "JRICHT" arespond "(THEOABONE STATEMENT AS ALREADY! KNOWN) " > 20 0 3 0 0

- c. If it can be proven that y is to the right of x, 140 200 10 rightp[y;x]=T; or if there is any type-1 link from y following the attribute "JRIGHT"; or if there is any type-1 link from x following the attribute "JLEFT"; then respond "(THE ABOVE STATMENT IS TMPOSSIBLE)".
- d. If rightp[x;y]=T, and there does not exist a direct type-2 link from y to x following the attribute "RIGHT", respond "(THE ABOVE STATEMENT IS IMPOSSIBLE)".

Truthment .ASVmfy jyā banga ta like-jah hidasga ja lan

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- e. Otherwise, create a type-1 link from y to x following the attribute "JRIGHT"; create a type-1 link from x to y following the attribute "JLEFT"; and respond "(I UNDERSTAND)".
  - 2. rightp[x;y] weiter pot a seaf keil i-war a grant hint f

purpose: To test whether it is known that the x is located to the 

method: "rightp[x;y]" is defined recursively as follows: If there is no type-1 link from y following the attribute "RIGHT", and no type-2 link from y following the attribute "RIGHT", the value of "rightp[x;y]" is NIL; if either of the above links exists and links to x, the value is T. Otherwise the value is the disjunction of the values of "rightp[x;y]" for all u which are linked to y by one of the above links.

### procedure:

- a. Compute u, the value of the type-1 link from y following the attribute "'JRIGHT".
  - b. If u=x, value is T; if there is no u, go to step d.

c. If rightp[x;u] = T, the value is T.

- d. Compute 2, the value of the type-2 link from y following the attribute "RIGHT".
- e. If  $\underline{x}$  is a member of list  $\underline{\ell}$ , the value is T; if there is no 1, the value is NIL
- f. If, for any veQ, rightp[x;v]=T, the value is T; otherwise the value is NIL.

note: "T" and "NIL" are special LISP symbols standing for "true" and "false," respectfully.

## $3_{n}$ right[x;y] we since the consequence of the parameters and the consequence $x_{n}$

purpose: To specify in the model that the unique element of set x is located to the right of the unique element of set y.

method: Check whether the statement is consistent with existing knowledge. If so, create a type-2 link indicating the positional relation. Otherwise, complain.

### procedure:

- a. If specify[x]=NIL or specify[y]=NIL, terminate.
- b. If rightp[x;y]=T, respond "(THE ABOVE STATEMENT IS ALREADY KNOWN)!
- c. If rightp[y;x]=T, respond "(THE ABOVE STATEMENT IS IMPOSSIBLE)".

  d. Otherwise, create a type-2 link from y to x following the attribute "RIGHT"; create a type-2 link from x to y following the attribute "LEFT"; and respond "(I UNDERSTAND)",

## 5-4. Hijrightseq[x;y] A new ac nobel was on Deagwards of Louis

purpose: To reply as to whether the x is located just to the right of 

method: Determine whether the links in the model indicate that x is just to the right of y, x cannot be just to the right of y, or neither.

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### procedure:

a. If specify[x]=NIL or specify[y]=NIL, terminate.

b. If there is a type-1 link from y to x following the attribute "JRICHT", respond "YES".

c. If rightp[y;x]=T; or if there is any type-I link from y following the attribute "JRICHT"; or if there is any type-1 link from x following the attribute "JLEFT"; then respond "NO ".
d. If rightp[x;y]=T and there does not exist a direct type-2 link

from y to x following the attribute 'RIGHT', respond "NO".

e. Otherwise, respond "(INSUFFICIENT INFORMATION)".

### 5. rightssq[x;y]

purpose: To reply as to whether the mais located to the right of the y.

method: Determine whether the links in the model indicate that x is to the right of y, to the left of y, or neither.

### procedure:

- a. If specify[x]=NIL or specify[y]=NIL, terminate.
- b. If rightp[x;y]=T, respond "YES".
  c. If rightp[y;x]=T, respond "NO".
- d. Otherwise, respond "(INSUFFICIENT INFORMATION)" 20 30 30 30 30

### 6. wheres[x]

purpose: To determine the locations of those objects which have been positioned with respect to the unique element of the set x.

method: Reply with the information provided by each positional link associated with x. earlier reformation by a barry of will will be a com-

### procedure:

a. If specify[x]=NIL, terminate.

- b. Compute u = the value of the type-1 link from x following the attribute "JLEFT"; v = the value of the type-1 link from x following the attribute "JRIGHT"; L = the value of the type-2 link from x following the attribute "LEFT"; and m = the value of the type-2 link from x following the attribute "RIGHT".
- c. If U, y, 1, and m all do not exist, respond "(NO POSITION IS KNOWN)".

  - d. If u does not exist, go to step f.
    e. Respond, "(JUST TO THE RIGHT OF THE u)", and go to the next step.
  - f. If v does not exist, go to step h.
  - g. Respond, "(JUST TO THE LEFT OF THE v)", and go to the next step.
  - h. If  $\mathcal{L}$  does not exist, go to step j.
- 1. Respond, "(SOMEWHERE TO THE RIGHT OF THE FOLLOWING ... !)", and go to the next step. j. If m does not exist, terminete.

  - k. Respond, "(SOMEWHERE TO THE LEFT OF THE FOLLOWING . . m)".

# 7. locates[x] c and a assert that and . . and I immediately and inda

purpose: To determine the location of the unique element of set x with respect to as many other objects as possible.

The Go thereway daine boundisheby wake for his or w

method: Construct a diagram of the left-to-right order of objects by searching through all chains of positional links starting from x and proceeding recursively. The form of the diagram is a list, with objects known to be adjacent appearing in subjects. If no positional links from x exist or if a well-ordering cannot be determined, make an appropriate comment. appropriate comment.

# procedure:

a. If specify[x] =NIL, terminate.

b. Set the initial diagram g="(x)".

c. Compute u = the value of the type-I link from x following the attribute "JRIGHT". If no u exters or if u is already in g. so to step f. d. Insert u just to the right of x in g. i.e. insert u right after

x in a sublist of g.

- e. Replace g by the result of executing this procedure starting from step c, with the current value of u replacing the argument x and the current value of g as the diagram.
- f. Repeat step c, for the attribute "JLEFT". In case of failure, go to step i.
  - g. Insert u just to the left of x in g.

h. Repeat step e.

- i. Compute Q = the value of the type-2 link from x following the attribute "RIGHT". If no & exists, go to step &.
- For each m & L: If m is already in the current g, ignore it; if there exists a v in g which is the object (or first object on a sublist) following x (or a sublist containing x), go to step k. Otherwise insert m after x (or the sublist containing x) in g, and repest step e, with the current value of m replacing x. When all mel have been treated go to step 4.
- k. If rightp[v;m]=T, insert m after x and continue with the next m in step j. If rightp[m;v]=T, then just for this value of m replace x by v and continue as in step j. Otherwise, respond to the time "(THE LEFT-TO-RIGHT ORDER IS)

(TO FURTHER SPECIFY THE POSITIONS YOU MUST INDICATE WHERE THE m IS WITH RESPECT TO THE v)".

- 1. Perform operations analogous to i, j, and k for the attribute "LEFT" of x.
  - m. If the current g="(x)", respond "(NO RELATIVE POSITION IN KNOWN)".
  - n. Otherwise respond, "(THE LEFT-TO-RIGHT ORDER IS) g".

### 8. whereg[x]

purpose: To determine the locations of those objects which have been positioned with respect to some element of set x.

method: Find an object  $\underline{u}$  of which an  $\underline{x}$  is an example or a part, and

which has positional links. Then find the locations of those objects which have been positioned with respect to  $\underline{u}$ .

To determine the location of the empres slement of 194001148 procedure: If  $\underline{\mathbf{x}}$  has any positional links, i.e., if the attributes "JRIGHT", "JIEFT", "RIGHT", and "LEFT" of x are not all missing, execute wherealx course about the mothered to amisho the aguerant gardones b. If appropriate comment. then execute wheres[u]. c. If the hypotheses of step b. hold for the attribute "SUBSET" execute wheres[u]. as if specifyix abil, terminant d. If Gu)[[there is a sequence of links following the attribute "SUPERPART-OF-RACH" from x to ula pring the attribute "SUBSET" from u to w x in a sublist of g. [w has at least one positional link]] where the basique .e. then execute wheres w. e. Otherwise respond "(NO RELATIVE POSTTON IS AND THE CONTROL OF T f. Repeat step c, for the attribute "NERY". In case at follow . go to acto i. Insert a just to the left of x on go че дриа давдой чий  $i_{s}$  -Compate k = the value of the typerallar than k and kattribute "RiGHT". If no & exhate, go to stop & 1. For each mel: II m il already to the current go ignore it: if there exists a y in g which is the object for these Johnson sublist) following g (or a suplist contains as, so her h. Otherwise insert who is the sublist recommend to the missississis with the property of the same of the wise the same of the contract of the contrac avier i ed liga i te e elle e garoslapor a lo locione e entitudi bia treated to to step  ${\mathcal L}$ z. Ild rightply:ml=T, insert w amen of not a screen with the cong starker in Alexandra film: Vietnam and the continue of the continue in a continue of the starker of by y and concinue as in step :. Otherwise respond "I THE LAWY-TO-RIGHT ORDER IS) (TO STREMER SPECIFY THE POSITIONS FOR HEND HUBBLESS MODES 1245 - 12 WITH RESPECT TO THE V)". Periorm operations analogous or the section of the section If the current g="(x)", respend "DFC RelativE for the two Stands of n. Otherwise respend, "(THE LEFT-19)-Right Office Th)

8. whereging

parpose; To determine the locations or those objects which have been positioned with respect to some clement of set g.

method: | Fied can object ... of which as y is an excepte en a next and

### B. Special Features.

SE SECTION OF SECTION

This section discusses the sample conversations for Fig. 6 which illustrate three special features of the SIR system. The first two -
the exception principle and resolving ambiguities. - illustrate how

(SIR can be used to simulate various aspects of human linguistic behavior.

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The third feature -- streamlining -- demonstrates of human linguistic behavior.

(MORRES A 21 TOO A 2171)

can automatically modify its model structure in order to save computer

memory space.

a) Exception principle: General information about .!!all the elements"

of a set is considered to apply to particular elements only in the absence (YUB A CL YAPAR (ATT))

of more specific information about those elements. Thus it is not necessarily contradictory to learn that "mammals are land animals" and (GRA12890000 1)

yet "a whale is a mammal which always lives in vater." In the program, this idea is simplemented by always preferring: for desired information (GRA1280000 1)

to the property-list of the individual concerned before looking at the Individual concerned before looking at the descriptions of sets to which the individual belongs.

The justification for this departure from the secretion printiples of Aristotelian logic is that this precedence of specific facts over background knowledge seems to be the way people operate,

[1] STAN OR WARD COMPANY OF THE SECRET OF THE

The present program does not experience the uncomfortable feeling people frequently get when they must face facts like "a whale is a SAUTAST JAIOSTS TO SHUDIT mammal which lives in water although mammals as a rule live on land."

However, minor programming additions to the present system could

### a. EXCEPTION PRINCIPLE

```
(***.
           THERE ARE 5 FINGERS ON EVERY HAND)
(I UNDERSTAND)
           THERE ARE THO HANDS ON A PERSON)
( I UNDERSTAND)
{ • • • .
           A BOY IS A PERSON)
(1 UNDERSTAND)
           TOM IS A BOY!
( UNDERSTAND)
. . . .
           DICK IS A BOY)
[ UNDERSTAND]
{ * * * .
           HARRY IS A BOYT
(I UNDERSTAND)
           TOM HAS NINE FINGERS)
(THE ABOVE SENTENCE IS AMBIGUOUS ** BUT I ASSUME (HAS) MEANS (HAS AS PARTS)) (I UNDERSTAND)
          DICK HAS ONE HAND!
(THE ABOVE SENTENCE IS AMBIGUOUS .. BUT I ASSUME (HAS) MEANS (HAS AS PARTS)) (1 UNDERSTAND)
          HOW MANY FINGERS DOES TOM HAVE (1)
(THE ABOVE SENTENCE IS AMBIGUOUS •• BUT I ASSUME (HAS) MEANS (HAS AS PARTS)) (THE ANSMER IS 9)
          HOW MANY FINGERS DOES DICK HAVE Q)
(THE ABOVE SENTENCE IS AMBIGUOUS .. BUT I ASSUME THAS) MEANS (HAS AS PARTS)) (THE ANSWER IS 5)
          HOW MANY FINGERS DOES HARRY HAVE Q1
(THE ABOVE SENTENCE IS AMBIGUOUS ** BUT I ASSUME (HAS) MEANS (HAS AS PARTS)) (THE ANSWER IS 10)
          HOW MANY FINGERS DOES JOE HAVE 4)
(THE ABOVE SENTENCE IS AMBIGUOUS ** BUT I ASSUME (HAS) MEANS (HAS AS PARTS)) (I LON*T KNOW WHETHER FINGER IS PART OF JOE)
```

FIGURE 6: SPECIAL FEATURES

### b. RESOLVING AMBIGUITIES

```
(***. JOHN IS A PERSON)

(I UNDERSTAND)

(***. DICK IS A PERSON)

(I UNDERSTAND)

(***. A CHAIN IS PART OF A BICYCLE)

(I UNDERSTAND)

(***. THE PUWER-SAM HAS A CHAIN)

(THE ABOVE SENTENCE IS AMBIGUOUS ** BUT I ASSUME (HAS) MEANS (HAS AS PARTS))

(I UNDERSTAND)

(***. JUHN DWNS A CHAIN)

(I UNDERSTAND)

(***. DICK HAS A CHAIN)

(ITHE ABOVE SENTENCE IS AMBIGUOUS ** BUT I ASSUME (HAS) MEANS (UWNS))

(***. THE CUCKOD-CLUCK HAS A CHAIN)

(***. THE CUCKOD-CLUCK HAS A CHAIN)
```

FIGURE 6 (Cont.)

#### c. STREAMLINING LINKAGES

```
JUHN IS A PERSON)
....
(I UNDERSTAND)
( * * * .
               JOHN IS A TECH-MANE
( | UNDERSTAND)
               JUHN IS A BOY)
[ UNDERSTAND)
(***.
               JOHN IS A STUDENTI
(I UNDERSTAND)
               JOHN IS A BRIGHT-PERSON)
(I UNDERSTAND)
               EVERY BOY IS A PERSON)
( UNDERSTAND)
               EVERY TECH-MAN IS A PERSUN)
(I UNDERSTAND)
               EVERY TECH-MAN IS A BRIGHT-PERSON)
(I UNDERSTAND)
               EVERY TECH-MAN IS A STUDENT)
( UNDERSTAND)
               EVERY BRIGHT-PERSON IS A PERSON)
( | UNDERSTAND)
               EVERY STUDENT IS A BRIGHT-PERSON)
( UNDERSTAND)
             EVERY STUDENT IS A PERSONI
(I UNDERSTAND)
END OF EVALQUOTE, VALUE IS .. (NO MORE INPUT SENTENCES)
FUNCTION EVALQUOTE HAS BEEN ENTERED, ARGUMENTS... STREAMLINE (JOHN)
(I FORGET THE MEMBER-ELEMENTS RELATIONS BETWEEN PERSON AND JOHN)
(I FORGET THE MEMBER-ELEMENTS RELATIONS BETWEEN STUDENT AND JOHN)
(I FORGET THE MEMBER-ELEMENTS RELATIONS BETWEEN BRIGHT-PERSON AND JOHN)
(I FORGET THE SET-INCLUSION RELATION BETWEEN PERSON AND TECH-MAN)
(I FORGET THE SET-INCLUSION RELATION BETWEEN BRIGHT-PERSON AND TECH-MAN)
(I FORGET THE SET-INCLUSION RELATION BETWEEN PERSON AND STUDENT)
END OF EVALQUOTE, VALUE IS .. NIL
```

FIGURE 6 (Cont.)

require it to identify those instances in which specific information and general information differ; the program could then express its amusement at such paradoxes.

- b) Resolving ambiguities: The criteria used by the program to decide whether "has," in the format "x has y," should be interpreted "has as parts" or "owns" are the following:
- 1) Let P be the proposition, "either y is known to be part of something, or y is an element of some set whose elements are known to be parts of something."
- 2) Let N be the proposition, "either y is known to be owned by something, or y is an element of some set whose elements are known to be owned by something."
  - 3) If PA~N, assume "has" means "has as parts."

    If ~PAN, assume "has" means "owns."

    If ~PAN, give up and ask for re-phrasing.
  - 4) Let P' be the proposition,

 $(\exists u)[[[y \text{ is known to be part of } \underline{u}] \lor [y \text{ is an element of some}]$ set whose elements are known to be parts of the elements of  $\underline{u}]] \land$   $(\exists w)[[u (w \lor u Cw) \land [x (w \lor x Cw)]].$ 

5) Let N' be the proposition,

 $(\exists u)[[[y \text{ is known to be owned by } \underline{u}] \lor [y \text{ is an element of some set whose elements are known to be owned by the elements of } \underline{u}]] \land (\exists w)[[u \in w \lor u \subset w] \land [x \in w \lor x \subset w]]].$ 

6) If P' \ ~N', assume "has" means "has as parts."

If ~P' \ N', assume "has" means "owns."

Otherwise, give up and ask for re-phrasing.

These criteria are simple, yet they are sufficient to enable the require at accidentify then taktaness in choos specific indomistic program to make quite reasonable decisions about the intended purand seminal information wilder the program could then one is pose in various sentences of the ambiguous word "has." Of course, amuscaer' at such pseadoxes. the program can be fooled into making mistakes, e.g., in case the sentence, "Dick has a chain," had been presented before the sentence warrangeani d alugak ". y sail x" namuel and of "grad" nadden obliga "John owns a chain," in the above dialogue; however, a human being sas as carry to make are the following: exposed to a new word in a similar situation would make a similar To inic od ou book's elly mentis' accidiacopany and error. The point here is that it is feasible to automatically versuching, or gis an element of come set whose elements are know resolve ambiguities in sentence meaning by referring to the descriptions of the words in the sentence -- descriptions which can automatically be created through proper prior exposure to unambiguous something, or y is an electron of a melser whose listens as a known sentences. Of Chairle more we but not be to

 $x \subset y \wedge y \subset z \Rightarrow x \subset z$  and  $x \in y \in z$  and  $x \in y \in z$  are an expression of  $x \in x \wedge x \subset y \Rightarrow \alpha \in y$ ;

otherwise the functions would not be able to make full use of the provided information available in the form of explicit links.

On the other hand, since the functions involved will be "aware" of these theorems, then the set of questions which can be answered is these theorems, then the set of questions which can be answered is the information to the right of the "> " independent of the presence or absence of explicit links which provide the information to the right of the "> ", provided the information to the left of the "> " is available.

THE DATE OF MAIN (MID AND SHEET)

The "STREAMLINE" operation starts with the object x which is its argument, and considers all objects linked to x, directly or indirectly, through set-inclusion or set-membership. All explicit links among these objects which can also be deduced by use of the above known theorems are deleted. A response of the form "(I FORGET THE SET-INCLUSION RELATION BETWEEN y AND z)" indicates that whatever links were created by some sentence of a form similar to "(EVERY z IS A y)" are being deleted, and the space they occupied is being made available for other use.

In the above example, the STREAMLINE operation deleted more than half the existing links, at no reduction in the question-answering power of the system. However, the time required to obtain answers to certain questions was significantly increased.

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Chapter VI: Formalization and Generalization of SIR

The present version of the SIR system not only demonstrates the possibility of designing a computer which "understands"; it also points the way toward more general, practical systems by providing a useful data representation (the model) and by suggesting useful general information retrieval mechanisms.

SIR's abilities were illustrated by Fig. 1 and, in greater detail, by the conversations of Fig. 5. Unfortunately, the system is quite limited in the number of semantic relations it can "understand" and in the depth of its apparent understanding of any one relation. Moreover, the present system has some basic features which make these limitations extremely difficult to overcome.

The purposes of this chapter are to identify those features which make SIR difficult to extend; to point out how those difficulties arose and how they may be overcome; and to propose a formalism and a computer implementation for a more general semantic information retrieval system which has most of the advantages of SIR but few of its limitations.

The SIR treatment of restricted natural language was discussed at length in Chapter IV and is not of concern here. This chapter deals only with the action of SIR on relational statements which precisely define the desired information storage or retrieval operations.

### A. Properties and Problems of SIR.

Let us now examine the present structure and mode of operation of SIR. In particular, we are interested in learning why SIR cannot be extended in simple ways to handle a greater quantity and complexity of

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information.

1) Program organization: The present computer implementation of SIR is an interdependent collection of specially designed subprograms.

Each different information storage or retrieval operation is controlled by a different subprogram.

Such a diffuse program structure has a certain advantage for producing early results with a new experimental system. SIR was primarily developed as an experimental vehicle through which one may learn the best forms of information representation and the best storage and retrieval procedures. As an experimental device, SIR must be easily amenable to changes in its structure and modes of operation. The programmer must be able to learn the most useful interpretations of relational statements and the most useful responses the system should make. This learning takes place as he tries, by means of all hoc changes to the program, different interpretations and different response modes. These program changes are easiest to make if the program consists of many separate subprograms without much overall structure.

As such a system grows more complicated, each change in a subprogram may affect more of the other subprograms. The structure
becomes more awkward and more difficult to generalize as its size
increases. Finally, the system may become to unwieldy for further
experimentation. (SIR is presently close to this point of diminishing
returns.)

However, by the time this barrier is reached many fruitful results may have been attained. Ad hoc features may coalesce into general

principles. Desirable features may be discovered, and uniform methods may emerge for handling problems which originally seemed quite different from each other. In particular, my experiences in developing SIR to its present state have enabled me to specify the more uniform, more general, more powerful system proposed in Sections B and C below.

2) The model: The model is a flexible body of data whose content and organization are crucial factors in SIR's learning and question-answering abilities. SIR's "knowledge" is derived from two sources: facts represented in the model, and procedures embodied in the program. Basic procedures in the program provide for automatic revision of the model, if necessary, whenever new information is presented to the system. No such automatic procedures exist for revising the program itself.

The greater the variety of information which can be stored in the model, the more flexible the resulting system is; the more specific requirements and restrictions which are built into the program, the more rigid and less general the overall system is. It seems desirable, then, to store in the model a great variety of information, including facts about objects, relations, and the operation of the program itself. The program would then consist simply of storage procedures which would modify the model, and retrieval procedures whose actions would be controlled by data in the model. The user could then simply "tell" the system how to change its retrieval procedures, whenever such changes are desired.

Such a flexible system, whose program is "driven" by the model, is an ultimate objective of this research. Unfortunately, this

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objective must be approached by successive approximations. A modelcontrolled system cannot be designed at the outset for the following reasons:

- a. In order to store all the significant, controlling information in the model, we must first discover what constitutes the significant information in a semantic information settled to the significant oping any workable program-plus-model system we are in a better position to recognize thirty importants feathful and to transfer control of them to the model.
- b. The value and efficiency of the system depends upon the structure of the model and the manner in which the program and model interactions of the model until the organization of the model and of the roversti system may be no proved reastble may be a
- c. The problem of how to express controlling information which we start wish to add to the model, e.g., how best to describe search and deduction procedures, must be solved along with the problems of representing and utilizing that information once it is in the model. Formalisms for describing such control procedures for describing such control procedures after some experience has been gained in the use of similar procedures. This experience has been gained in the use of similar procedures. This experience has been gained in the use of similar procedures. This experience has been gained in the use of similar procedures. This experience has been gained in the use of similar experimentation with the program portion of simplified semantic information retrieval systems.

of classes. The number, kind, and interpretation of the descriptors of classes. The number, kind, and interpretation of the descriptors of cattributes) in the model is determined by the program. The information about how the meanings of certain attributes are related to each other is incorporated in the subprograms which identify those attributes, attributes, attributes, attributes, attributes, attributes attributes.

with the system has brought me to the point where I can confidently propose an improved, generalized system. The system proposed in sections B and C below keeps the now proven description-list organization for the model; it increases the variety of data to be stored in the model; it transfers some of the information about the attributes

from the program to the model; and it provides the user with a simplification fied method for experimenting with the deductive procedures of the algoni system.

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i first auscover what com 3) Question-answering method: In order to describe how SIR's one ow huseys ishop, sulq-mergorq oldninov yay, higo question-answering behavior has been achieved and how it can be itten to the mode improved, I must first introduce some notation. As described in and officiency of the system diggids Section III.D.3, each relation in the SIR system is a dyadic relation One method limit the complexity of the e.and hence is represented in the model by two attribute links. Table a. gives the correspondence between relation names and attriwish the plan to the model to the the service bute names, and a typical English interpreterion for seach relation to the b Topscalar to the state of the second and set-membership, respectively, although functional notation, we have ereexisted accent with the program port "equiv[x;y]," is used for all other relations. Also, the e.g., usual symbols of mathematical logic, which are defined in Appendix I, will be used below when convenient our like a being made as self a case of a sec-

A relation "holds" for specified arguments, i.e. a relation and the with specified arguments (called a predicate) is "true, " if and only one. if any reasonable English interpretation of the relational statement is a true English statement. An English interpretation should be analysis considered "reasonable" only if the natural-language processing part of the system would translate it into the given relational statement. A relation with specified objects as arguments clearly is true if the objects are linked in the model by the attributes which correspond to the the relation. However, frequently such a predicate is "true" even a many when its arguments are not directly linked. In such cases the truth year adel neje rese i patise a la Paso i ete el errà un espatica en adazon figitivo i most, i vigi

Relation	Attribute on property-list of x		Typical English
xCy State	SUPERSET	SUBSET XX9 of G3	An x is a x.
xey	MEMBER HAR IN THE THE	ELEMENT SEW MELL	aria a zezedos i en par
equiv[x;y]			<u>x</u> and y name the same object.
			Eyery y owns an x.
own[x;y]	OWNED	POSSESS	y owns an x.
			An x is part of a y.
		•	An x is part of y.
right[x;y]	LEFT	ceping, so sandir	The x is to the right of the y.
			The x is just to the right of the y.

### Table a: RELATIONAL NOTATION

करण पुनरार्वत के को अधिकार अने, कार रिवास कर कुले उन्होंक्सरावान स्वक्राबहुदारावृत्वे के प्राधिकात

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of the predicate can be determined indirectly from other information available in the model or in the program.

SIR contains a separate subprogram for determining "truth" for each relation in the system. These are the subprograms responsible for answering "yes-or-no" questions. For example, the answer to the question, "is the chair to the right of the table?" would be found by a subprogram called "rightq" which deals with the truth of the "right" relation. "Chair" and "table" would be the inputs to the "rightq"

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During the development of SIR, procedures for establishing the truth of relations had to be explored independently for each relation and so a separate program was written for each relation. The detailed operation of these subprograms was described in Chapter V. Now, as we consider how to generalize the system, the time has come to look for common features of these subprograms. Such common features could serve as the basis for a simpler, more unified program structure.

Indeed, such common features have been found, and they are exploited in the general system to be described in Sections B and C below.

The first step in trying to simplify the truth-testing procedures is to express the procedures in such a way that their operations can easily be compared and understood. In practice each of the truth-testing subprograms operates by searching the model, looking for certain combinations of attribute links. However, since the existence of an attribute link implies the truth of a corresponding predicate, we may consider the subprogram as deducing the truth of a predicate from the fact that certain other predicates are true. Such deduction animals ranks are vibratible in the first-order predicate mangong add not replace the predicate calculus (the "quantificational calculus").

Frequently the truth of a predicate depends upon the fact that

The relation involved has a special property, e.g., transitivity.

These properties of relations may conveniently be described by "definition" statements in which a bound variable stands for the name of some unspecified relation. These definitions are simply abbreviations which in the statements of the stat

will become ordinary quantificational calculus statements when the construction of the second statements when the construction of the second statements when the construction of the second statement of the second statement

The properties defined below are useful for describing some of the most a distance of the state of a distance of the state of the state

Symmetry:  $A(P) = df(\forall x)(\forall y)[P[x;y] \Rightarrow P[y;x]$ 

Reflexivity: R(P) =df (\sqrt{x})[P[x;x]]

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Transitivity:  $\mathcal{J}(P) = df(\forall x)(\forall y)(\forall z)[P[x;y] \land P[y;z] \Rightarrow P[x;z]]$ 

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The following logical sentences hold throughout SIR and represent basic properties of the "equiv" relation:

 $(\forall P)(\forall x)(\forall y)(\forall x)[\Re x;y] \land \operatorname{aduly}[x;x] \Rightarrow \Re [x;y]]$ 

 $(\forall P)(\forall x)(\forall y)(\forall z)[P[x;y] \land equiv[y;z] \Rightarrow P[x;z]]$ 

Table b. lists predicate calculus statements corresponding to the deduction procedures actually used in the SIR subprograms for truth-testing. These statements were obtained by studying the SIR subprograms, and they accurately represent the operation of those subprograms except for the following:

- a. All quantifiers range over only the finite universe of objects, classes, and relations represented in the model.
- b. Each subprogram contains built-in mechanisms for searching the model in the course of trying to apply one of the deduction procedures. The linkage structure of the model ellows the grograms to make direct, exhaustive searches through just the relevant partions of the model.
- c. When alternative deduction procedures are available for testing a predicate, each subprogram specifies the order in which the procedures should be attempted. As is illustrated by the "Exception Principle" (Section V.B.) with use of atternate deduction procedures may result in different answers to a question. This means that, from a purely predicate-calculus point of view, the deduction procedures together with the information stored in the model may form an inconsistent system. Therefore the order in which deduction procedures are used influences the answers obtained. In the present form of SIR the ordering rule has been that those procedures dealing with indirect links are to be used only if no answer can be obtained by using those procedures dealing with more direct links.

d. Each subprogram is independent and contains complete pregrams for with deduction procedures. Since some of the deduction procedures in different subprograms are similar, some program casquents appear a language several times in the SIR system. For example, programs which test whether a particular class inclusion relation holds appear in most of the truth-testing subprograms. This program redundancy results from the independent subprogram organization of SIR and should be removed in a more uniform system.

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Deduction Procedures (9) A aggiving Person
Relation being tested
                            and the M^{2}(\mathcal{F}_{0}) , which is a constant (1)^{n} . The first standard
                                                  2.
                                                          x=y \Rightarrow x \subseteq y
                                                          equiv[x; y] > xCy and got gar a ted sall
                                                  3.
 6
                                                  4. αξκράζου ⇒ αξορος ο only lo zellachony closed
                                      5. 6. 7. T[equiv] R equiv] . A [equiv]
equiv
                                                 8. ~ wing(*; x) > (y) = ($\forall ($
owng
                                                  9. \operatorname{owng}[x;y] \land z \subset y \Rightarrow \operatorname{owng}[x;z]
   The transfer of the 10. Howing x pyly is z wowing z; y it is at a less
12. \operatorname{owng}[x;y] \wedge z \in y \Rightarrow \operatorname{own}[x;z]
                                                        testing. These statements were obtained by a
                                               13. \sim partg[x;x]
partg
                                               14.0 part gray A & Cy whomes x 2 has a sensing ord
                                                          part[x;y] x c part[z;y] 1qansa amagonq
                                               15.
part
                                               16. part[x;y] \land partg[z;x] \Rightarrow part[z;y]
                                               17. partgir; ylacey partix; elstidesep fla ...
                                                 classes, and relations replayersted in the oneders
right, jright
                                               18.
                                                          right[x;y] \Rightarrow \sim right[y;x]
                                               19. Jerght like this contains margared dual .d
                                               20. Bjright[x;y] = right[x;y] samas self at ishow
                                               21. Stright s; Jewes Jright x; y see see the
                                               22. jright(x) / Auty must klitt(x;y) a sandandas
                                                          right[x;y] \land right[y;z] \Rightarrow \sim jright[x;z]
                                               23.
                                                            c. When alternative deduction procedures -
                                  preducate, cach subprogram specifica en electricio selec-
       Should be accompted. As as illustrated as the blanch we be to a
   #7.65-11 Table by Deduction Procedures in Sir Subprocrams 4.7 agains 3.
       in different answers to a quesition. This name that, arms a cond-
                      predicator-calculas peint of view, the deadstron procedure of
      Universel quantification over all free variables is assumed .003 403 40
       systems, illuriare the reder in which dediction project condi-
             infingaça the answers obtained. If the contract of the couple the
               ាន (១៩៣) ស្គ្រាស់ ស្រែស្រាស់ និងស្រី ប្រែសាស្ត្រ ទទួល ស្គ្រាស់ ស្គ្រាស់ ស្គ្រាស់ ស្គ្រាស់ ស្គ្រាស់ ស្គ្រាស់ ស្
   links are probe parel only if no and to our modificant for the fibrar
                                                                           proceedargs dealing with more direct
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CONTROL DESTA MOREN ON PERE OFFICE

Thus far I have been discussing only those programs which enswer a "yes-or-no" questions. More complex questions, such as "Where is the table?" and "How many fingers does John haves!, require different; question answering procedures. In SIR confidence and additional subprograms for each of these complex question forms to These subprograms will be a discussed further in Paragraph of John Low 2018 and a line of the complex question forms to These subprograms will be a

Biv Formalism for a General System of the ports for the conjust of a bound of the conjust of the

Given a suitable formal system. A separate truth testing subprogram
for each relation in the SIR system would not be necessary. A Instead;
a single "proof-procedure" program Couldobervel foromewering allowance
"yes-or-no" questions. A son modey a self-of-sense telegram and a son less are not as son loss.

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The deduction procedures of Tabley by sould be seed as the sations of such a formal system. However, others and of sthe server was a suggested an externative system which is more tensible, more intuitively meaningful, and easier to extend to incorrect and one of the sate of the server of ormal system is a the subject of schispe extensions and the sate of the section of the same of the same is a subject of schispe extensions and the same of the sa

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the truth of a predicate involving one of the delations is decreased the truth of a predicate involving one of the delations is decreased white the teath of some predicated unvolving the other to where the twenth of some predicated unvolving the other to where the twenth of some predicated unvolving the other to where the twenth of some interest of the statement in Table buy we have any that the some deductions interest and the statement in Table buy we have say that the some interest and the same int

Interactions may, be cleasified informally as follows: (a) golden .

- a. Interactions between the Corap relation and some other relations
- by interactions between relations whose meanings are similar to each other. (This "similarity" will be defined more precisely in Section 2 below.)

- c. Interactions which arise principally because of some peculiarity of one of the relations involved an anisabath need avail as a continuous some peculiarity of the relations involved an anisabath need avail as a continuous some peculiarity of the relations involved an anisabath need a relations and the relations are relative to the relations of the relations are relative to the relations of the relations are relative to the relations are relative to the relations of the relations are relative to the relative to the relations are relative to the relations are relative to the re
- d.d.Other interactions., shot sasua valquos croff . zaoldzaep "on- c--eo "

Interactions are sof. Interest because they creates the liggest's ideal obstacled to generalizing the SIR system. a whenever a green we detion is up added to the system; the sprogrammer must adapt if you is the relations to in the system which interact with the new greation; and due diffy the care system to allow for the interactions. With the present system, this means modifying each of the question answering subprograms associated with the interacting relations. This form ideals reprogramming task accounts for the fact that the ideal care segment in the present system version of SIR domain allow for sail the statutively accesses interest actions between relations in the system. For example, sifp SIR is say of told that an as is parted five ray ye add that a rown on year in cannot be deduced that of x owns contact to perform, this wand similar deductions as it is parted of every ye add that a rown on year in cannot be seen to show the system. SIR would have not show about additional ting exections among the shape relations parts parts; parts;

Almost all the interactions accounted for inather present system; and in the deduction procedures of Table b. are of type "a," "b," or "c," according to the above classification schemes wite equivalent involve (the waveletions or C, are lations whose amendings are similarly or relations with with dividual peculiar properties and Theoformal system; to be described below; will eliminate, the need for explicitly aconsidering any interactions of these three types as Once as new relations as properly described according to sample, intuitive rules be any type "a, wall believe "eliminates between attack others relations will assessmentically be accounted for by the logical system, and thingh setters (types "d") sintered to not took of the logical system, and thingh setters (types "d") sintered to not took of the "gains limital actions" a solution.

below.)

actions may still exist, they will be easy to describe and modify.

For example, a single simple statement will be sufficient to make

the system "aware" of the interaction between part-whole and ownership relations illustrated in the previous paragraph.

2) SIR1: A proposed formal system for truth-testing: The formal system called "SIR1" to be proposed here will consist of: definitions of certain terms, including terms which describe strings of symbols; a standard interpretation for the symbols; and a logical method for determining whether certain strings called "sentences" of SIR1 are "true." The significance of the system is that all "yes-or-no" questions which can be answered by SIR, and a great many which cannot, are expressible as sentences in SIR1; I.E., the standard interpretation of a formal sentence is its corresponding English question. Further, if a sentence is "true" in SIR1, then the snawer to its corresponding question is "yes." These points will be illustrated by examples below. A computer implementation of SIR1 will be discussed in Section C of this chapter.

### a. Definitions:

basic object =df any object which is described in the model and which has the following property: No object described in the model may be related to a basic object by being a member or a subset of it.

basic relation =df a symbol which names a relation whose arguments must all be basic objects.

variable =df a symbol used in place of the name of some unspecified object described in the model. The standard interpretation of the name of an object is, of course, the object itself.

basic predicate =df a basic relation written as a function of the names of basic objects or of variables which stand for the names of basic objects. The standard interpretation of a predicate is that the specified relation holds between the specified objects.

where v<sub>1</sub> is any variable and v<sub>2</sub> is any variable, any object name, or the special symbol "M" which stands for "model." These figuratifiers are related in the first-order predicate calculus as follows:

the system 'energy but  $(1) (\forall \alpha \in x)[R[\alpha]] = df (\forall \alpha \in M)[\alpha \in x \Rightarrow R[\alpha]]$ ship relations illustrated in [[G]A x30] [M30E] about [[0]A] (x30E)

where  $(\forall \alpha \in M)$  and  $(\exists \alpha \in M)$  are the usual universal and existential quantifiers of mathematical logic, respectively, except for an explicit reminder that they range over only the finite universe of objects described in the model; and Rice is any predicate, although it usually contains at least one occurrence of the symbol a among its arguments.

An  $\underline{6}$ -quantification of a string  $\underline{S}$ , is the string  $\underline{Q}[Q[S]]''$  where  $\underline{Q}_{i}$  is any  $\underline{6}$ -quantifier. The first variable in  $\underline{Q}$  is then called bound by the Enquantification of Stor all its occurrences in Q and in Store including occurrences as the second variable of other E-quantifiers.

A link-predicate is defined recursively as follows:

i) A basic predicate is a link-predicate; or the strings "vev" and "vev," where ver and vertex are any object-names, or variables, eare link predicates not seep "on-ro-see" link are link-predicate is a link-predicate. Link-predicates may be used to represent most of the relations which are represented by attribute links in the present version of SIR.

the standard leterpretation of a formal spattence is its corresponding:

swolloh as yelveruper benifeb at (ffw) alumnof-bennof-lew A

i) Alink-predicate is a wff and not specificated and in the propositional function of wff's is a wff.

iii) Any 6-quantification of a while same with through the control of towers

Angoccurrence of a wartable in a wff is called free if the rand occurrence is not bound by an E-quantification of some string containing that occurrence. will be discogned in Section C of this chapter.

A sentence =df a wff which contains no free variables initial

\_An<u>\_oblect=predicate\_=df</u>\_a.wff\_which\_contains\_exactly.one\_free wariable-rate following property: No object described as the following if to Inches a religious comment, calch y despite curad a ci featales selvem

b. Logical system:

The axioms of SIR1 are sentences which, under standard interpretation, describe properties of individual basic relations and apecify

ampres make of the basic care

typen"d" interactions between basic relations. has problem with to someway ent voi boxis suchu ketdervey vo no egocida bised 16 aomew basic objects. The acordard autorouser also of a predictor is that in specified relation notes between the second it denotes

A STATE MATERIAL CONTRACTOR BUILDING MATERIAL CONTRACTOR CONTRACTO

energies and anti-

Any sentence in Sixi can be transibrated into a sentence in the standard first-bider predicate calculus (the suguentificational calculus") by putting each E-quantifier into 123 dentifier of the and the equations (1), and then omitting the "ense Vallathe datal deduction procedures of the quantificational enfouture are receptable deauc\_1878 tion procedures in SIRI. Therefore, any theorem provable from SIRI exions in the quantificational caledius is wish a theorem of sixi, i.e., it is a "true" sentence of sixi, provided em a are inserted. into all quantifiers, regardless of the state of the current model. expresses the same thing In other words; SIRI is reducible to the quantificational calculus.
To boa (i d. anuol acongress and lis lo notional calculus) ( This reducibility provides with methods and hamely the methods of a quantificational calculus, such as subordinate Proof Derivation 33000 ""("Natural" Deduct 10h") -1 for proving whether sentences of Sirloare is theorems. However, we need different, more direct methods for testing mentura seem narestor situate the history resident and the second seem of the second s testing methods must be implemented on the computers for they compared the computers for they compared the computers for they compared to the computers for they computers for the computer for the computers for the computers for the computers for the computer for the computers for the computers for the computer for the computers for the computer for the computer for the computers for the computer for the computers for the computer for the stitute the basic question-answering mechanish of the generalized semantic information retrieval system, However, Ic shall first describe a totally unpractical trutheresting method which demonstrates propositional calculus, e.g., by trutherestic unalysta. with interest 'boddfirth's griffed to the filleston of the ball bot answered 'YES," if and only if this ligal expression to him the sentences with respect to particular SIRI model. A more efficient, heuristic approach will be described in paragraph C.2 below.

The SIRI model is quite similar to the Wir Model. It consists of a finite number of object names, each of which is true of the described object, or it may be a link which relates the described object to another object. This

latter object is named in the value corresponding to the given attri
("anbutes: In Section C.I. shall describe the nature of SIRL attributes are more precisely. For present gurposes it is sufficient to assume that the information carried by each attribute on a property-list in the SIRL model can be expressed in some well-defined way as a SIRL sentence.

deduced from the SIR1 axioms and the information in the SIR1 model.

A decision procedure for this deduction follows: "such" a sink of the sink of the

- i) is For each attribute in the model, write the SIRL sentence which expresses the same thing.
- ii) Let A = the conjunction of all the sentences found in i) and of all the SIR1 exicus. Consider the sentence abivorq vilidionber and (2) A > S
  where Sois the sentence being tested done actuals is about a comp
- iii) Put all f-quantifiers in (2) into the "EM" form by using equations (1).
- iv) Let o<sub>1</sub>, o<sub>2</sub>,..., o<sub>n</sub> be the names of the objects described in the model. Eliminate the duantifiers in (2) by replacing each string of the form (\(\sigmu v \text{M})[R[v]]\), where v is any variable and k is any predicate possibly depending on v with the finite conjunction

 $R[o_1] \wedge R[o_2] \wedge \dots \wedge R[o_n];$  and by replacing each string of the form ( $\exists v \in M$ )[R[v]] with the disjunction

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ogmantic information retrievel system of the lower Vigola Vigola is

houristic approach will be described in paragraph G.2 below.

v) Test the resulting expression by a decision procedure for the propositional calculus, e.g., by truth-table analysis. S is true with respect to the model, and the question corresponding to S should be answered "YES," if and only if this final expression is a theorem of the propositional calculus as a factoristic of the propositional calculus.

The Similar is quite similar to the comments; of railing a quite similar is a constant.

- a SIR1 wff which contains exactly one free variable. If that free variable is replaced by an object-name, the object-predicate becomes a
  - a link which relates the described object to scottier of the This

applied to an object in the SIRI model is that the sentence obtained by replacing the free variable in the predicate by the object-name is a true sentence. This resulting sentence may then be used as an additional axiom in any SIRI logical deduction procedure.

Object-predicates may be placed on the property-list of any object in the SIRI model. Their purposes are to describe those properties of the object which cannot easily be expressed, in terms of link-predicates, as specific associations with other objects.

ii) Basic relations: The "E" relation occupies a special place in SIRl because of its connection with Equantifiers, and is treated in the formalism as if it were a basic relation. The identity relation "=" is also treated as a basic relation because identity is a useful feature to have in a logical system based on the quantificational calculus. The SIR relation equiv" was simply an equivalence relation used to identify when different object names referred to the same object. In SIRl it is sufficient to subsume the function of "equiv" under the "=" sign; i.e., the formal statement "x=y" is considered to be true if either x and y are the same symbol, or if "equiv[x;y]" is a true predicate in the SIR model.

The predicates in Table c. show the basic relations and the labellation of the labellatio

iii) Connections: between Silvand Silvand: Table c<sub>2</sub>
lists a SIRl expression which should be used in place of each SIR predicate. Corresponding expressions have exactly the same interpretations; the SIRl statements are more complicated, but they utilize

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STR1 contended the standard interpretation Standard Interpretation
                                                                                                            which is a object in the SIRI model is a integral as a member of the set \underline{\mathbf{y}}.
                                                                                                           end equalberg end of aldertax sext and purifical extensions {\bf Elther} \ {\bf x} \ {\bf and} \ {\bf y} \ {\bf are} \ {\bf identical}, \ {\bf or} \ {\bf they} \ {\bf are} \ {\bf two}
          stud scattered This retailing sentence may then be seed as an end of
                                                                                        tioner suiom in any SIRI togics! Yearform of cadus
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                                                                                                              (interpretation: x has exactly one member.)
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SIR Predicate
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                                                                             The state of the formal state of the formal statement (x;x) is (x;x) and (x;x)
own[x:v]
                                                                                                            (∀βεγ)(]αεχ)[partb[α;β]]
partg[x;y]
                                                                                                             If "equiv(x:y)" is a true predicate in the SLE of (x; x) and (x; x) is a true predicate.
part[x;y]
right[x;y]
                                                                                                             (βαξχ)(ββξy)[rightb[α;β]] single[x] single[y]
                                                                                                             cate predicate needed by S[R] in order to deal (xaαE) (xaAE) (xa
jright[x;y]
                                                                                                                                                                                                     thous con de by SIR programs.
                                 Table c,: 28TR PREDICATES EXPRESSED THOSE TRACE Judane (11)
                       tists a sidirexpression which should be used on proceed nach STR
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                                                                                                            profactions; the BiBi statemoutes are seen than it
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SIR counterparts.

defined as follows:

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P is symmetric:
                 fewer basic symbols and they show tore logical (seprecture than thear) &
                                                                                                                                                                                                                                            P is asymmetric:
                                                                                                                                  \mathcal{J}(P) = \mathcal{J}(V \times (M)(V \times (M)(P) \times (V))
                                The SIR1 link-predicate corresponding to "partg[x;y]" in Table c2
                                                                                                                                                                                                                                                is reflexive:
                has the interpretation, "Some x is part of every; x)4"] (141the)1gh; thus)4s
                the interpretation used in most SIR question-answering subprograms at 9
                                                                                                                                         \mathcal{E}(P) = df \ (\forall x \in M) \sim (\forall \beta \in K) (\exists \alpha \in X) [P[\alpha; \beta]]
                 "partg[x;y]" might equally well be interpreted, "Every \underline{x} is part of some
                                                                                                                                                                                                                                            P is transitive:
                y," in which case, the AIRL: link-prediction (Vers) (IKA) (part block 814) %
                 should be used. Actually the interpretation of "marked k;yddinguagested
([[v:x]^{A}, [x:y]]) = ([v:x]^{A} \times ([v:x]^{A}) \times ([v:x]
  Notice that these properties will be expressed by ordinary SIR! sentences
                occurs because the natural-language input system in the present version
           when the bound vertable "P" is replaced by the name of a SIRi reletion.
```

of SIR cannot discover the finer meanings of "An x is part of a y." Table d is a list of all the axioms necessary to give SIRL at least Perhaps the most suitable representation for this latter sentence is the question-answering ability of the SIR deduction procedures in a conjunction of two SIR1 link-predicates Table h, except for the "axioms" derived from object predicates on  $(\forall \beta \in y) (\exists \alpha \in x) [partb[\alpha; \beta]] \land (\forall \alpha \in x) (\exists \beta \in y) [partb[\alpha; \beta]]$ the property-lists of particular objects. In Table b, deduction pro-The SIR predicate "right[x;y]" was interpreted as "The x is to cedures no. 1=4, 9-11, 14, and 15 all represent interactions with the the right of the y." This English sentence implies first that x and "¿" or "C" relations, i.e., type "a" interactions. Corresponding y are each sets containing unique elements, and secondly that those axioms are not needed in SIRI because of the way "C" is defined elements bear a certain positional relationship to each other. In (see Table ca) and the way E-quantifiers are used. Table b. no. 12 SIR the special subprogram "specify" was used to determine the nature and 17 are interactions between "similar" relations, i.e., type "b" of the sets involved, before the positional information was considered. interactions. "Similar" relations are those which are defined in Similarly, the SIR1 expression must be the conjunction of the objectterms of a single basic relation in SIRL. Additional axioms are not predicates "single[x]" and "single[y]" to describe the special nature needed because information about interactions between "similar" relations of x and y, and the link-predicate whose interpretation is, "an x is are implicit in their definitions as link-predicates. Procedure no. 16 to the right of a y." Similarly, object-predicates, as well as a linkis really a statement of the transitivity of the basic part-whole predicate, are needed to represent the SIR "jright" relation. relation (a type "c" interaction), somewhat obscured by a statement era anoitaler IRIE to seitreque under send :: IRIE to amoixA (vi of the interaction between the similar "part" and "part" relations

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P is symmetric:
 《(P)> =df=(∀xen)(∀yen)[P[x;y] 李四yxid > ets is en aledente all est reason
                                                              ASE Count Froatis.
 P is asymmetric:
 \mathcal{J}(P) = df (\forall x \in M)(\forall y \in M)[P[x;y] \Rightarrow \sim P[y;x]]
  (1) - Liki liak-prodicate vortespordiam to "party kiyi" a Tebio ()
 P is reflexive:
 Action to the organization of the part of the part of the part of the part of the call
 P is setsmonreflexiverens and lesem All deem of loss counsissing man and
  \mathcal{P}(P) = df (\forall x \in M) \sim (\forall \beta \in x) (\exists \alpha \in x) [P[\alpha; \beta]]
"partsy klyf" sitght equally well be interpreted, "Every k is mart ex hoss
 P is transitive:
 J(P) (=dF)(www)(W)(W)(W)(W)(W)(W)(P)(W;W](W;W](W;W](X;W)); do let if if if it
 Pristaniquely Ainked:" To nordederquetal and vilsaded abase of Mande
  \mathcal{U}(P) = \text{df } (\forall x \in M) (\forall y \in M) [P[x;y] \Longrightarrow (\forall \alpha \in M) [[\alpha \neq y \Longrightarrow \sim P[x;\alpha]] \land [\alpha \neq x \Longrightarrow P[\alpha;y]]] ) 
 Notice that these properties will be expressed by ordinary SIR1 sentences
bocurs because the natural-language input system in the prosent version
 when the bound variable "P" is replaced by the name of a SIR1 relation.
      of the carest discover the finer meanings of "An wile part of A y .
      Table d. is a list of all the axioms necessary to give SIR1 at least
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 the question-answering ability of the SIR deduction procedures in
                                  a conjugation of two SIRI link-predicates
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                  (\forall \beta \in \forall i \exists 0 \in x) [partb(\alpha; \beta]] \land (\forall \alpha \in x) (\exists \beta \in y) [partb(\alpha; \beta]]
 the property-lists of particular objects. In Table b, deduction pro-
     The Six profit cate "right[x;y]" was interpreced as "the girls to
 cedures no. 1-4, 9-11, 14, and 15 all represent interactions with the
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 "c" or "c" relations, i.e., type "a" interactions. Corresponding
     y are elch sets conteining unique stements, and secondly thus thur
 axioms are not needed in SIR1 because of the way "C" is defined
             elementa hone a commain positional relationabile na made etem
 (see Table c2) and the way &-quantifiers are used. Table b. no. 12
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 and 17 are interactions between "similar" relations, i.e., type "b"
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  Abeliancy, the SIR! emmession must be rig analyses but the object-
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           product story of Arrand property the Solar programmes and the Solar products.
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 vi Actions of SIRI: Some useful proposities of 181 cointrops are
 of the interaction between the similar "part" and "partg" relations
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                                                         cf. no. 8 and 13, Table b. These are "experimental"
   R(parth) and the wattoms, which should be dropped from the system if
 too many exceptions turn up.

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                                                         cf. no. 18, Table b.
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  (\forall x \in M) (\forall y \in M) (\forall z \in M) [rightb[x;y] \land rightb[y;z] \Rightarrow \sim jrightb[x;z]]
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               the trive of table b. are theorems in A[R] . The marner and down
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(a type "b" interaction). Interactions 21 and 22 of Table b. are of type "c," for they are due solely to the peculiar property of "jright" which is expressed in SIR1 by 72(jrightb). Finally, no. 20 and 23 of Table b. are true type "d" interactions, and corresponding axioms are necessary in SIR1.

Let me now make this discussion more precise. The deductive es. ro. & and til Tanic by there are teach imposes systems of SIR and SIR are both based on the quantificational ion m<mark>any exceptions town</mark> calculus. The only difference between them is that the SIR deduction procedures, in Table b., are a description of the operation principles of an existing computer program. SIR1 is a formally developed system which may eventually contribute to the specification for a computer program. If the SIR1 system with its short list of axioms (Table &) is already as effective a "yes-or-no" question-answerer as the no. 21 and 22, Table b. . were served brown - th. Wynderb) programs described by the SIR procedures in Table b., then adding those procedure rules to SIR1 cannot increase the power of SIR1.  $(v_i(x)) = (v_i(x)) = (v_i(x))$ In other words, SIR1 must already contedn all the information available in the rules of Table b. To prove that this is indeed the (THO) (VIME) (V set)) ( state be x: y) X is taken [ 1 x] (V) (V) (V) (V) case, I have shown that SIR1 sentences corresponding to each of the rules of table b. are theorems in SIR1. The method used was Sull less trans monime out deal aff to reduce the SIRL exioms and sentences to the quantificational calculus and then to prove the theorems by Subordinate Proof Derivations (Appendix I). The details are given in Appendix II.

v) <u>E-quantifiers:</u> The most obvious difference between SIR1 and the quantificational calculus is the occurrence in SIR1 of E-quantifiers. These new symbols serve three functions, the most obvious but least important of which is notational conciseness. Since the value of any notational device depends upon its

understandability, E-quantifiers are valuable because they indicate the intended interpretation of SIRI sentences to the user or reader. Finally, E-quantifiers are important for the computer implementation of SIRI.

They are indicators which relate the formal system to particular model search-procedures. Details of a proposed implementation scheme are presented in Section C.

this recogning to find wave of asing the court to store in the model

C. Implementation of the General Question-Answering System.

as SIR and yet have the uniformity and generality of the SIRI formalism at have the following components:

- i) a model patterned after the SIR model but containing more complete information in its linkages and containing a larger class of describable objects.
- 11) a theorem-proving program which can determine whether certain assertions are true, on the basis of axioms of SIRL and current information in the model.
- iii) a programming language for specifying question-answering procedures which are more complex than truth-testing.

In addition, these components must be designed to work together related to form a compact, efficient system. A detailed description of each of these components of the proposed system will follow shortly.

A program to translate natural or restricted English into formal relational terms, and a program to annex new relational information to the model, are also necessary components of any semantic question—

- 199(d), are also necessary components of any semantic question—

- 199(d), are also necessary components of any semantic question—

- 199(d), are also necessary components of any semantic question—

answering system. The latter annexing program is straight-forward and and all the basic mechanisms are already symilable in SIR. English translation is a linguistic problem whose detailed study is beyond the scope of this paper. The trivial format-matching solution (Chapter IV) may be

used until something better becomes available. In any case, I shall assume the availability of some mechanism for accepting new information in a form convenient to the human user, and then inserting corresponding relational information into the model.

1) The model: As discussed in section A.2 above, one objective of this research is to find ways of using information stored in the model to control the operation of the system, since that information can be modified most easily. Since the operation of any theorem-proving program is "controlled" by the axioms of the formal system involved, the axioms for SIRl should be stored in the model.

The SIR model consists of objects and associated property-lists The advantage of this model structure is that the program using the model can obtain all the information about an object, such as how it is related to other objects, simply by referring to the object itself. The SIR1 axioms of Table d. all describe either properties of SIR1 basic relations or interactions between basic relations. These axioms should be stored, then, on the property-lists of the basic relations which they affect. In this way the theorem-proving program will be able to find relevant axioms by looking at the property-lists of the basic relations it is concerned with, and the human user or programmer will be able to modify the axiom set by "telling" the system to modify its model, without any reprogramming being necessary. Objectpredicates define additional axioms which apply to particular objects. Therefore, they should be stored on the property-lists of the objects วางการเพียง สารใช้สิดสิต กรรมเรียกล่าง เราะบบสิงกัน involved.

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In SIR, a relation between objects is represented in the model by attribute-links on the property-lists of the objects. Each relation is uniquely represented by particular attributes. Simple (types "a" and "b") interactions between relations can not be represented in the model, but rather have to be "known" by the program.

As has been shown, the class of SIR relations roughly corresponds to the class of relations represented in SIRI by link-predicates. Each link-predicate, in turn, is defined in terms of a SIRI basic relation. We must now decide how to represent relational information in the SIRI model.

Each basic relation could be uniquely represented by particular attributes. However, these attributes would not be sufficient to represent all the facts which were representable in SIR. For example, the sentence "Every hand is part of a person," could be represented in SIRI by locating every object in the system which is a member of the set "hand," and linking each of them to some member of the set "person" with the attributes corresponding to the parts basic relation. However, it is not clear which hands should be parts of which persons; and the general fact concerning hands and persons would be unavailable for future deductions, e.g., when a new individual "person" is introduced into the model.

Alternatively, one could represent each possible link-predicate by a different attribute. The disadvantages of such a scheme would be twofold: First, much of the flexibility introduced by the definition and use of link-predicates would be lost, since special symbols would have to be assigned as attributes for each link-predicate actually used in a model; secondly, the important structure of the link-predicate,

i.e., the basic predicate and E-quantifiers of which it is composed, would be undiscoverable except by means of some table look-up or other, decoding procedure.

I propose that, corresponding to the attribute-links of SIR, SIR1 should use descriptions of the link-predicates involved. The attribute on the property-list of an object should itself be a property-list.

This subproperty-list would contain special attributes whose values were the basic relation involved and the string of £-quantifiers which produce the link-predicate from that basic relation. An additional item on the subproperty-list could identify the argument-position of the described object, thus eliminating the need for more than one symbol (corresponding to the attribute-link symbols of SIR) for each basic relation. With this representation no special symbol assignment or other anticipatory action is necessary in order to add new link-predicates to the model. Any link-predicate recognized by the input program and based on an available basic relation is representable.

The names of object-predicates should be another kind of attribute which may appear on SIR1 property-lists. The object-predicates should themselves by SIR1 objects whose property-lists contain their definitions as SIR1 wff's. In this way object-predicates may easily be defined or applied to new objects.

In summary, the basic objects in the SIR1 model are the words which denote: individuals, classes, basic relations, and object-predicates. A property-list is associated with each basic object.

Attributes in the descriptions of individuals and classes are either the names of object-predicates, or themselves property-lists which describe

and a second of the second

link-predicates. If lists describing link-predicates, the values corresponding to those attributes give the other objects associated with the described object through the described link-predicate. The property-lists of basic relations contain the axioms which specify properties of the described relations. The property-lists of object-predicates contain the definitions of the object-predicates in terms of SIR1 wff's.

2) The Theorem-prover: In paragraph 8.2 above I presented a decision procedure for testing the truth of any STR1 sentence with respect to a given SIR1 model. Unfortunately, that procedure is impractical since it requires the enumeration of every object and every link in the model, and the consideration of every known logical truth in the course of each truth-test. Clearly these procedures would involve an inordinate amount of time. Also, I have gone to great lengths to develop a model structure which enables the system to save time by having information organized and accessible in a convenient way; the above-mentioned decision procedure completely ignores the structure of the model.

Instead of an impractical decision procedure, I propose that SIR1 use a heuristic Theorem-Proving program ("TP") for its truth-testing.

The will start its truth-testing with the most relevant axioms and model linkages, introducing additional facts only when needed. The model structure will dictate what constitutes "most relevant," as will be explained below.

The best example of a heuristic theorem proving program in Newell and Simon's "Logic Theorist" (LT) (27), a program which proves theorems

in the propositional calculus. Since TP will be modeled somewhat after LT, let us consider the general behavior of LT. LT must be given a list of true theorems or axioms, and a statement (the "problem") whose proof is desired. The system tries to prove the test-statement by showing that it, or some statement from which it can easily be deduced, is a substitution instance of a true statement. The true statement must be either a theorem or a statement whose proof is easily obtained from the list of theorems. LT has several methods -- the principal ones called chaining, detachment, and replacement -- for creating statements from which the problem statement can be deduced, and for selecting "relevant" theorems from the theorem list. LT also contains special devices for keeping track of sub-problems and keeping out of "loops."

IT was designed largely as a model of the behavior of naive students of logic, and is reasonable successful as such. It has not been a very effective theorem-prover, partly because its methods and selection heuristics are not powerful enough, and partly because the problem domain -- the propositional calculus -- has a simple decision procedure (46) which makes any alternative approach seem weak. TP must deal with a more complicated problem domain than that of LT. It is concerned with a domain containing a possibly large, although finite, number of objects, relations, and axioms. Also, the objects and relations as well as the axioms may be changed from problem to problem. However, the actual proofs of SIR1 sentences by TP will, on the average, be shorter and simpler than typical LT proofs. After all, TP parallels the human mechanisms for recalling facts in memory and doing some simple ressoning, not for solving formal mathematical problems. Development of elsborate logical ability in a computer must come after the achieve-

ment of our present goal: a mechanism for simple, human-like communication. Deductive methods similar to those of LT should be adequate for TP, provided we can provide a mechanism for selecting the "most relevant" true facts from which to start each deduction; and of course the central information organizational device of STR and STR1 -- the model -- is just such a mechanism.

Therefore, I propose that TP contain the same deductive methods as LT, and in general be patterned after LT, with the following important exceptions:

- a. In trying to apply its methods, LT always scans the complete list of true theorems. TP should initially attempt a proof with a small list of "most relevant" truths extracted from the model. If the proof methods fail, the list of truths should be gradually expanded until the "relevant" portion of the model is exhausted; or, more commonly, until the specified time or effort limits have been reached. One method of generating "relevant" truths for the proof of a SIR1 sentence  $\underline{S}$  is the following:
- i) Let B= the set of all basic relations which appear in S. Let F= the set of all object-names in the model which appear in S as arguments of members of B.
- ii) Construct a truth list consisting of three parts: those axioms which appear on the description lists of the basic relations in B, those link-predicates which involve relations in B and which are described by attributes of objects in F, and those axioms obtained from object-predicates which appear on the property lists of objects in F.

If a proof cannot be found, the initial truth list can be expanded by enlarging B or F in any of the following ways, and then repeating step ii):

iii) Add the "¿" relation to B. This relation is important for deductions which involve transforming or removing {-quantifiers.

- iv) Add to B any new basic relations which appear in the current truth list. Whenever basic relations interact, an axiom on the property-list of one will name the other, thereby introducing it into the system. Also, axioms from object-predicates may introduce new basic relations.
- v) Add to F all object-names which appear in <u>values</u> of those attributes of objects already named in F, which involve relations already named in B.

Each iteration of step iv) or v) and step ii) will add facts to the truth list which are more indirectly related to the test sentence than any facts previously available. When no new facts can be added in this way, the truth list will contain all the information in the model which may be relevant for the desired proof. However, I expect that in most cases true sentences will be provable from a truth list obtained in very few iterations.

b. SIR1 is concerned with the truth of relational statements with respect to the model, whereas LT is concerned with the universal truth of logical propositions. The ultimate test of the truth of a sentence in LT is whether or not the sentence is a substitution instance of a known sentence. The corresponding ultimate test of the truth of most SIR1 sentences is whether or not certain links exist in the model. Every SIR1 sentence is a propositional function of link-predicates. A link-predicate is true of the model if it exists as an explicit link in the model, or if it can be deduced from axioms or higher-order link-predicates explicit in the model. Therefore, for the ultimate test of the truth of a link-predicate, TP must contain subprograms for eliminating  $\mathfrak{E}$ -quantifiers. For example,  $(\forall \alpha \in x)[P[\alpha]]$  is true of the model if  $P[\mu]$  is true of the model, for every object  $\mu$  such that  $\mu \in x$  is true of the model. Thus, the  $\mathfrak{E}$ -quantifier structure of SIR1 sentences serves as an important guide for the theorem-proving program.

c. The problem of implementing the "Exception Principle," discussed in Section A.3.c above for SIR, is still with us in SIR1. This means that the use of different sets of "truths" extracted from the model may lead to different answers to the same question. The solution to this problem is simply to be very careful in building and expanding the list of "truths" used by TP. I believe the iteration described in a. above is adequate, since it introduces the most closely related facts first. However, some experimentation in this area, once a working TP system is developed, will certainly be of interest.

In summary, an English question should be answered "yes" by the generalized semantic information retrieval system if and only if TP can prove the truth, with respect to the model, of the SIR1 sentence which corresponds to the question. TP attempts to prove the truth of sentences by going through the following steps:

- i) Test whether the sentence is immediately implied by direct links in the model.
- ii) Create a list of the axioms and link-predicates in the model which are most closely related to the sentence. Attempt to deduce the truth of the sentence from this list of truths, using both logical transformation methods such as those of LT, and model-dependent methods such as elimination of  $\xi$ -quantifiers.
- iii) After a reasonable amount of effort, add to the list of truths the axioms and link-predicates which are next-most-closely related to the sentence.

Repeat steps ii) and iii) until proof is completed or abandoned.

Note that TP operates in the finite domain of the propositional calculus. No provision has been make for true quantificational deductions, such as proving in general

$$(\exists y)(\forall x)P[x;y] \Rightarrow (\forall x)(\exists y)P[x;y]$$

Therefore TP could not, for example, perform the derivations of Appendix II which relate SIR and SIR1. The problem TP does attack is that of selecting relevant information from a large (although finite) store in order to construct proofs efficiently. Of course, a similar program for quantificational deduction would be a welcome addition to TP.

3) Complex question-answering: Some of the questions which SIR can answer require the system to perform more elaborate information retrieval tasks than simply testing the truth of an assertion. The answers to questions like, "How many fingers does John have?" and "Where is the book?" must be computed by searching and manipulating the data stored in the model in order to create appropriate responses.

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Let us define a "question type" as a class of questions whose answers are found by following the same computational procedure.

Questions of the same type generally differ from each other by referring to different objects in the model; those object-names are inputs to the computational procedure. In the previous sections we have considered the special type of all "yes-or-no" questions. In SIR, this class of questions was considered to be made up of many different question types -- one for each SIR relation -- and there was a corresponding multiplicity of computational procedures. In SIR1, the computational procedure for all "yes-or-no" questions is simply TP. However, TP requires as an input not just the names of objects, but rather the complete SIR1 sentence which corresponds to the question.

Unfortunately, no other SIR question types can be combined easily for a more general system. Each question type requires a different

procedure for searching through the network of links, identifying useful information when it is found, and manipulating the information to produce the answer. Computer programming languages are well suited for specifying computational procedures, and for reasons described in Section III.A, the LISP language was quite convenient for specifying the complex question-answering procedures of STR. However, as one attempts to enlarge and generalize STR it becomes obvious that these programs should be made easier to write and easier to understand wherever possible. The full generality of LISP must be kept available, since new question types may require, in the answering process, unanticipated kinds of data manipulation; but the devices described below may be used to simplify the construction of question-answering programs.

In LISP, the flow of control within a program is normally determined by special functions called "predicates." The LISP system evaluates each predicate according to built-in or separately provided evaluation procedures, and chooses the next operation to performed according to whether the value of the predicate is "T" or "NIL" (corresponding to "true" or "false"). The STR1 procedure-specification language should be similar to LISP, but should also allow the use of an additional class of predicates: namely, statements whose LISP values are "T" if a particular STR1 sentence is true with respect to the model, and "NIL" otherwise. The procedure for evaluating these additional predicates would be just the procedure ordinarily used by STR for determining the truth of STR1 sentences, namely TP. Thus the full power of the STR "yes-or-no" type of question-answering procedure could automatically be used within the procedure for

answering a more complex type of question. Suppose that in the course of the procedure for answering the question, "What is the relative position of x?" it is determined that y is to the right of x and also that a z is to the right of x. The procedure could then contain the statement,

if  $(\exists \alpha \in z)[\text{rightb}[\alpha;x] \land \text{rightb}[y;\alpha]]$  then go A else go B where A and B are locations of appropriate further instructions in the procedure. The procedure writer need not consider how to answer the question, "Is a z between x and y?" for TP will do that for him to be a second of the procedure writer need not consider how to answer the question, "Is a z between x and y?" for TP will do that for him to be a second of the procedure writer need not consider how to answer the question.

As a special application of this method for procedure-writing, let us consider how to obtain "no" or "sometimes" answers to questions of the "yes-or-no" type. The existence of separate programs for each relation in SIR permitted the consideration of special properties of the relation in determining an appropriate replying In our generalized system, TP can reply "yes" if the SIR1 sentence & corresponding to the question is provable; otherwise the reply must be "insufficient nationals and the laws information." Although a "no" answer cannot be obtained by TP directly, we can build into TP the ability to make a negative reply if it determines that the sentence ~S is provable; but no general change to TP can account for special properties of individual relations. However, this flexibility of SIR is recovered in the generalized system, without relinquishing any of the uniformity and generality of the SIR1 formalism and the TP program, by the use of simple procedures written in the LISP-plus-TP specification language. For home example, the procedure for answering the question, "Is an x a y?" might be as follows:

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if  $(\forall \alpha \in x)[\alpha \in y]$  then YES;

else if  $(\forall \alpha \in x)[\sim \alpha \in y]$  then NO;

else if  $(\forall \alpha \in y)[\alpha \in x]$  then SOMETIMES;

else (INSUFFICIENT INFORMATION)

There remains the problem of implementing the specification language on a computer. When TP is available, it will be a simple matter to design an interpreter which would route control between TP and the LISP interpreter. Whether a compiler for these procedures is feasible depends on many factors, including the precise form of the TP system.

The point here is that implementation of this procedure-specification language, a key part of the generalized semantic question-answerer, is feasible at the present state of the programming art.

Leaving backs by the Thermost wors

In summary, a simple formalism has been presented which adds to (o galiādinas erās) ខេត្តប្រាក់ក្នុងនេះ (anstrum) មាន ស្រីក្រុមិន មិនប្រាក្សិត បានប្រាក្សិត LISP the truth testing power of TP. of This procedure specification. Then the type decision then the color of language, together with the SIR1 formalism, a corresponding wordassociation model structure, and the TF truth-testing program, constitute will be a constitute to be a second of the second of t tute the basis for a "generalized" semantic information retrieval system. the marker descended in Chapter On the basis of information gleaned from the development of SIR, I have been able to describe this "generalized" system which has all the bon នៅទៅមាន ខ្លួនបញ្ជាប់។ ដែលនេះ ខេត្តការនេះ ។ បានមួយប្រជាជន្តរ មា (១៩) នៅ នៃសម្រាប់ នេះ question answering ability of STR and accepts a much larger class of questions. More importantly, new relations can be added to the សុខជាសាហានី និស្សាសាក្រាល សាហាក្រាល and the property of the state of the "generalized" system and the axioms of its proof procedure can be ్ఖాగు, ఈ ఏ ఏలల కాల్ నగ్ గడు అందుకాంతున్నాని. చిప్పి ఇంటే ఇచ్చా నుండుకున్నాని అనికా నినియోక్ కాన్ కి modified without any reprogramming, and question answering procedures บอักษณะ อักษาอยู่ สักระการกำหรือจาก กรอง กุล อีกระดูรสุดราชุติ can be introduced and modified much more easily than they can be in SIR.

## Chapter VII: Conclusions

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A. Results.

- 1) Question-answering effectiveness: Chapter I described how

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  question-answering behavior is a measure of a computer system's abil
  ity to "understand." SIR represents "meanings" in the form of a word
  association, property-list model. As a result SIR is more general, more

  powerful, and, judging from its conversational ability, more "intelligent" than any other existing question-answering system. With respect
- to the fundamental problems of the other systems discussed in Chapter II:

  The point berg is that implementation of the other appearance is that implementation of the other in the course of the other in t
- a) SIR is not limited to a rigid prepared data structure and corresponding programs with specific, built-in, ad hoc definitions of "mean-arings" as is the "Baseball" program. Rather, it constructs its data structure as information is presented to it, and interprets "meanings" from "learned" word associations.
- b) SIR is not restricted to the sentence-by-sentence matching of:
  Phillips! "Question-Answering Routine " Instead the SIR model proj 927 I
  vides access to relevant stored facts in a direct, natural way.
- c) SIR, unlike SNYTHEX, does not require grammatical analyses which become more detailed and more complicated as the system expands in Incass stead, question-answering is based on semantic relationships, and the program structure can be simplified while enlarging the scope of the just system in the manner described in Chapter VI.
- d) The SIR model is not tailored for a single concept like the family relationships of SAD-SAM. However, the property list structure of the model can easily be used to represent various special-nurpose models and thus take advantage of their benefits, while permitting the storage of up any relational information.
- e) The SIR system is not restricted to testing the universal truth of a complete statement, regardless of the meanings of its components, as is Darlington's program. Rather, SIR procedures can be devised to answer any form of question, and the answers are based on SIR's current boundaries as determined by word associations in the model.

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f) Although conceptually similar to Bennett's word relation system, SIR represents a vast improvement in that its list-structure model permits a direct representation for arbitrary word relations; the system contains programs for handling several different relations and their interactions; and both input formats and program logic may easily be modified.

of a common, be a such interespent of galage where blood reso were

ably natural communication between people and computers. Although somewhat stilted, both the input and the response languages used by SIR are sufficiently close to natural English to be easily understood by an untrained human. The input format recognition process used in SIR (Section IV, B) illustrates how far one may go toward "understanding" natural language, in the sense of recognizing word associations, without reference to grammatical structure. Of course, such a scheme cannot be generalized to cover any large portion of a natural language. It was used here simply as a device to get past the input phase and into the problems of representation and retrieval. However, this format matching process can easily be expanded to handle any sufficiently small portion of English.

Even in its present primitive state the process is not excessively restrictive to the untrained user. With the present system, the user could be instructed to present in complete English sentences simple facts and questions, and not to use any sentences with subordinate clauses, adjectives, conjunctions, or commas. These sentences may be about class relations, part-whole relations (possibly involving numbers), possessions, and left-to-right ordering relations. When used in a time-sharing environment (11) in which each sentence receives an immediate response, the system would have the effect of a "teaching machine"

in training its user to restrict himself to recognizable sentence (the forms. After a few trial runs the programmer can easily add any new management of a sentence forms which frequently arise, thus improving the chances of success for the next user. If this training process is too slow, the new user could study sample conversations from previous tests, or refer to an outline of available formats, before composing new statements to SIR. These processes are much simpler than learning a "programming" language. A sorted list of formats and more sophisticated similarity tests in the matching procedure would allow the addition of many more formats to the system with no corresponding increase in time required for recognition.

At the output end, the system demonstrates that "Intelligent" responses are frequently possible without an elaborate generative grammar,
as long as one can anticipate the classes of responses and frame each
class in a suitable format.

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The model: An important feature of SIR is the flexibility of the property-list structure of the model. Independent or related facts can automatically be added to or extracted from the system, and the same data may be expressed in more than one way.

Several existing computer systems, e.g. airline reservation systems, permit dynamic fact storage and retrieval. However, they depend upon the use of fixed, unique representations for the information involved. In SIR, there can be many representations which are equally effective in providing correct answers. E.g., the system "knows" that the statement, "A finger is part of John" is true if (a) there is an

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explicit part whole link from FINGER to JOHN; of if (b) there are links by means of which the retrieval programs can deduce that a finger is part of a person and John is a person; or if (c) there are links by means of which the retrieval programs can deduce that a finger is part of a hand, and a hand is part of John; etc. In addition, the system can automatically translate from one representation to another having some advantages. E.g., the streamline operation described in Section.

V.B., reduces storage space requirements by removing redundancy in the representation, without making any changes in the system.

The property-list model turns out to have advantages even when another form of model seems more natural. For example, left to right spacial relations seem most easily represented by a linear ordering; but i.e., mx is to the left of y' could be modeled by placing x anead of some y in a left-to-right list. However, incomplete information can cause throuble for such a model. If it is known that x is to the left of y' and z is to the left of y, the linear ordering system cannot suniquely model the relative positions of x, y, and z is the property of the pr

consiler of the entropy of and the entropy of the entropy of

<sup>4)</sup> Present state: The processing time per statement for the SIR 90 system with a standard LISP configuration on an IM 7094 computer with 5123 32K words of memory was about one second. All the examples prepared for Figure 1 and Figure 5 of this paper, including loading and compiling

all programs, took about 6 minutes of gomputer time. The SIR system, and the relations, processing programs, and language formats described in this paper, utilizes almost the full capacity of the computer.

any particular practical question answering problem. Enth consists not a second collection of relations which were introduced, as described in Saction of the model. These relations do not make the particular practical questions and possibilities and of the model. These relations do not make the particular structure and possibilities and of the model. These relations do not make the particular structure and possibilities and full or logical relationships to each other and them are not structure and the model.

auccessful in the sense that it has demonstrated the suggest defines of the first word association property list model and it has an extendent entering the described in Chapter Wishich extendes the duses of the first same model.

The scope of the present system indicates that it would be feasible to use the SIR model and present program organization in a practical information retrieval system for an IRM 1090 size computer, provided the system involved a reasonably small number of relations whose interparties actions are clearly understood. One possible application is a record trieval system which has been proposed at the RAND reprosestion formation about documents in Soviet cybernetics (24) In their system then users will be interested in indirect relationships and implications, as well as the storage and retrieval of apecific facts concerning authors and subjects of technical papers to decide a second concerning authors

52% words of memory was about one second. All the stamples propered for Right's I am Rights This paper, the aution loading and worpities

- 5) Question-answering details: The following points, although obvious in hindsight, did not become apparent until the program was
  fairly well developed:
- a) A question-answering system cannot give definite negative replies without special information about the completeness and consistency of its data. The fact that SIR does not have such information accounts for frequent occurrences of the "INSUFFICIENT INFORMATION" response in places where a clearcut "NO" would be preferred.
- b) If x stands in relation R to y, then a one way link, e.g., from x to y through attribute R1 on the property list of x, may be sufficient for most question-answering applications. Nowever, in the course of expanding the system the reverse link, from y to x through attribute R2 on the y property-list, may be much more convenient. To allow for any eventuality in a general system both links should be provided from the start. Two-way links also provide the accessibility needed to experiment with various tree-searching procedures.
- c) It is frequently possible for search procedures, even when unsuccessful, to provide extremely useful information to the user or programmer by specifying why they were unsuccessful. This point is discussed further in Section IV.C.

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- B. Extensions of SIR. The resemble of the section is the section of the section o
- 1) Adding relations: Two major obstacles, in addition to computer memory size, stand in the way of extending a SIR-like system by adding new relations and their associated programs: (a) the problem of interaction between a new relation and those already in the system, requiring modifications throughout the system for even minor additions; and (b) the problem of the time required to search through trees of words linked by relations. This time apparently must grow exponentially as the number of relations increases.

The problem of interactions can best be overcome by replacing SIR with a generalized system. As discussed in Chapter VI, this change would greatly reduce the interaction problem and simplify the introduction

of new relations. In addition, the programs would probably be significantly smaller in the generalized system. Not only would all "yes-or-no" type question-answering programs be replaced by a single, "theorem; proving" program; in addition, the procedure specification language of the generalized system would result in more compact, as well as more readable, programs.

The other obstacle to the expansion of a semantic information recough attribute &1 on the program with all trieval system is the same obstacle which occurs in programs for theorem proving, game playing, and other areas of articifical intelligence and doud wajeve las the problem of searching through an exponentially growing space of possible solutions. Here there is no basic transformation that can be HIMBBE TO made to avoid the mathematical fact that the number of possible interconnections between elements is an exponential function of the number of elements involved. This means that in SIR, the time required to search for certain relational links increases very rapidly with both the number of individual elements which can be linked and the number of different relations which can do the glinking. However, many of the heuristics for reducing search effort which have been suggested in ... other areas concerned with tree-structured data can be applied here.

ent (non-interacting) groups; e.g., spatial relations are quite independent of temporal relations. The search space affected by a new relation is really just the space of interacting relations; which may be a
very small subset of the total space of relations. The axioms of the
generalized system can be used to identify the groups of interacting relations. Secondly, the existence of two-way links permits the search

and the contract of the contra

for a path between two points in the data structure to proceed from to visite by the "reffer force of the either end (whichever is likely to produce a more efficient search), Amino alimpin ed a misambera traba ibadope i na R or possibly from both ends simultaneously toward an unknown common Cardi adi Lareibrage vilses the band point. Finally, semantic information in the model might be useful in ា ស ស ភាពបាន**រាស្លាប់ និងលាស ខណៈ ១**៣៩ នេះ ស្រែ ១០១៩ឆ្នាំ suggesting intermediate points to use as "stepping stones" in a larger ាននៅរា កន្លងរបស់ស្ត្រីស្តាំស្ត្រីស្តី មូលថា នេះការ ខ្លាំងបែកស tree search, thus greatly reducing the search effort. I believe that ver distribute a la collega apparatada se la t the use of these and similar heuristic devices, along with expected in-ំ ១៣ ទេស ទៅស្នេក ១៩៩ ស។ ក្រៅបានមាន១១៩១៩ creases in computer speed and memory size and the introduction of parallel i. Man ini jis bere i ugʻtak sa ib bibab direk processing computer hardware, will make a large-scale semantic informa-Content of the second of the second party tion retrieval system practical.

- 2) Adjectives and n-ary relations: All the relations in the present system are binary relations. The model can be extended to handle arbitrary n-ary relations as follows:
- r ban in S 🜶 🕻 A south night o a. Unary operators could be simply flags on the property lists of the objects to which they apply. Or, if for purposes of uniformity we forbid the use of flags, then they could be attributes whose values ည့်ရှိ လေသင်းသောသည်။ မိန်းသော်မြောင်းသည်။ နှင့်သော အားမက်မ are always a dummy symbol which indicates that the attribute is to be ใฐเลาสอยอย 9 ปี ปี อสาก **3**ปี. interpreted as a unary operator. In handling adjectives, the following borki Hadeo wo dolot yishiil odt decision would have to be made: should an adjective be modeled by an s char and omen besiden od block Will unary operator, or should it be the value of some attribute? For example, THEOL The daily legary will constitute "little red schoolhouse" could be represented in the model in any of the (BOCK: JIM)) " the property of the Lorenty following ways: THE PORT OF THE SECOND OF THE
- ii) The same object, which has on its property list the attribute ""MODIFIERS" with associated value "(LITTLE, RED)."

iii) The same object, which has on sits property list the attribute-value pairs "(SIZE, LITTLE)" and "(COLOR, RED)."

without on a collider on is dikely to produce a more lifetimate searchi, The second representation is equivalent to the first but avoids the Don'there tros back ends edwellere een the teware as anknown common need for unary operators. The third representation contains the most nt ludoge od idgim fotor iki se a literator ni deliki kiliki i in information and is most consistent with the present form of the SIR segment a militaraman garagata" ee ee oo maalag verebus oo e militaraga k model, but has the disadvantage that it requires the use of a dictionary mans evention to the Alexander education reduction of the Alexander Alexander (Alexander Alexander) to establish appropriate classifications of adjectives. The "best" ent becomple this goods repaired attenues as tone and settle a comment of representation to use would have to be determined by experimentation affire to be recognized to the contract of the and would depend upon the organization of the information retrieval Participation of the mean of the group of the first operation and the admitted of the participation of the contract of the con programs which use the model.

b. Trinary (e.g., those involving transitive verbs) and higher order relations could be represented in various ways analogous to the treatment of binary relations. <u>E.g.</u>, the n-ary relation <u>R</u> can be along the property of the property o

logic received the beautiful to their

$$\langle x_1, x_2, \dots, x_n \rangle \in \mathbb{R}$$
 if and only if

 $\langle x_2, \dots, x_n \rangle = \mathbb{R}1[x_1] \wedge \langle x_1, x_3, \dots, x_n \rangle = \mathbb{R}2[x_2] \wedge \cdots \wedge \langle x_1, x_2, \dots, x_{n-1} \rangle = \mathbb{R}n[x_n],$ 

ear jog Die kan 180 efte be where the value of the attribute  $\underline{Rj}$  on the property list of  $\underline{xj}$  would be of or all administrations of the new bound of the lettings conside a square set the ordered sequence  $(x_1, \ldots, x_{j-1}, x_{j+1}, \ldots, x_n)$ . More specifically, quivolion and the variable  $(x_1, \ldots, x_{j-1}, x_{j+1}, \ldots, x_n)$  the edge of the letting  $(x_1, \ldots, x_n)$  and  $(x_1, \ldots, x_n)$  the edge of the letting  $(x_1, \ldots, x_n)$  and  $(x_1, \ldots, x_n)$  the edge of the letting  $(x_1, \ldots, x_n)$  and  $(x_1, \ldots, x_n)$  the edge of the letting  $(x_1, \ldots, x_n)$  and  $(x_1, \ldots, x_n)$  the edge of the letting  $(x_1, \ldots, x_n)$  and  $(x_1, \ldots, x_n)$  the edge of the letting  $(x_1, \ldots, x_n)$  the edge of the edge of the letting  $(x_1, \ldots, x_n)$  the edge of the trinary relation established by the statement, "John gave a book to discussed to the save of contract and the same of the save of the Jim" could be factored into the three relations "GIVER," "GIVEN," and ကိုရိုက္သန္လေ ကိုယ်ကို သိုင္းသည္။ မိုင္းေရးမွာေသည္ သည္သည္။ မိုင္းေသည့္ မိုင္းေသည္ မိန္းေတြကို မိုင္းေတြကို မိန "GETTER." The propety list of "JOHN" would have the pair "(GIVER, with all you are lighted cars as the breeze eyes of elegic Treated books, but with (BOOK, JIM))," the property list describing "BOOK" would contain "GIVEN, (JOHN, JIM))," and "(GETTER, (JOHN, BOOK))" would be placed on dodako o**ne <sup>it</sup>. 9. ič**kuroj**ić?** – mis – ki ko juseci se sisjini kastev drojic ob j "JIM's" property list: Once again, the practicality and afficiency of it such a representation can only be discovered by developing and experi-Profile Company Set of the Contant of the Caucal Office menting with working computer programs.

3) Next steps: The present SIR system, and its generalized version discussed in Chapter VI, are only first steps toward a true "understanding" machine. Eventually we must solve the "advice-taker" problem (22), which involves controling the operation of the machine merely by "advising" it, in a suitable English-like language, of the desired procedures or results.

One approach to the "advice-taker" is to develop programs which can produce other programs in accordance with simple instructions.

Such program writing programs could be an outgrowth of current work on computer language "compilers," if the input and output forms are sufficiently well-defined. Simon (39) is working on this approach by developing a system which accepts a broad range of English statements as input to such a program-writing program.

SIR suggests an alternative approach. Rather than developing a program which writes other programs to do specified tasks, I propose we develop a single, general program which can do any task provided the program is properly controlled by information in its model. "Giving advice" would then require only the relatively simple process of inserting appropriate control information into the model. The SIR model provides its programs with information about the truth of particular relations between specific objects. The model in the generalized system also provides the "theorem-prover" program with axioms which describe properties of relations and interactions between relations. The next generalization should involve adding to the model information which will specify and control theorem-proving and model-searching procedures for the program.

 After the above two approaches to an "understanding" machine have been developed independently, they should be synthesized. The program-writing program should be incorporated into the general program of the model-dependent system. The resulting system would then be able to construct arbitrary procedure specifications, in accordance with simple instructions which had been placed in its model.

Ultimately the "intelligent" machine will have to be able to absorded and struct from the information in its model, "realize" the necessity for additional action, and create the necessary instructions for itself.

The design of such an "artificial intelligence" awaits the development of automatic concept formation and inductive inference systems (20,41) as well as the generalizations of SIR described above.

input it such a program-writing program.

## C. Concerning Programming.

written after the development of a large computer program such as SIR frequently appear as if they could have been established without the tedious effort of programming. This is rarely true, and in fact, new systems which are described as complete "except for the programming" usually require fundamental modifications if and when they are translated into operating programs. The reasons for the importance of actually writing operating programs. The reasons for the importance of actually writing the program include the following:

program which writes other programs to relations of the same to the

- a) Without a program it is extremely difficult to tell whether the specifications for a system are really complete and consistent. Crucial decisions may be considered minor details, and contradictions may go unnoticed, until one is compelled to build an operating system.
- b) The process of programming not only turns up fallacies in the specifications for a system, but also generally suggests ways for avoiding them and improving the system. Thus programming can be much more valuable than just searching for errors in the original specification. A

completed "debugged" programmed system usually turns out to be a compromise between the system as it was originally specified a simpler system which was more feasible to actually construct, and a more elaborate system whose new features were thought of during the programming process. This resulting system is frequently as useful and certainly more reliable than the originally specified system, and in addition it may suggest the design of even more advanced systems. With SIR, for example, methods for implementing the "exception principle" and resolution of embiguities arose from the design of the basic question-answerer, and the specifications for the generalized system of Chapter VI are based largely on properties of the final, working SIR system.

- c) The programming process frequently turns up insights which might not otherwise be discovered (see for example paragraph A Instead of the control of the c
- d) Finally, the resulting program provides at the same time and emenstre of tion of the feasibility of the ideas upon which it is based, a measure of the practicality of the system instems of time and space requirements and an experimental device for testing variations in the original specifications, as a condition of the process of the first of the firs

find cacceeding words, and Tree. The the court by a corresponding to be upon the

procedure would simplify coding and allow the programmer to concentrate on the more important problems of program organization and search strategies. Such a standard representation would have to be flexible enough to handle the most complicated cases. In SIR, the uniform use of only typeros 1 links or all property-lists and only type-1 links on all property-lists and only type-1 links on all property-lists and only type-1 links on all sub-property-sists would probably achieve the desired result colonsatemative, some-what more complicated (but more economical of storage) way to addieve the same result of freeing the programmer from concern for details, would be allow several kinds of linkages to be used wherever they were best suited (e.g., type-1,-2, and -3 links) but require all retrievel grams to be able to recognize the type of a link and treat each one same appropriately.

ages were used in the generalized system, the mature of the links

appropriate for particular relations could be stored in the model on the completed "bobyscon a accordance description as more relations." In this way the type-life in this "following by the type-life in this "following the control of the relations of the control of the contro

3) Programming tree-search: "In order to handle some of the respectively

atose from the design of the basic question-answerer; and the specific trions and tohib wint 5 and 2 and 2 and 5 and 5 and 5 and 5 and 1 as a sorq lavely the sort the final, weeking SIK system. The facility in the LISP language for defining functions of functional e). T**he propra**mming process Grego attivitions of theights which authorized arguments permitted the design of programs providing a powerful ability to specify complex search procedures. For example, one of the most susetion of the feasibility of the ideas againmented it is based to be asure ful functions was offind[start; link; test]; in where detartdecanobe and to and an unperimental device for feating varieties in the estation's speci word in the model structure, "link" specifies which attribute to use to see find succeeding words, and "test" is the name of a function to be applied in turn to each word reachable from "start" abong the Rind of path specified by "I pake" of the value of " rest" appleed to alwood is the special of symbol "NIL," the search continues; otherwise the value of maind fand and the result of the search) is fust the value of thest. This result may 2012 contain the word which satusfied the fast and the saccessful path page exposi the list of words which link "stant" to the selected word in the desired way. Note that sthe function "find" can be cascaded, i.e., "test" can be another application of "find" itself. Big., In testing whether every A TERM is part of some B, we may wish to test whether there to a class u such some that every A is a u and every u is part of some B. This test is carried out simply by executing the following function (given in LISP meta-2) beares language motation); and testing whether tis value is "NIL" or not! at among

find[A; SUPERSET; \[[u][find [u; SUPERPART-OF-EACH; \[[v][v=5]]]]].

If a uniform representation (as described in paragraph 2, above) had been used throughout SIR, then it would have been easy to develop a see a season.

The second secon

complete set of general network-tracing functions like "find." Such a set of functions could be the basis for a language which makes programming tree- and network-searching systems much simpler than it is now. Such a il englis sa Bisage angut mola gerithass language might thus contribute to research in the areas of pattern recogni-Cassir serius aegres esitore esta tion, game-playing (36), and network analysis as well as semantics and inaractics![ស្ងប់ ជំអ្នកស្រុសស្រុសស្រុស ប្រ formation retrieval. Note that the success or failure of an application ម ស្នងស្រាក់ **នូកជ «មា**ណ្ឌស្នា រូបស្នែក **ស្នស (នរិញ្**យស្នេក ១១៤ of the function "find" depends only on the connectivity of the network; no ochoro s no opinim di ante i cista della con the order in which nodes are generated and tested, and therefore the . Son and greek two saldsometer ville. efficiency of the system for various kinds of networks, must be decided regulation of the restriction of the section with in advance and built into the definition of the function.

4) Program simplification: The "procedures" presented in section

V.A. which were described as "rough flow charts" for the retrieval programs,

may seem unnecessarily complicated. This is true for the following reasons:

grafic grant (very the first of the state of the first first against a decrease viliables of state

- a) Each procedure was written as an explanation of how a particular program operates, and the place of these programs in the over-all program structure was de-emphasized to avoid confusion. There is must more hierarchical structure and use of common subroutines in the actual SIR program than is indicated in those procedures.
- b) As with most programming tasks, many possible simplifications occur to the programmer as after thoughts. If I started over now, I could certainly construct a nester, more compact SIR system -- especially by incorporating some of the ideas discussed in paragraphs 2 and 3 above. However, I would be more inclined to ignore SIR altogether and instead start programming the generalized system of Chapter VI.
- c) Unfortunately, many of the "simple" reasoning procedures the program must go through really are complicated. It was surprising to me how many possible routes one may take to deduce a simple fact like. "A is part of B."

് പ്രവാധ പ്രവാദ്യ ആരം പ്രവാദ്യ വിവാദ്യ വിശാഗ വിശാഗ ആര് അവ വരു വിധാനം വ്യാദ്യ ആര് വിജ്യ വേഷ്ട്ര ക്രിക്ക് വിവര്

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സംഗ്രാധ്യക്തും വിവേദന് അവസാന് സംസ്ത്രാസ് ആദ് ഒന്നു വിജോഗിക്ക്കാര് വിഷ്ട്രാസ് വിഷ്ട്രീ മേഴ്യന് വിവേദ

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and they are the compared to the compared the state of the state of the compared the compared to the compared

- D. Subjects for Future Experiments.

  Entire 3 of the subjects of the subject of the sub
- the control of the Alam Alaka ognicial a tree sound off to bluer sacintumba to the 1) Search procedures: The relative merits of different treesearching procedures should be investigated, since any device which signifi--lagroup madding to researche of the spanning admits those and ideal agreement cantly reduced search effort would be a valuable contribution to the iono game∗playing (36), and nethond enaltils as th practicality of SIR-like systems. In seeking a path between two nodes, not boaring, as is staffed no assessed add task both. (avoisted notificated) for example, one might compare the procedure of moving one ply from each is the indianal factor of the content end, alternately, and looking for a common node, with the procedure of the <u>Circui</u> in which notes are gonerated and . Notes, and the fellow too continually branching out from one node, searching for the other. Even follows of team, advantage to all a series of motove odf is yearstifted. this latter procedure can be performed in either a "breadth first" or a more naturally recursive "depth first" manner. While the first procedure mentioned above cuts the effective depth of a successful search in half, Maaynbabook rogram romplification: That it also introduces matching problems in order to recognize success, and V.A which were described as "roput flow charter for the retry laterage. makes it more difficult to discover the complete successful path. Which imy seem caacessarily complicated. This is that the The Tallowing regions; of the various procedures is "best" will depend on the size of the networks, e). Dach procedure was urilinan as an confament of the love particular pr the relative frequency of success, the average Pength of successful paths; itraciere was dereappasized to aveid cociesies. There i vert more bieretc. Therefore the best way to determine the most efficient methods is grow item is indicated in those procedures. to experiment on an operating system, preferably with respect to a parh) os with most programming tasks, mong gorelass. co the programmer as atten thoughts. If I is also 1170 860 ticular problem area. cainis consumat a mealer, represende especie especie especie in apparent a ్రాయ్లో ద్విధ 2019ల ఆర్మ్ ముందుకుల్లో కార్యులోని ఆర్మిక్స్ కార్యులోని కేట్ ఆయుక్షామ్ ముందుకుల్లో మేకుండానికి మ
  - should be investigated. One might expect a trade-off here between space and time; i.e., that a removal of redundant links, for instance by "streamlining" operations, should save storage at the expense of increasing the average question-answering time, while introducing redundant links, for instance by adding as explicit links all question-answers which are successfully obtained, should use up space but speed up the question-answering process. However, this trade off is not strictly necessary.

ever, i weble be mare authoral to force els occor els ani casterdent to

they use time by requiring spurious parts of the network to be stardhed! Which redundant links to weed out, as well as which search procedure to use, depends on the characteristics of the model and questions in a particular application and must be determined by experimentation.

Another structuring problem to be considered is that of consistency?

At present SIR tries to test the consistency of each input sentence with the information it already has stored, before adding the new relations to the model. It might be more efficient to biindly accept each imput and then check the consistency of the model from time to time, say between input sentences; a complianting of the problems and occur. This procedure would give later information equal precedence on the problems and with earlier inputs, which might be a preferred arrangement for some appropriations.

Ambiguity in language: An system similar to Six could be used as a basis for a study of ambiguity in language. The example given above in section v. shows how six can resolve an ambiguous world meaning on the or basis of related word meanings. Similarly an expanded version of the meaning ings (or, more precisely, the contents of the property lists) of the mean words in the sentence. Thus the system could be as effective as people in recognizing the structural difference between sentences like,

havior (28) and the process of memorialist consense syllations (14). Per-

"Bring me the bottle of milk which is sour," and

"Bring me the bottle of milk which is cracked."

Such a study might contribute to our knowledge of the use of language and how people resolve ambiguities. It could investigate how much

paper in the corter inputs, property of the papers of the papers of the papers of the corter toputs, papers of the corter toputs, papers of the papers of th

Psychologists have simulated on a computer mamuri placed application of griphics and the process of mamorisms and sense and sense of the process of partial places. And the process of process of the partial places of the

<sup>&</sup>quot;Bring as the bootle of malk which is sone," and

<sup>&</sup>quot;Bring me the bottle of milk which is crassed."

Such a study mignt contribute to our knowledge of the use of ranguage and how people receive audinow people receive audinoses. It could investigate how much

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## Appendix I: Notation

Carryan to the Substitute of Entry the Substitute of the Substitut	Pept. Natte is Thanks. Combridge, and a ling	.18
re real early state of	of this section is to present some of the formal than the section is to present some of the formal distance of the formal distance of the formal distance of the section is the section of	32.
nse <b>et Assidhe</b>	ymbols will be explained by means of definitions y	.33.
examples, or sta	tements of interpretation. The second of the control of the contro	34.
Symbol in the	Research in a of bloctronic: and computes a cate COMPT Progress aristoplers const. If a cate company const.	.38
A.B.C. Altrended	the propositional connectives.	.ðŧ
A ≯B MOA	A and B (are both true).  A or B or both manusce and are JANVON and a ward.  A implies B.  A if and only if B.	" ( <b>t</b>
X, Y, Z, trait for and α βγγ λατικό to a	variables; mames of unknown objects or sets a mone of constants; names of particular objects or secsated of is a member of the set x.	.88.
Aug <b>* G y</b> rege 9 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7		39.
<b>*,1Y</b> mdeerd of er -useYillsK constant (♥ <b>x</b> )		* 65
1.30 (3x) (3x)	existential quantifier; symbol of the second of the existential quantifier, pp. 2. pp. 2 quantifier the exists an x such that A is true.	41.
(49) 19:00 10:00 1	an where exists an a such that a is true.  an unordered sets of the pable that a is true.  the property of the pable to be a set of the paperty of the paper	. 242
B. Subordinate	Suppose the transfer to the source of the so	43.
. 1 & Subordinate & P	reof disda method for preving Logical deductions in	tkè÷
The state of the s	Maly("auliolia   Ismaitaschitmaup add"), auluolag-stagir W.W. Norken and Co., N.Y. 1961,	
similar to the s	ined here is due to Prof. Hartley Rogers, Jr. It is a control of the control of t	).
. Satt Y. A . sus	Zirl. P. Semartic Analysis. Cornell V. Press, 1to.	L. i

<u>Definition</u>: Subordinate Proof Derivation of a formula B from a finite, possibly empty, set of formulas 2 =df
an arrangement of formulas and long brackets satisfying the conditions:

- 1) The first k lines of the derivation consist of the formulas of Q.
- 2) Given  $\underline{n}$  lines of the derivation, the  $\underline{n+1}$  line may consist of any formula whatever, if a new long bracket is begun to the left of that formula inside all existing brackets not previously terminated.

Definition: In a Subordinate Proof Derivation, line i is called an ancestor of line I if j < I and line j occurs inside no long brackets other than those containing line &. electional calcutus statement of the partitional calcutus statement of the containing the

- 3) Given in lines of a derivation, the nel line may consist of a formula A (without a new long bracket) if
  - i) A is a known true theorem.
- ii) A is implied, in the propositional calculus, by any set of formulas in ancestor lines to the net line, or its accordance in a castor lines to the net line, or line by an allowable use of the method of US. UG, ES, EC, II, or I2.

Definitions: Let A be any formula, and let Q and B be terms and a definition of the formula obtained from A by substituting B for every free observence of α in A, i.e., for every occurrence of α not within the scope of a quantifier containing Q.

- US =df Universal Specification, by which  $(\forall \alpha)$ A becomes  $A_{\alpha}^{\alpha}$
- UG =dr Universal General Latton, by which he becomes (Va) Association to be comes (Va) Association
- ES =df Existential Specification, by which (30)A becomes A .

  EG =df Existential Generalization, by which A becomes (JB) A .
- 11 =df A rule which allows insertion of a formula of the form α=α.

  12 =df A rule by which a comps A prie de role A fini and relience so the

Certain conditions restrict the allowable usage of most of these quantifier transformation methods. These conditions, which well at each of the transformation methods. conflicts between variable interpretations and dependencies between constants; are toobinvolved to present in this routdinesses a save of

- 4) An innermost long bracket may be torminated at (and ducluding) that n line if we write as the n+1st line [Am)C] where A and C are, respectively, the first and last formulas in the long bracket in questions and
- 5) An innermost long bracket may be terminated at the nth line if that bracket begins with a formula ~A and has for its last two lines C and
- 6) The last line has no long brackets and is the formslax Bat De A マストラス

(20) (00 = 10) (00) (00) (00) (00) (00) Main Theorem (given here without proof): If there is a Subordinate proof Derivation of B from Q, then B is quantificationally deducible from Q.

Appendix II: Derivations of SIR Deduction Procedures : no line led
Each of the 23 deduction procedures listed in Table b. is a
theorem of the SIR1 formal system. The proofs, presented below,
generally consist of four statements:
i) The SIR deduction procedure, as stated in Table b. a sole is singuous
ii) A corresponding SIR1 wff, obtained through use of the correspondences of Table c. spondences of Table c. state of sale and the state of sale and the sale and
iii) The quantificational calculus statement obtained from the
formula in ii) by eliminating (-quantifiers as described in Section (5) The section (5) The section (6) The section (7) The section (7) The section (7) The section (8) The se
iv) The outline of a Subordinate Proof Derivation for the state- ment in iii). These proofs are outlines in the sense that occasionally several steps are combined into one, line numbers are
occasionally several steps are combined into one, line numbers are used as meta-symbols to stand for lengthy expressions, and derived rules of inference such as "modes ponens" are used when convenient.  However, enough detail and explanation is presented so that complete
formal "SPD s" can easily be constructed if desired.  3013 V1044 TO S SCHOOL STORY OF A MOY SERVED AND ELECTRICAL STORY OF THE STORY OF
The axioms of SiRl, as given in Table d. and its associated o equa-
definitions, are introduced into the Subordinate Proofs as "true" of
theorems whenever necessary, which the second second second theorems whenever necessary, respectively.
free variables in the initial and final statements in the following:
rances per un la secon la agaza eldawafil i la balance esa sibece e sauci proofs, is, assumed. esa, le callenge a conficil de l'archicem nobusi colenare espisa
In some cases, the proofs of SIR deduction procedures follow as a go
immediately from SIR1 axioms or definitions, so thet "SPD so are that the or livery of the soul of the
unnecessary. The second of the second of the second of the
and in the following of the company of adjoint to the company of t
xCy_yCz⇒xCz osło or as ber seebored general on and onal sadt co
$(\forall \alpha)[\alpha(x\Rightarrow \alpha(y), (\forall \alpha)[\alpha(y\Rightarrow \alpha(z)\Rightarrow (\forall \alpha)[\alpha(x\Rightarrow \alpha(z))])]$ $= (\forall \alpha)[\alpha(x\Rightarrow \alpha(y), (\forall \alpha)[\alpha(y\Rightarrow \alpha(z)\Rightarrow (\forall \alpha)[\alpha(x\Rightarrow \alpha(z))])]$ $= (\forall \alpha)[\alpha(x\Rightarrow \alpha(y), (\forall \alpha)[\alpha(y\Rightarrow \alpha(z)\Rightarrow (\forall \alpha)[\alpha(x\Rightarrow \alpha(z))])]$ $= (\forall \alpha)[\alpha(x\Rightarrow \alpha(y), (\forall \alpha)[\alpha(y\Rightarrow \alpha(z)\Rightarrow (\forall \alpha)[\alpha(x\Rightarrow \alpha(z))])]$ $= (\forall \alpha)[\alpha(x\Rightarrow \alpha(y), (\forall \alpha)[\alpha(y\Rightarrow \alpha(z)\Rightarrow (\forall \alpha)[\alpha(x\Rightarrow \alpha(z))])]$ $= (\forall \alpha)[\alpha(x\Rightarrow \alpha(y), (\forall \alpha)[\alpha(y\Rightarrow \alpha(z)\Rightarrow (\forall \alpha)[\alpha(x\Rightarrow \alpha(z))])]$ $= (\forall \alpha)[\alpha(x\Rightarrow \alpha(y), (\forall \alpha)[\alpha(y\Rightarrow \alpha(z)\Rightarrow (\forall \alpha)[\alpha(x\Rightarrow \alpha(z))])]$ $= (\forall \alpha)[\alpha(x\Rightarrow \alpha(y), (\forall \alpha)[\alpha(y\Rightarrow \alpha(z)\Rightarrow (\forall \alpha)[\alpha(x\Rightarrow \alpha(z))])]$ $= (\forall \alpha)[\alpha(x\Rightarrow \alpha(y), (\forall \alpha)[\alpha(x\Rightarrow \alpha(z)\Rightarrow (\forall \alpha)[\alpha(x\Rightarrow \alpha(z))])]$ $= (\forall \alpha)[\alpha(x\Rightarrow \alpha(x\Rightarrow \alpha(x)\Rightarrow (\forall \alpha)[\alpha(x\Rightarrow \alpha(x)\Rightarrow (x,x)\Rightarrow ($

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1. [(\forall \alpha)[\alpha \in x \Rightarrow \alpha \in y] \land (\forall \alpha)[\alpha \in y \Rightarrow \alpha \in z]
                                                                                                                            US1 (by US in line 1)
2.
          \beta \in x \Rightarrow \beta \in y
                                                                                                                                                                     US1
3.
        |β€y≯β€z
4.
               βєх
                                                                                                                                                                     4,2
5.
               β€у
                                                                                                                                                                     5,3
6.
           Lβ€z
7.
       \beta \in x \Rightarrow \beta \in z
8. \lfloor (\forall \alpha) [\alpha \in x \Rightarrow \alpha \in z]
                                                                                                                                                                     UG7
     1.⇒8. qed.
2) x=y \Rightarrow x \subset y
     x=y \Rightarrow (\forall \alpha \boldsymbol{\epsilon} x) [\alpha \boldsymbol{\epsilon} y]
    x=y \Rightarrow (\checkmark \alpha) [\alpha \in x \Rightarrow \alpha \in y]
1. \sqrt{x}=y
2.
                ~(∀α)[α€x ⇒α€y]
                                                                                                                                                                     2
3.
                (3\alpha) \sim [\alpha \in x \Rightarrow \alpha \in y]
                                                                                                                                                                     ES3
                \sim [\beta \epsilon x \Rightarrow \beta \epsilon y]
4.
5.
               \beta \in X \wedge \sim \beta \in Y
                                                                                                                                                                     12-1,5
6.
               β€У
7.
              ~β€y
8. \lfloor (\forall \alpha) [\alpha \in x \Rightarrow \alpha \in y]
     1.⇒8. qed.
3) equiv[x;y]\Rightarrowx\subsety
     x=y \Rightarrow (\forall \alpha(x) [\alpha(y)]
                                                                                                        same as 2).
\alpha \in \mathbf{x} \wedge (\mathbf{y} \beta \in \mathbf{x}) [\beta \in \mathbf{y}] \Rightarrow \alpha \in \mathbf{y}
    \alpha \in \mathbb{X} \setminus (\forall \beta) [\beta \in \mathbb{X} \Rightarrow \beta \in \mathbb{Y}] \Rightarrow \alpha \in \mathbb{Y}
1. [\alpha \in \mathbf{x} \land (\mathbf{v} \beta) [\beta \in \mathbf{x} \Rightarrow \beta \in \mathbf{y}]
2. \alpha \in x \Rightarrow \alpha \in y
                                                                                                                                                                     US1
                                                                                                                                                                     1,3
3. Δ(y
     1. ⇒3. qed.
5) \( \tag{(equiv)}
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axiom.

·7(=)

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1. [(Ya)[xex+xe] \ (\varange a)[xey+xee]
      6) (equiv)
                                                                                                                                                                                                                                                                                                                                                                                    2. Bex + Bey
                                                      រើកស្រាស់ ស្គាក់ នេះស
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                    Q(**)
                                                                                                                                                                                                                                                                    axiom.
                                                                                                                                                                                                                                                                                                                                                                                                        X48
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                                                                                                                                                                                                                                                                                                                                                                                     7. |β€x ⇒β€z
      7) 4(equiv)
                                                                                                                                                                                                                                                                                                                                            3. [(Ya) [aex = nex!
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                      L(=)
                                                                                                                                                                                                                                                                    axiom.
                                                                                                                                                                                                                                                                                                                                                                                   COMERCY X (C)
      8) \simowng[x;x]
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                     \sim (\forall \alpha \in x) (\exists \beta \in x) [ownb[\alpha; \beta]]
                    R(ownb)
                                                                                                                                                                                                                                                                    axiom.
                                                                                                                                                                                                                                                                                                                           9) \operatorname{owng}[x;y] \wedge z \subset y \Rightarrow \operatorname{owng}[x;z]
                   (\forall \beta \in y) (\exists \alpha \in x) [ownb[\alpha; \beta]] \land (\forall \alpha \in z) [\alpha \in y] \Rightarrow (\forall \beta \in z) (\exists \alpha \in x) [ownb[\alpha; \beta])
                                                                                                                                                                                                                                                                                                                                                                                                            BEy
                                                                                                                                                                                                                                                                                                                                                                                                                                                        . Ò
                   (\forall \beta) [\beta \in y \Rightarrow (\exists \alpha) [\alpha \in x \land ownb[\alpha; \beta]]] \land (\forall \alpha) [\alpha \in x \Rightarrow \alpha \in y]
                                            \Rightarrow (\forall \beta) [\beta \in z \Rightarrow (\exists \alpha) [\alpha \in x \land ownb[\alpha; \beta]]]
                                                                                                                                                                                                                                                                                                                                                8. \left[ (\forall x) (c \in x \Rightarrow c \in x) \right]
      1. [(\forall \beta)[\beta \in y \Rightarrow (\exists \alpha)[\alpha \in x \land \text{ownb}[\alpha; \beta]]] \land (\forall \alpha)[\alpha \in z \Rightarrow \alpha \in y]
                                                                                                                                                                                                                                                                                                                                                                                                                        US1
      2. \gamma \in \mathcal{Y} \Rightarrow (\exists \alpha) [\alpha \in \mathbf{x} \land \text{ownb}[\alpha; \gamma]
                                                                                                                                                                                                                                                                                                                                                                                                                        US1
      3. | Y€z ⇒ Y€y
                                                                                                                                                                                                                                                                                                                                                                                                                         3,2
      4. \gamma \in z \Rightarrow (\exists \alpha) [\alpha \in x \land \text{ownb}[\alpha; \gamma]]
                                                                                                                                                                                                                                                                                                                                       ASHIV (X) VI TROY
      5. [(\forall \beta)[\beta \in z \Rightarrow (\exists \alpha)[\alpha \in x \land ownb[\alpha; \beta]]]
                                                                          ged.
                                                                                                                                                                                                                                                                                                                                               ₹₹?∀(♥'Ω'€x)
                                                                                                                                    10)
                                           \operatorname{owng}[x;y] \land x \subset z \Rightarrow \operatorname{owng}[z;y]
                                                                                                                                                                                                                                                                                                                                                     O MEASONS (
                    (\forall \beta \in y) (\exists \alpha \notin x) [ownb[\alpha; \beta]] \land (\forall \alpha \notin x) [\alpha \in z] \Rightarrow (\forall \beta \notin y) (\exists \alpha \notin z) [ownb[\alpha; \beta]]
\forall \beta \in \{\forall \beta \in x\} (\forall \beta \in x) (\exists \alpha \notin x
       \Rightarrow (\forall \beta) [\beta \in y \Rightarrow (\exists \alpha) [\alpha \in z \land \text{ownb}[\alpha; \beta]]]
                      Vi~ ⇔usi
                              \gamma \leftrightarrow (3\alpha) [\alpha \in x \land \text{ownb}[\alpha; \gamma]]
      2.
      3.
                                  TYEY
                                                                                                                                                                                                                                                                                                                                                                                                                       3.2
                                                                                                                                                                                                                                                                                                                                                                           aed.
      4.
                                            (\exists \alpha) [\alpha \in x \land ownb[\alpha; \gamma]]
                                                                                                                                                                                                                                                                                                                                                                                                                       ES4
      5.
                                            \mu \in \mathbb{X} \setminus \text{ownb}[\mu; \gamma]
                                                                                                                                                                                                                                                                                                                                                                                                                        US1
      6.
                                           µ€x ⇒µ€z
      7.
                                          \mu \in \mathbb{Z} \setminus \text{ownb}[\mu; \gamma]
                                      (3\alpha)[\alpha \in z \land \text{ownb}[\alpha; \gamma]]
      8.
      9.
                                                                                                                                                                                                                                                                                                                                                                                                                        UG9
                           (\forall \beta) [\beta \in y \Rightarrow (\exists \alpha) [\alpha \in x \land ownb \in \beta]]
10.
                   1. \Rightarrow 10.
                                                                               ged.
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owner; ylx x 22304n[2; y] old 1 to 1 (3308-(x38 4/x 1128-1128-) (3308-
11)
                 (3afx) [ownb[a;y]] A (Vafx) (afx) (afx) Townb[a; 9]]
                (3a) [afx A ownb [a; y]] A (\d) [afx \approx afz] \approx (3a) [afz \approx ownb [a; y]]

[[] \left\[ \left\[ \approx \right\] \approx \right\[ \approx \right\] \approx \quad \approx \right\] \approx \right\[ \
                                                                                                                                                                                                                                                                                                                                                                                                                         [Widding vall
                                (\exists \alpha)[\alpha \in x \land ownb[\alpha; y]] \land (\forall \alpha)[\alpha \in x \Rightarrow \alpha \in z]
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                             Bex Lownb[β;y]
                                                                                                                                                                                                                                                                                                                                                                            (iv:s)dane (sam ver)
3.
                     BEX-BEZ
                    βezλownb[β;y]
                    [\alpha(y)][\alpha(z \wedge ownb[\alpha; y)]
                                                                                                                                                                                                                                                                           iv ulitragen gyvittane a tyrullarka
                                                                                   qed.
                                                                                                                                                                                                                                                                                                                                                                               9. ((37) outsey, participle, 7).
                                           owng[x;y] \land z \in y \Rightarrow own[x;z]
                 (\forall \beta \in y) (\exists \alpha \in x) [ownb[\alpha; \beta]] \land z \notin y \Rightarrow (\exists \alpha \notin x) [ownb[\alpha; z]]
                (\forall \beta)[\beta \in y \Rightarrow (3\alpha)[\alpha \in x \land ownb[\alpha; \beta]] \land z \in y \Rightarrow (3\alpha)[\alpha \in x \land ownb[\alpha; z]]

    (∀β)[βξy ⇒(∃α)[αξx ∧ ownb[α;β]] ∧ εξy
    zξy ⇒(∃α)[αξx ∧ ownb[α; z]]

                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         1,2
3. [(\exists \alpha) [\alpha \in x \land ownb[\alpha; z]]
               1.=> 3.
                                                                                 qed.
                                                                                                                                                                          \mathbb{P}_{\mathcal{L}_{\mathcal{A}}} = \mathbb{P}_{\mathcal{A}} = \mathbb{P}_{\mathcal
                                                                                                                                                                                                                                                                                                                                                                                           L. Petroli, J. A. Rex A Dex
13) ~ partg[x;x]
                                                                                                                                                                                                                                                                                                                                            14=84= x301(8 V) / x3V
                   \sim (\sqrt{\alpha}(x))(\beta(x))[partb[\alpha;\beta]]
                   (partb)
                                                                                                                                                                                                                                                                                                                    axiom.
                                           partg[x:y] ∧ z Cy → partg[x;z]
                ( Bey) (acex) [partb[a; B]] ( voez) [ory) (vez) (jerx) [partb[a; B]]
Proof is the same as proof of (9), with "ownb" replaced by "partb."
                                                                                                                                                                                                                                                                                                                                       Triple serves state of state
                                             part[x;y] AxCz = part[z;y] s A [x] = 1 ginto A [] q; c] d ingril t (86f) (x5v f)
15)
 (∃αξx)[partb[α;y]] (∀αξx)[αξz] ⇒ (∃αξz[partb[α;y])
(∀aξx)[aξz] → (∃αξx)[αξz] → (∃αξx)[αξz] → (∃αξx)[αξz] → (∃αξx)[αξz] → (∃αξx)[αξz] → (∃αξx)[αξz] → (∃αξx)[αξx] → (∃αξx)
Proof is the same as proof of (11) with sowh replaced by partb."
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 $part[x;y] \land partg[z;x] \Rightarrow part[z;y]$ 

16)

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(\exists \alpha \in x)[partb[\alpha; y]] \land (\forall \beta \in x)(\exists \alpha \in z)[partb[\alpha; \beta]] \Rightarrow (\exists \alpha \in z)[partb[\alpha; y]]
                             [(3\alpha)[\alpha(x) + \alpha(x)]] \wedge (\forall \beta)[\beta(x) + \alpha(x)] \wedge (\forall \beta)[\alpha(x) + \alpha(x)] \wedge (((x) + \alpha(x)) \wedge ((x) + \alpha(x)) \wedge (x) \wedge (x
                                                  Yex A partb[Y;y]
                                                                                                                                                                                                                                                                                                                                                                                                                                [\alpha(x \land ownb[\alpha; y]] \land (\forall \alpha)[\alpha(x \Rightarrow \alpha(x)]]
                                                  \gamma \in point(]\alpha)[\alpha \in z \land partb[\alpha; \gamma]]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                [v;a]dnwo [s;y]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            . 7.
                                                    (3\alpha)[\alpha \in z \land partb[\alpha; \gamma]]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            څ.
                                                    μ6ε partb[μ;γ]
   5.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  wmb[B;y]
                                                     T(partp)
   6.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     x \in A \cap [x;y]
                                                    partb[\mu;\gamma] \land partb[\gamma;y] \Rightarrow partb[\mu;y]
   7.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        ued.
                                       \mu \in z \land partb[\mu; y]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        EG8
   9. \lfloor (3\alpha)[\alpha \in z \land partb[\alpha; y]]
                            1. -> 9.
                                                                                                                                            qed.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         ovre_{x}[x;y] \wedge z \in y \Rightarrow ovr[x;z]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            12)
                                                                             partg[x;y] \wedge z \in y \Rightarrow part[x;z]
   17)
                            (\forall \beta \in y) (\exists \alpha \in x) [partb[\alpha; \beta]] \wedge z \in y \Rightarrow (\exists \alpha \in x) [partb[\alpha; z]] \times z \cup (\infty \in y) (\exists \alpha \in x) [partb[\alpha; z]]
Proof is the same as proof of (12) with own replaced by the same as proof of (12) with own replaced by the rep
                                                                        1,2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     3. (G\alpha)[\alpha \in x \land ownb[\alpha;z]]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        qed.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          1.⇒3.
Lemma 1:
                                                                                                                               (\forall \alpha) (\forall \beta) (\forall x) [single[x] \land \alpha \notin x \land \beta \notin x \Rightarrow \alpha \neq \beta]
                                       [single[x] \land a \in x \land b \in x]
   2.
                                                     (\exists \alpha) [\alpha \in x \land (\forall \beta) [\beta \in x \Rightarrow \beta = \alpha]]
                                                  Y \in X \setminus (\forall \beta) [\beta \in X \Rightarrow \beta = Y]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    3.
 4.
                                                  a€x =>a=Y
                                                                                                                                                                                                                                                                                                                                                   .molxs
   5.
                                                  a≖γ
                                                  b€x ⇒b=γ
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 6.
 7.
                                                  b=v
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        1,6
 8.
                                         a=b
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     14), t^{-7} to g[x;y] \wedge z \subset y \Rightarrow partg[x;z]
                                                     ī.⇒8.
                            (A a)(A b) (A x) (aire) ((306x) (bear place) (A a) (A 
                                                                                     Proof is the came as proof of (9), with "ownb" replaced by "partb."
   18)
                                                                             right[x;y] \Longrightarrow \sim right[y;x]
                          (3\alpha(x))(3\beta(y))[rightb[\alpha;\beta]] \wedge single[x] \wedge single[y] \wedge single[x] \rightarrow [(\alpha y)(\beta x)[rightb[\alpha;\beta]] \wedge single[y] \wedge single[x]
                 (\exists \alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}]] \wedge (\forall \alpha \in \mathbb{Z})[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}]] \wedge (\exists \alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}]] \wedge (\exists \alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}]) \wedge (\exists \alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}])) \wedge (\exists \alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}]) \wedge (\exists \alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}]) \wedge (\exists \alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}])) \wedge (\exists \alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}]) \wedge (\exists \alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}])) \wedge (\exists \alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}]) \wedge (\exists \alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}])) \wedge (\exists \alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}])) \wedge (\exists \alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}])) \wedge (\exists \alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}])) \wedge (\exists \alpha \in \mathbb{Z}[\alpha \in \mathbb{Z}
                                                                                Proof is (Alelania (Chile and Chile) and the confidence of the con
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part[x;y] partg[z;x] = part[z;y]

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(3α)[αεκ Λ (3β)[βεγ Λrightb[α;β]]] Λsingle[κ] Λsingle[γ]
              YEX A (3B) [BEY Arightb[Y:B]]
   2.
              μ€y∧rightb[γ;μ]
   3.
                       (3a) [aey (3B) [bex (rightb[a; B]]]
   4.
                      ωεγΛ (3β) [βεκ Λrightb[ω;β]]

Λεκ Λrightb[ω;λ]

Single[x] Λεκ Αγελ

US-Lem.1
   5.
   6.
   7.
                                                                                                                          1,2,6,7
1914 (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (1,000) (
   8.
                      single[y] ∧ μξy ∧ ωξy⇒μ=ω
   9.
 10.
                                                                                                                                                               1 VII 3233 /3,8,10,12
11.
                      rightb[λ;ω]
                                                                                                                     video, a selepsidaging (Core Axion
                      (rightb)
12.
                                                                                                                                                    Fightings to the property of t
                      rightb[λ;ω] → ~rightb[ω;λ]
13.
14.
                       ~rightb[ω;λ]
                  rightb[ω;λ]
15.
16.
17. [4. A single[y] A single[x]]
         1.⇒17. qed.
   19)
                     (right)
                                                                                                                             (3\alpha \in x)(3\beta \in y)[rightb[\alpha; \beta]] \wedge (3\alpha \in y)(3\beta \in z)[rightb[\alpha; \beta]] \wedge single[x]
                (∃α) [αξχ Λ(∃β) [βξγ Λ rightb[α;β]]] Λ(∃α) [αξγ λ (∃β) [βξχ Λ rightb[α;β]]] Λ single[x] Λ single[y] Λ single[z]
                      \Rightarrow (3\alpha) [\alpha \in x_{\Lambda} (3\beta) [\beta \in z_{\Lambda} rightb[\alpha : \beta]] \Rightarrow single[x] \Rightarrow single[z]
                Asingle[y]
                YEX Λ (3β) [βεγΛ rightb[γ;β]
   2.
                μξy Λ rightb[γ;μ]
   3.
               wey Λ(3β)[βεz Λrightb[ω;β]]

λεγ Λrightb[ω;β]

ES4
   4.
   5.
                                                                                                                                                                                                                    US-Lem.1
   6.
                single[y] ∧ μεγ∧ ωεγ⇒μ=ω
                                                                                                                               . 1941 1131 19 34.04 180 81 1,3,4,6
   7.
                μ=ω
                                                                                                                                                                                                                     3,7,12
   8.
                rightb[γ;ω]
                                                                                                                                                                                                                     Axiom
   9.
                T(rightb)
               rightb[γ;ω] ∧ rightb[ω;λ] ⇒rightb[γ;λ]
10.
               \lambda \in \mathbb{Z} \setminus \text{rightb}[\dot{\gamma};\lambda]
11.
12. (3β)[βez Arightb[γ;β]]
2. (3β)[βez Arightb[γ;β]]
13. Yex \12.
14. (3α) [αεκ Λ (3β) [βε z Λ rightb [α;β]]] EG13
         1. \wedge single[x] \wedge single[z] \Rightarrow 14. \wedge single[x] \wedge single[z] qed. 15
```

```
20)
                   jright[x;y] \Rightarrow right[x;y]
                                                                                     _010 A ([[4;ω]dungirA γ38]((42) A . (40)
        (3αξχ) (3βξy) [jrightb[α;β]] \single[x] \single[y]
                  \Rightarrow (\exists \alpha \in x) (\exists \beta \in y) [rightb[\alpha; \beta]] \land single[x] \land single[y]
        (3α) [αξx Λ(3β)[βξy Λjrightb[α;β]]] Λ single[x] Λ single[y] Λ
                  ⇒(∃α) [αεx ∧(∃β) [βεy ∧ rightb[α;β]]] ∧ single[x] ∧ single
            (\exists \alpha) [\alpha \in x \land (\exists \beta) [\beta \in y \land jrightb[\alpha; \beta]]
             \gamma \in X_{\Lambda}(\exists \beta)[\beta \in y_{\Lambda}] \text{ irightb}[\gamma; \beta]
             μένω jrightb[γ;μ]
            (\forall x)(\forall y)[jrightb[x;y] \Rightarrow rightb[x;y]]
                                                                                                                                                                                     Axiom
            jrightb[γ;μ] ⇒rightb[γ;μ]
                                                                                                                   landingir- = [w; d) rad
  6.
          μεγκrightb[Y;μ]
            (\exists \beta)[\beta \in y \land rightb[\gamma; \beta]]
                                                                                                                                                                                     EG6
  8.
          Y€x ∧ 7.
  9. \lfloor (\exists \alpha) [\alpha \in x \land (\exists \beta) [\beta \in y \land rightb[\alpha; \beta]] \rfloor
                                                                                                                   (18) Smis & (Vlorante A
10.
        1. \wedge single[x] \wedge single[y] \Rightarrow 9. \wedge single[x] \wedge single[y]
                                                                                                                                                                  (1110-11-17)
                                                                                                                                                                                                  (61
  21)
                   jright[x;y] \land z \neq y \Rightarrow \sim jright[x;z]
                     The SIR programs assumed that "zy" was equivalent to the
  assertion, "the z is not the y." This latter preferred interpretation can be expressed directly in the SIRI formalism by
  Therefore the appropriate SIRI statement corresponding to (21) is:
        (3αξx)(3βξy)[jrightb[α;β]] \ single[x] \ single[y] \ single[z]
                  (Yaez) [afy] (uE) fightb[a; \beta] single[x] \single[z]
        (3α) Ιαξχ Λ(3β) [βεγΛjrightb[α;β]]] Λ single[x] Λ single[y] Λ single[z]
                 \wedge (\forall \alpha) [\alpha \in z \Rightarrow \alpha \notin y]
               Proof is in the proof of (22) below.
                  jright[x;y] \land z \neq x \Rightarrow \sim jright[z;y]
  As discussed in the above note, the appropriate SIRI statement is:
  (βεγ) (βεγ) [ single[x] \ single[y] \ single[z] \ (βεγ) \ (βε
                    \wedge (\forall \alpha \in \mathbf{z}) [\alpha \notin \mathbf{x}]
                    \rightarrow \sim [(\exists \alpha \in z)(\exists \beta \in y)[jrightb[\alpha; \beta]] \land single[z] \land single[y]]
```

```
(aα) [αεχ Λ (aβ) [βεγ Λ jrightb[α;β]] / single[x] / single[y] / single[z]
                                                 \Lambda (\forall \alpha) [\alpha \in z \Rightarrow \alpha \notin x]
                                                 A stagle let a real election of the substantial content of the letter of
                                (3a) [aex A(3b) [bey/jrighteda; $1] & single[x] & single[y]
                               λέχ Λ(∃β)[βέγ Λ]ríghtb[λ;β]]
ωέγ Λ]ríghtb[λ;ω] (θΕ) Λ γερ (εξ) Λ (([θ[ρ]dadgir Λ ν ∋θ) (θΕ) Λ κ) Β52 εξ)
       3.
                                                                                                                                                                                                                                 moixA stagle() Astagle() Astagle()
      4.
                                ひ(jrightb)
                                jright bit, wh = (40) [tow = birlight bit, a] 198] (4E) x x 20 (0E) }
       5.
                                                 \wedge [\alpha \neq \lambda \Rightarrow \sim \text{irightb}[\alpha; \omega]]
                                 (4 a) [[a+w = 2] [18h [b[X]a]] } [a+x - ]+18h b [a; w]] (8) 1 (8)
       6.
                                           7.
                                                     (3a) [aex \ (3B) [Bez \ jrightb[a;B]][[8; u] didaji \ v36] (4E) \ - - - - -
      8.
                                                                                                                                                                                                                                                                                                                                              is a late of the l
       9.
                                                        \gamma(x \wedge (\beta))[\beta(z \wedge jrightb[\gamma; \beta]]
                                                                                                                                                                                                                                                                              10.
                                                        \mu \in \mathbb{Z} \wedge \text{jrightb}[\gamma; \mu]
                                                                                                                                                                                                                                                                                                                                     TALY I day to A VEST Lement
                                                         single[x] \lambda (x \wedge y \in x \Rightarrow y = \lambda
12. be.l.
                                                                                                                                                                                                                                                                                              Y=000 734/ Y30/ (2) + (1) 29 4, 11
                                                        γ=λ
13.
                                                         μ€z ⇒μ€y
                                                                   \frac{1}{1600} \frac{1}{1600
 14.
15.
                                                                                                                                                                                   - (人) 引き取れてい 会(人) with to [win] d 、 [win] d 
16.
                                                                   HEY
                                                                                                                                                                                                                 [[E]][[ex/[38]][86x/[38]][E]
                                                         μ≠ω
17.
                                                                                                                                                                                                                                                          let x x (3B) (cer x jrightblass)
 18.
                                                         μ≠ω ⇒> ~ irightb [λ;μ]
                                                                                                                                                                                                                                                                                                                              [d:6]didgin[ A x 37 18 :CI
19.

√jrightb[λ;μ]

                                                                                                                                                                                                                                                                                 14.12. 15. 10. 16. X A SEX - 12. 41
20.
                                                           jrightb[λ;μ]
21
                                                                                                                                                                                                                                                                              d=14 + 13d , 13 | 1 | 1 | 21 | 1 | 7.01
22:
                                              \stackrel{\sim}{\sim} [8. \wedge single[x] \wedge single[z]]
23
                                                                                                                                                                                                                                                                                                                                                        idzidadging∫
24
                                          single[z] \land single[x] \land (\forall \alpha)[\alpha \in z \Rightarrow \alpha \in x]
                                                                                                                                                                                                                                                                                                                                               in aldoly in the
                                                         (3\alpha)[\alpha \in \mathbb{Z} \land (3\beta)[\beta \in \mathbb{Y} \land \text{jrightb}[\alpha;\beta]]]
25.
26.
                                                         a \in z_{\wedge} (\exists \beta) [\beta \in y_{\wedge}] \text{ irightb[} a; \beta ]
                                                                                                                                                                                                                                                                27.
                                                         bey Ajrightb[a;b]
                                                                                                                                                                                                                                                                                                                                                                                                                   US Lem 1
28.
                                                         single[y] ∧ bfy ∧ wfy ⇒ b=w
                                                                                                                                                                                                                                                                                                                                                                                                                  1,27,3,28
29.
                                                                                                                                                                                                                                                                                                                                                                                                                              US24
30.
                                                         a€z ⇒a€x
                                                              Га=λ
31.
                                                                                                                                                                                                                                                                                                                                                                                                                               26,30
32.
                                                                     a€x
                                                                                                                                                                                                                                                                                                                                                                                                                               2,31,12
                                                              _a∈x
33.
34.
                                                         a≠λ
                                                                                                                                                                                                                                                                                                                                                                                                                              US6
35.
                                                         a \neq \lambda \Rightarrow \sim jrightb[a; \omega]
                                                                                                                                                                                                                                                                                                                                                                                                                                34,35
36.
                                                           \sim \text{jrightb}[a;\omega]
                                                                                                                                                                                                                                                                                                                                                                                                                  26,29,12
37.
                                                         jrightb[a;ω]
38.
                                               ~25.
                                                                                                                                                                                                                                                                                                                                                                                                                               38,24,1
                                          \sim [25. \wedge single[z] \wedge single[y]]
39.
40.
                                24.⇒39.
                                                                                                                                                                                                                                                                                                                                                                                                                              23,40
41.
                           [7 \Rightarrow 22.] \land [24 \Rightarrow 39.]]
42.
                                1. \Rightarrow [[7. \Rightarrow 22.] \land [24. \Rightarrow 39.]]
                                                                                                                                                                                                                                                                                                                                                                                                                               42
43.
                                [1. \Rightarrow [7. \Rightarrow 22.]] \setminus [1 \Rightarrow [24. \Rightarrow 39.]]
                                                                                                                                                                                                                                                                                                                                                                                                                               43
                                1. ∧ 7.⇒22. qed(21).
                                                                                                                                                                                                                                                                                                                                                                                                                               43
                                1.∧24.⇒39.
                                                                                                                             qed(23).
```

```
23) Entisht[x;y] A right[x; e] = wirisht[raz] dungint A velication of the
    (306x)(386y)[rishtb[0:8]] \(Gex)(386x)[rishtb[0:8] \(Asingle[x] \)
          ⇒~(30€x)(30€x)(1rishthlkiz]] Mainslalk Mainslelz).
    (\exists \alpha) [\alpha \in X \land (\exists \beta) [\beta \in Y \land rightb[\alpha; \beta]]] \land (\exists \alpha) [\alpha \in Y \land (\exists \beta) [\beta \in X \land rightb[\alpha; \beta]]]
     single[x] single[y] single[z]
          [[slefanie / [xlefanie / [[aspldidaixi / ase] (4E) / xso] (DE) >
     [(30) [aex \ (38) [Bex vistel (31)] (32) [aex vistel (31) [aex vistel (32)]
          μεχ Λ (3β)[βεχ Λrightb[μ;β]] [[β;μ]dangar (Λ κ3θ](βε) Λ κ3ω] (σε)
 2.
 3.
      \omega_{X} \wedge rightb[\mu;\omega]
                                                 COL (30) (per Althoughly: 6) [
 4.
      \gamma \approx (3\beta)[\beta \in z \land rightb[\gamma; \beta]]
                                                                                       ES1
                                                              - Luivida Gista Se
      λεπικ rightb[γ;λ]]
                                                       STATESTA XBA XIXINIBADIA
 6.
      single[y] \wedge \omega \in y \wedge Y \in y \Rightarrow \omega = Y
 7.
 8.
      rightb[\omega;\lambda]
                                                                                       5,7,I2
 9.
       (\forall x)(\forall y)(\forall z)[rightb[x;y] \land rightb[y;z] \Rightarrow \sim jrightb[x;z]]
                                                                                       Axiom
10.
                                                                                       US9
     [xightb[\mu;\omega] \land rightb[\omega;\lambda] \Rightarrow \sim jrightb[\mu;\lambda]
11.
         (3\alpha)[\alpha \in x \land (3\beta)[\beta \in z \land jrightb[\alpha; \beta]]
12.
        \Re x \wedge (\exists \beta) [\beta \in z \wedge jrightb[a; \beta]]
                                                                                       ES11
                                                              Las Haster Land
                                                                                       ES12
13.
         bez A jrightb[a;b]
                                                                    Tuikld again w
                                                                                       US+Lem. 1
14.0
         single[x] ∧ µ€x ∧ a€x ⇒µ=a
                                                                       is: Aldmini
                                                                                      2,12,14
15.
         μ=a
                                                    [[s]oignis \ [x]oignis \ .3] US-Len.]
16.
         single[z] \lambda \in z \wedge b \in z \Rightarrow \lambda = b
17.
         λ≖b
                                        Leboses Sullowy) A lebelgeria A la pignia A
18.
         jrightb[\mu;\lambda]
19.
         ~jrightb[μ;λ]
                                          [[4:v]dddgfx[/.:34](45)/.s3v](bE)
                                                 og dea A (3b) (Bey A jrignt bia; 8]]
      ~11.
20.
                                                                                                65
21. [x] [11. \land single[x] \land single[z]]
                                                               Játajá Mark vya
                                                                                               , Ç<u>Ç</u>
 1. 21.
                 qed.
                                                      Ringsolvin os nesy spec
                                                                                               .88
  BE.S. VE I
      5524
                                                                                               .OE
                                                                                              1.18
    1,000
  1 11:5
       080
                                                             luisidinigiri~ = xits
    12.
                                                                    last program will
   12.95,0X
                                                                       (wro) I Mary
  1.58,26.1
                                                 Mills A stepped a fall of the fall of the
    (1) V "
                                                               [1,98 $32,1,20 $4,5]
                                                         1.4((1.45)) [1.45] + 11.4((1.45))
                                                 \{1, \Rightarrow [7, 722, ]7, \{1, \{24, \Rightarrow 39\}\}\}
                                                              -(INIDOD . SS # 7 4 1)
                                                             1. A JAJAS 19. gedak31.
```

#### a. SET-INCLUSION

```
(THE NEXT SENTENCE IS . .)
(EVERY KEYPUNCH-OPERATOR IS A GIRL)
  (THE FUNCTION USED IS . .)
 ..nc rumcium used is ..)
Setr-Select
(IGENERIC - KEYPUNCH-OPERATUR) (GENERIC . GIRL))
(THE REPLY ..)
  THE SUB-FUNCTION USED IS . .)
  SETR
(KEYPUNCH-UPERATUR GIRL)
 (I UNDERSTAND THE SUBSET RELATION BETHEEN GIRL AND KEYPUNCH-DEERATOR)
(I UNDERSTAND THE SUBSET RELATION BETHEEN KEYPUNCH-DPERATOR AND GIRL)
 (THE NEXT SENTENCE IS . .)
(ANY GIRL IS AN EXAMPLE OF A PERSON)
  (THE FUNCTION USED IS . .)
 SETR-SELECT
(IGENERIC ... GIRL) (GENERIC .. PERSON))
(THE REPLY ...)
(THE SUB-FUNCTION USED IS ...)
  SETK
 SEIN
(UIRL PERSON)
(ITS REPLE's a)
(I UNDERSTAND THE SUPERSET RELATION BETWEEN PERSON AND GIRL)
(I UNDERSTAND THE SUBSET BELATION BETWEEN GIRL AND PERSON)
(THE NEXT SENTENCE IS . .)
THE FUNCTION USED IS ...)
SETMO-SELECT
(LIGHERIC - KEYPUNCH-OPERATURI I GENERIC - PERSUMIN
THE TERMET ...)
THE SUB-RUNCTION USED IS ...)
SETHG

(KEYPUNCH-DERRATOR PERSON)
(115-REPLY ) E
VES
 ITHE NEXT SENTENCE IS . .)
  (THE FUNCTION USED IS . .)
 (THE FUNCTION USED IS . .)
SETRO-SELECT
((GENERIC . PERSON))
(THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
SETRY
(PERSON PERSON)
  (ITS REPLY . .)
  (THE NEXT SENTENCE IS . .)
(IS A PERSON A GIRL Q)
  (THE FUNCTION USED IS . .)
  (THE FUNCTION USED IS . .)
SETRG-SELECT
(IGENERIC . PERSON) (GENERIC . GIRL))
(THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
SETRG
(PERSON GIRL)
  (ITS REPLY . .)
SOMETIMES
  (THE NEXT SENTENCE IS . .)
(IS A MONKEY A KEYPUNCH-OPERATOR Q)
  (THE FUNCTION USED IS . .)
(THE FUNCTION USED IS ...)

SETRIG-SELECT
(QUERTIC . MONKEY) (UENERIC . KEYPUNCH-OPERATOR))

(THE SEPLY ...)

(THE SUB-FUNCTION USED IS ...)

SETRIG
(MONKEY KEYPUNCH-OPERATOR)

(INSUFFICIENT INFORMATION)
```

```
(MAX [8M-7094)
           IITS MEPLY . .)
           II UNDERSTAND THE ELEMENTS RELATION BETWEEN MAX AND IBM-7094)
           II UNDERSTAND THE MEMBER RELATION BETWEEN ISM-7094 AND MAX)
           (THE MEXT SENTENCE IS . .)
           (AN ISH-7094 IS A COMPUTER)
           (THE FUNCTION USED IS . .)
           SETR-SELECT
           (IGENERIC . IBH-7094) (GENERIC . COMPUTER))
           (THE REPLY . .)
           ITHE SUB-FUNCTION USED IS . . )
           SETR
           (IBN-7094 COMPUTER)
W.
           LITS REPLY . . .
           II UNDERSTAND THE SUPERSET RELATION BETHEEN COMPUTER AND IBM-7094)
           (I UNDERSTAND THE SUBSET RELATION BETWEEN ISM-7094 AND COMPUTER)
           (THE MEXT SENTENCE IS ....)
           (IS MAK A COMPUTER O)
           (THE FUNCTION USED IS . .) ...
           SETRO-SELECT
           ((UNIQUE . MAE) [GENERIE . COMPUTER))
           (THE REPLY . S)
           (THE SUB-FUNCTION USED IS . .)
,4,5
           IMAX COMPUTERS
           (ITS REPLY . .) &
           ITHE HEXT SENTENCE IS ....
           THE BOY IS AN INCTASTUDENTE
           ITHE FUNCTION USED IS . . .
           SETR-SELECT
           (ISPECIFIC . BOY) (GENERIC . MIT-STUDENT))
           THE REPLY . .!
           (THE SUB-FUNCTION USED IS . .)
           SETASL
```

I UNDERSTAND THE ELEMENTS RELATION BETWEEN GOZBOG AND BUY)

11 UNDERSTAND THE MEMBER RELATION BETWEEN BOY AND GOZBOG)

14 UNDERSTAND THE ELEMENTS RELATION BETWEEN GOZBOG AND MIT-STUDENT)

14 UNDERSTAND THE ELEMENTS RELATION BETWEEN MIT-STUDENT AND GOZBOG)

1.4 265 1.4 2.5 2.5 2.5 3.5 2.5 4.5 2.5 5.5 2.5 2.5 5.

(THE NEXT SENTENCE IS . .)

(THE FUNCTION USED IS . .)

ITHE SUB-FUNCTION USED IS . .)

([UNIQUE . MAX) (GENERIC . IBM-7094))

(MAX IS AN IBM-7094)

SETR-SELECT

SETAS

(THE REPLY . .)

(BOY MIT-STUDENT)

(GO2840 IS A BOY)

(ITS REPLY . .)

```
(THE MEXT SENTENCE IS . .)
   (EVERY MIT-STUDENT IS A BRIGHT-PERSON)
   ITHE FUNCTION USED IS . .)
   SETR-SELECT
   (IGENERIC . MIT-STUDENT) (GENERIC . BRIGHT-PERSUN))
   (THE REPLY . .)
   TTHE SUB-FUNCTION USED IS . . )
   SETA
   INIT-STUDENT BRIGHT-PERSON!
   (ITS REPLY . .)
   II UNDERSTAND THE SUPERSET RELATION BETWEEN BRIGHT-PERSON AND MIT-STUGENT)
   (I UNDERSTAND THE SUBSET RELATION BETWEEN MIT-STUDENT, AND BRIGHT-PERSON)
   (THE MEXT SENTENCE IS . .)
   IIS THE BOY A BRIGHT-PERSON ...
   THE FUNCTION USED IS . . 1 4
   SETHO-SELECT
    ((SPECIFIC . BOY) (GENERIC . BRIGHT-PERSON))
   (THE MEPLY . . F.
   SETAS18
   (BUY BRIGHT-PERSON)
   IITS REPLY . .1
   (THE NEXT SENTENCE IS . .)
   LJOHN IS A BOYN
   SETH-SELECT
(LUNIAME - JUNNS (GENERIC - BOYI)
(THE SEELY - 12
(THE SEELY - 12)
(JOHE SUB-FUNCTION USED IS . 41

(JOHE SUB-FUNCTION USED IS . 41
   SETRO-SELECT
((SPECIFIC . MOY) (GENERIC . MRIGHT-PERSON))
   (THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
   SETHSLO
   (BOY BRIGHT-PERSON)
   TETS MEPLY . .)
   (MHICH BOY . . (602840 JOHN))
```

```
(THE NEXT SENTENCE IS . .)
   (THE MAN IS A JERK)
    (THE FUNCTION USED IS . .)
  SETR-SELECT
(ISPECIFIC - MAN) (GENERIC - JERK))
    ITHE REPLY . . I
   ITHE SUB-FUNCTION USED IS . . I
  SETRS1
   (MAN JERK)
   (ITS REPLY . .)
   (602840 IS A MAN)
 (602840 IS A RAN)

(I UNDERSTAND THE ELEMENTS RELATION BETWEEN GO2840 AMD MAN)

(I UNDERSTAND THE MEMBER RELATION BETWEEN MAN AND GO2840)

II UNDERSTAND THE ELEMENTS RELATION BETWEEN GO284C AND JENKI

II UNDERSTAND THE MEMBER RELATION BETWEEN JERK AND GO2840)
   (THE NEXT SENTENCE IS . 4
   IJACK IS A DOPE
   ITHE FUNCTION USED IS . ...
 SETRS
   IJACK DOPE!
  (I UNDERSTAND THE MEMBERS MELATION BETWEEN JACK AND DOPE)
  ITHE FUNCTION USED IS . SE
  SET SECTORNI PUNIQUE / JACKI)
   THE REGLY & .J To Ba
THE SUB-FUNCTION USED IS , .)

CHOIS ACK.

CITY BEST AND THE EQUITY WELATION BETWEEN JOHN AND JACK)

CI UNDERSTAND THE EQUITY WELATION BETWEEN JACK AND JOHN!
 THE HERT SERTENCE IS . ...
THE FUNCTION USED IS . J. SERRE THE COUNTY OF THE PERSON O
   (THE SUB-FUNCTION USED IS . .)
   SETHSQ
   (JOHN DOPE)
  (ITS REPLY . .)
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(THE NEAT SENTENCE IS . .)
            (15 THE MAN A DOPE C)
            ITHE FUNCTION USED IS . . 1
            SETHY-SELECT
             (ISPECIFIC - MAN) (GENERIC . COPE))
           (THE REPLY . .)
ITHE SUB-FUNCTION USED IS . .)
            SETRSIO
            (MAN DOPE)
             IITS REPLY . . 1
            (INSUFFICIENT INFURNATION)
            (THE NEXT SENTENCE IS . .)
            IJOHN IS THE MANT
            ITHE FUNCTION USED IS . . )
          FIRESPONDITUM USEN IS ... ( COMMENTE ... JOHN) ( SECTFIC ... MAN) ( THE MEPLY ... ) ( THE SEME FUNCTION LOSED IS ... )
        COUNT NAME CONTROL OF THE EQUIV RELATION BETHEEN JOHN AND GOZEAU I UNDERSTAND THE EQUIV RELATION BETHEEN JOHN AND GOZEAU I UNDERSTAND THE EQUIV RELATION BETHEEN GOZEAU AND JOHN)
           (THE MENT SENTENCE IS . .)
       (THE THACTION USED IS ...)
SETAIL SELECT
(ISPETITE C. MAN) TGENERIC . (IDPE))
(THE THE-PUNCTION MAD IS ...)
SETAILS
(THE MERLY ...)
(THE MERLY ...)
(THE MERLY ...)
(THE THREE TON USED IS ...)

(THE PHOTTON USED IS ...)

(THE THREE IN THE COMMETC. THE THREE IN THE COMMETC. THE COMMETC. THE THREE IN THE COMMETC. 
         (THE NEXT SENTENCE IS . . )
            (IS THE MAN A DUPE Q)
            (THE FUNCTION USED IS . .)
           SETAQ-SELECT
((SPECIFIC . MAN) (GENERIC . DOPE))
           (THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
            SETHSIO
            (MAN DOPE)
            (1TS REPLY . .)
(WHICH MAN . . (G02840 JIM))
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(THE MEXT SENTENCE IS . .)
LEVERY FIREMAN OWNS A PAIR-OF-RED-SUSPENDERS)
 (THE FUNCTION USED IS . .)
OWN-SELECT
((GENERIC . PAIR-OF-RED-SUSPENDERS) (GENERIC . FIREMAN))
(THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
(THE SOUP-GROUNDESS FIREMAN)

(PAIR-OF-RED-SUSPENDERS FIREMAN)

(ITS REPLY . .)

(I UNDERSTAND THE POSSESS-BY-EACH KELATION BETWEEN PAIR-UF-RED-SUSPENDERS AND FIREMAN)

(I UNDERSTAND THE OWNED-BY-EACH RELATION BETWEEN FIREMAN AND PAIR-OF-RED-SUSPENDERS)
(THE MEXT SENTENCE IS ...)
(DUES A PAIR-OF-RED-SUSPENDERS OWN A PAIR-OF-RED-SUSPENDERS Q)
(THE FUNCTION USED IS . .)
(THE FUNCTION USED IS ...)

CHMU-SELECT

(IGENERIC . PAIR-OF-RED-SUSPENDERS) (GENERIC . PAIR-OF-RED-SUSPENDERS))

(THE REPLY ...)

(THE SUBF-UNCTION USED IS ...)

UWNKQ

(PAIR-OF-RED-SUSPENDERS PAIR-OF-RED-SUSPENDERS)

(ITS KEPLY ...)

(INU ** THEY ARE THE SAME)
(THE NEXT SENTENCE IS . .)
(DUES A DUCTOR DWN A PAIR-OF-RED-SUSPENDERS Q)
THE FUNCTION USED IS . . !
ONNU-SELECT
((GENERIC - PAIR-OF-RED-SUSPENDERS) (GENERIC - DOCTOR))
(THE REPLY - .)
(THE SUB-FUNCTION USED IS - .)
UNNRY

IPAIR-OF-KED-SUSPENDERS DOCTORI
(1TS REPLY . .)
LINSUFFICIENT INFORMATION)
(THE NEXT SENTENCE IS . .)
LA FIRECHIEF IS A FIREMAN)
 (THE FUNCTION USED IS . .)
(THE FUNCTION USED IS . .)

SETR-SELECT
((GENERIC - FIRECHIEF) (GENERIC - FIREMANI)
(THE REPLY - .)
(THE SUB-FUNCTION USED IS - .)

SETR
(FIRECHIEF FIREMAN)
(ITS KEPLY - .)
(I UNDERSTAND THE SUPERSET KELATION BETWEEN FIREMAN AND FIRECHIEF)
(I UNDERSTAND THE SUBSET RELATION BETWEEN FIRECHIEF AND FIREMAN)
(THE NEXT SENTENCE IS . .)
(DOES A FIRECHIEF UWN A PAIR-OF-RED-SUSPENDERS W)
 (THE FUNCTION USED IS . .)
(THE FUNCTION USED 15 • •)
OWNG-SELECT
((GENERIC • PAIR-OF-RED-SUSPENDERS) (GENERIC • FIRECHIEF))
(THE REPLY • •)
(THE SUB-FUNCTION USED 15 • •)
 OWNER
(PAIR-OF-RED-SUSPENDERS FIRECHIEF)
(ITS REPLY . .)
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#### d. OWNERSHIP, GENERAL

(THE NEXT SENTENCE IS ., .)

(THE FUNCTION USED IS . .)

DWNAGU

TALFRED OWNS A LOG-LOG-DECITRIG!

(THE REPLY ....)

DWN-SELECT ((GENERIC , LOG-LOG-DECITRIG) (UNIQUE . ALFRED))

([UNIQUE . VERNON) (GENERIC . TECH-MAN))

(I UNDERSTAND THE ELEMENTS RELATION BETWEEN VERNON AND TECH-MAN)

II UNDERSTAND THE MEMBER RELATION BETWEEN TECH-MAN AND VERNON)

(THE SUB-FUNCTION USED IS . .)

(THE REPLY . .)

SETRS (VERNON TECH-MAN)

IITS REPLY . .1

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ILOG-LOG-DECETREG ALFRED)
 (1. UNOSESTAND THE POSSESS RELATION BETMEEN LOG-LDG-DECITRIG AND ALFRED)
  (THE NEXT SENTENCE IS . .)
  IA LOG-LOG-DECITRIG IS A SLIDE-RULE)
 THE EUNCTION USED IS ...)
  (IGHNERIC . LOG-LOG-DECITRIC) (GENERIC . SLIDE-RULE))
 (THE SUB-FUNCTION USED IS . .)
  SETA
  (LOG-LOG-DECITRIC SLIDE-RULE)
 ITS REPLY . .)
(1 UNDERSTAND THE SUPERSET RELATION METHEEN SLIDE-RULE AND LOG-LOG-DECITALS)
 II SHOPE STAND THE SUBSET RELATION BETWEEN LOG-LOG-DECITRIC AND SLIDE-HULE)
 ITHE HERY SENTENCE IS . . )
  IDDES ALFRED OWN A SLIDE-RULE U)
  (THE PHOEFIGN USED IS . .)
  OHNO-SELECT
   ((GENERIC . SLIDE-RULE) (UNIQUE . ALFRED))
  THE WENT JULY USED IS . ..
   (SET 100 100 E 10 PR FO)
   LITT MERCY
   AER CONT.
                   HEART & CONTRACTOR OF
 I THE WEST SENTENCE IS . . )
LEVENY ENGINEERING STUDENT DWNS A SLIDE-MALE)
 (THE PURETON USED TS ...)
ONE SELECT
(IGENERIC - SLIDE-RULE) (GENERIC - ENGINEERING-STUDENT))
  ITHE REPLY . . .
In The Place of User to 12 and 12 and
                                                                                                                                                                          Control programme and the control of the control of
  (SLTDE-HULE ENGINEERING-STUDENT)
1502年 THE CONTROL THE POSSESS-BY-EACH RELATION BETWEEN SLIDE-KULE AND ENGINEERING-STUDENTH

LI UNDERSTAND THE POSSESS-BY-EACH RELATION BETWEEN ENGINEERING-STUDENT AND SLIDE-RULE)
            anna an Anna an Anna an Anna Anna an A
 ITHE NEXT SENTENCE IS . . I
  (THE PONCTION USED IS . .)
  SETR-SELECT
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THE MEXT SENTENCE IS . . .
  (A TECH-MAN IS AN ENGINEERING-STUDENT)
  THE FUNCTION USED IS . . .
  SETA-SELECT
  FIGERERIC . TECH-MAN) (GENERIC . ENGINEERING-STUDENTI)
  ITHE HEPLY . . .
  ITHE SUB-FUNCTION USED IS . .)
  SATA
  ITECH-HAN ENGINEERING-STUDENT)
  ILTS REPLY . .)
  LE UNDERSTAND THE SUPERSET RELATION BETWEEN ENGINEERING-STUDENT AND TECH-MANT
  TE UNDERSTAND THE SUBSET RELATION BETWEEN TECH-MAN AND ENGINEERING-STUDENTS
   ISHE NEXT SENTENCE IS . . )
  TOOKS YERNON OWN A SLIDE-RULE OF
  IZLIDE-RULE VERNON)
  ILTS REPLY . ..
  MASSIFIED JUST 1997.
            21540 HW #6681
  THE NEXT SENTENCE IS . . )
  18045 AN ENGINEERING-STUDENT DWN THE LOG-LOG-DECITAIG U)
  ITHE PUNCTION USED IS . . .
ONNE BEECT PROTEING STOCKER CONTRIBUTE CONTR
 180866 28 A LOG-LOG-DECITRIG)
11 UNDERSTAND THE ELEMENTS RELATION BETWEEN GO2840 AND LOG-LOG-DECITRIG)
12 UNDERSTAND THE REPRET RELATION BETWEEN LOG-LUG-DECITRIG AND GO28401
12 THROUGH FOLIANT INPURMATION)
  I THE ACKY SENTENCE IS . . .
  I MEPARO 'IS A TECH-MANI
STIME FUNCTION USED IS . .)
SERWINGER IT
HUNSUME . ALFRED) IGENERIC . TECH-MAN))
 SHIRE
 SALFRED TECH-MAN)
 IITS REPLY . . .
17 UNDERSTAND THE ELEMENTS RELATION HETWEEN ALFRED AND TECH-MAN)
TIME FUNCTION USED IS . . )
DWNU-SELECT
( SPECIFIC . EDG-LUG-DECTTALG) (GENERIC . ENGINEERING-STUDENT))
THE ALPLY . ...
THE SUB-FUNCTION USED IS . ..
DHNKSGO
ILUG-LOG-DECITRIG ENGINEERING-STUDENT)
IITS REPLY . . .
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TIME NEXT SENTENCE IS . .)
(A NOSE IS PART OF A PERSON)
(THE FUNCTION USED IS . .)
PARTH-SELECT
(IGENERIC - NOSE) (GENERIC - PERSON))
(THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
PARTR
(NOSE PERSON)
LITS REPLY . .)
II UNDERSTAND THE SUBPART-DE-EACH RELATION BETWEEN MUSE AND PERSONS
II UNDERSTAND THE SUPERPART-OF-EACH RELATION BETWEEN PERSON AND NUSE!
(THE NEXT SENTENCE IS . .)
(A NOSTRIL IS A PART OF A NOSE)
(THE FUNCTION USED IS . .)
PARTR-SELECT
((GENERIC . NOSTRIL) (GENERIC . NOSE))
(THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
PARTR
(NOSTRIL NOSE)
(ITS REPLY . .)
(I UNDERSTAND THE SUBPART-OF-EACH RELATION BETWEEN NOSTRIL AND NOSE)
II UNDERSTAND THE SUPERPART-OF-EACH RELATION BETWEEN NOSE AND NUSTRILL
(THE NEXT SENTENCE IS . .)
IA PROFESSOR IS A TEACHER!
(THE FUNCTION USED IS . .)
SETR-SELECT
(IGENERIC . PROFESSUR) (GENERIC . TEACHER))
(THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
(PRUFESSOR TEACHER)
(ITS KEPLY . .)
II UNDERSTAND THE SUPERSET RELATION BETWEEN TEACHER AND PROFESSOR)
(I UNDERSTAND THE SUBSET RELATION BETWEEN PROFESSUR AND TEACHER)
(THE NEXT SENTENCE IS . .)
(A TEACHER IS A PERSON)
(THE FUNCTION USED IS . .)
SETK-SELECT
((GENERIC . TEACHER) (GENERIC . PERSON))
(THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
SETR
(TEACHER PERSON)
(ITS REPLY . .)
II UNDERSTAND THE SUPERSET RELATION BETWEEN PERSON AND TEACHER)
(I UNDERSTAND THE SUBSET RELATION BETWEEN TEACHER AND PERSON)
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(THE NEXT SENTENCE IS . .)
(IS A NUSTRIL PART OF A PROFESSOR W)
(THE FUNCTION USED IS . .)
PARTRU-SELECT
(IGENERIC . NOSTRIL) (GENERIC . PROFESSOR))
(THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
PARTRU
(NUSTRIL PROFESSOR)
(ITS REPLY . .)
YE 5
(THE NEXT SENTENCE IS . .)
IIS A NOSE PART OF A NOSE U)
(THE FUNCTION USED IS . .)
PARTRU-SELECT
(IGENERIC . NOSE) IGENERIC . NOSE))
(THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
PARTRO
INDSE NOSE1
(ITS REPLY . .)
[NO , PART MEANS PROPER SUBPART)
(THE NEXT SENTENCE IS . .)
(A PERSON IS A LIVING-CREATURE)
(THE FUNCTION USED IS . .)
SETR-SELECT
(IGENERIC . PERSON) (GENERIC . LIVING-CREATURE))
(THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
SETR
(PERSON LIVING-CREATURE)
(ITS REPLY . .)
(I UNDERSTAND THE SUPERSET RELATION BETWEEN LIVING-CREATURE AND PERSON)
(I UNDERSTAND THE SUBSET RELATION BETWEEN PERSON AND LIVING-CREATURE)
(THE NEXT SENTENCE IS . .)
(IS A NOSTRIL PART OF A LIVING-CREATURE Q)
(THE FUNCTION USED IS . .)
PARTRU-SELECT
((GENERIC . NOSTRIL) (GENERIC . LIVING-CREATURE))
(THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
PARTRO
(NOSTRIL LIVING-CREATURE)
(ITS REPLY . .)
SUMETIMES
(THE HEXT SENTENCE IS . .)
IIS A LIVING-CREATURE PART OF A NOSE U)
(THE FUNCTION USED IS . .)
PARTRQ-SELECT
(IGENERIC . LIVING-CREATURE) [GENERIC . NUSE)]
(THE KEPLY . .)
(THE SUB-FUNCTION USED IS . .)
PARTRO
(LIVING-CREATURE NUSE)
(175 REPLY . .)
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INU . NOSE IS SUMETIMES PART OF LIVING-CREATURE!

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(THE NEXT SENTENCE IS . .)
(A VAN-DYKE IS PART OF FERREN)
       (THE FUNCTION USED IS . .)
 THE FUNCTION USED IS ...)

PARTR-SELECT
(IGENERIC . VAN-DYKE) (UNIQUE . FERREN))
(THE REPLY ...)

THE REPLY ...)

PARTRGU
(VAN-DYKE FERREN)
(IT UNDERSTAND THE SUPPART RELATION DETWEEN VAN-DYKE; AND PARRENS)

IT UNDERSTAND THE SUPPART RELATION DETWEEN VAN-DYKE; AND VAN-DYKE)
     (THE NEXT SENTENCE IS . .)
(A VAN-DYKE IS A BEARD)
     THE FUNCTION USED IS . .)
 THE FUNCTION USED IS ..)

SETM-SELECT
((GENERIC - BEARD))

THE REPLY ...

CTHE SUB-FUNCTION USED IS ...

THE REPLY ...

CTHE SUB-FUNCTION USED ...
SETR
(VAM-DYNE BEARD)
(ITS NEFLY - )
(IT UNDERSTAND THE SUPENSET RELATION DETWEEN BEARD) AND BEARD)
(I UNDERSTAND THE SUBSET RELATION DETWEEN VAM-DYNE AND BEARD)
(I UNDERSTAND THE SUBSET RELATION DETWEEN VAM-DYNE AND BEARD)
(THE MEXT SENTENCE IS - )
(ITHE MEXT SENTENCE IS - )
(ITHE MEXT SENTENCE IS - )
(ITHE FUNCTION USED IS - )
PARTNG—SELECT
   THE FUNCTION USED IS ... PARTRE-SELECT SAF WAS SELECT (IGENERIC ... BEARD) (UNIQUE ... FEMBEN)) (1989 FUNCTION USED IS ...)
PANTRUUQ
(BEAND FERREN)
(ITS REPLY - )
YES
                                                                                                                                                                                                                                                                                                                       - 1 (1995年) 
     (THE NEXT SENTENCE IS . .)
(A CAT IS A DISPLAY-DEVICE)
 CIMERING CRY TGENERIC . DISPLAY-DEVICE (THE AEPLY ...)

CHE AEPLY ...)

LINE SUB-FUNCTION USED IS ..)

SETN

CCHT DISPLAY-DEVICE)

(ITS REPLY ...)

(I UNDERSTAND THE SUPERSET AELATION BETWEEN DISPLAY-DEVICE AND CAT)

(I UNDERSTAND THE SUBSET AELATION AETHERN CRI AND CLEAN AT SACRAY.
ITHE NEXT SENTENCE IS ...)

(A CRT IS 'PART OF THE POP-1)

(THE FUNCTION USED IS ...)

PARTY-SELECT

(THE REPLY ...)

(THE REPLY ...)

(THE SUM-FUNCTION USED IS ...)

PARTRGS

(CRT POP-1)

(ITS REPLY ...)

(LTS REPLY ...)

(LO2240 IS A POP-1)

(LO2240 IS A POP-1)

(LO2240 IS A POP-1)
                                                                                                                                                                                                                                                                                                                       CONTRACTOR STANDARD CONTRACTOR CO
                                                                                                                                                                                                                                                                                                           ्रिक्ट होते । इस्ट्रेस १९४४ अस्टिक विस्
     LUJUNG IS A PUP-1)

(I UNDERSTAND THE ELEMENTS RELATION BETWEEN SQUARD AND POP-1).

(I UNDERSTAND THE BETWEEN RELATION BETWEEN POP-1 AND ESCAL).

(I UNDERSTAND THE SUPPART RELATION BETWEEN CAT AND ESCAL).

(I UNDERSTAND THE SUPPART RELATION BETWEEN CAT AND ESCAL).
   ITHE NEXT SENTENCE IS . .) ISAM IS THE POP-1)
     ITHE FUNCTION USED IS . .)
   THE SUB-PUNCTION USED IS - - - EQUIV TELATION BETWEEN $2 (148(612 (292 (374)) 4 (158 AP)) THE EQUIV RELATION BETWEEN $200(4) AND $200(4) A
                                                                                                                                                                                                                                                                                                           The control of the man and the control of the contr
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E. PART-WHOLE, SPECIFIC

· 1500 以信仰**的** 1400年代持**持** 

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(THE NEXT SENTENCE IS . .)
IA SCREEN IS PART OF EVERY DISPLAY-DEVICE)
(THE FUNCTION USED IS . .)
PARIR-SELECT
(IGENERIC - SCREEN) (GENERIC - DISPLAY-DEVICE))
(THE REPLY - .)
(THE SUB-FUNCTION USED IS . .) PARTK
PARTH

(SCREEN DISPLAY-DEVICE)

(ITS REPLY . .)

(I UNDERSTAND THE SUBPART-OF-EACH RELATION BETWEEN SCREEN AND UISPLAY-DEVICE)

(I UNDERSTAND THE SUPERPART-OF-EACH RELATION BETWEEN DISPLAY-DEVICE AND SCREEN)
(THE NEXT SENTENCE IS . .)
(IS A SCREEN PART OF SAM U)
(THE FUNCTION USED IS . .)
PARTRU-SELECT
((GENERIC . SCREEN) (UNIQUE . SAM))
(THE KEPLY . .)
(THE SUB-FUNCTION USED IS . .)
PARTRGUQ
(SCREEN SAM)
(THE NEXT SENTENCE IS . .)
(A BEARD IS PART OF A BEATNIK)
(THE FUNCTION USED IS . .)
THE FUNCTION USED IS ..)
PARIK-SELECT
((GENERIC - BEARD) (GENERIC - BEATNIK))
(THE NUB-FUNCTION USED IS ..)
PARIK
(BEARD BEATNIK)
ITE AND BEATHIN)
(ITS KEPLY . .)
(I UNDERSTAND THE SUBPAKT-OF-EACH KELATION BETWEEN BEAKD AND HEATHIK)
(I UNDERSTAND THE SUPERPART-OF-EACH RELATION BETWEEN BEAKD AND HEATHIK)
ITHE NEXT SENTENCE IS . .)
(EVERY COFFEE-HOUSE-CUSTOMER IS A BEATNIK)
ITHE FUNCTION USED IS . ..
SETR-SELECT
((GENERIC - COFFEE-HOUSE-CUSTOMER) (GENERIC - BEATNIK))
(THE REPLY - .)
(THE SUB-FUNCTION USED IS - .)
 SETR
SEIR (COPFEE-HOUSE-CUSTOMER BEATNIK)
(ITS REPLY . .)
(I UNDERSTAND THE SUPERSET RELATION BETWEEN BEAINTK AND CUFFEE-HOUSE-CUSTOMER)
(I UNDERSTAND THE SUBSET RELATION BETWEEN COFFEE-HOUSE-CUSTOMER AND BEATNIK)
(THE NEXT SENTENCE 15 . .)
(BUZZ IS A COFFEE-HOUSE-CUSTOMER)
 (THE FUNCTION USED IS . .)
SETR-SELECT
((UNIQUE - BUZZ) (GENERIC - COFFEE-HOUSE-CUSTOMER))
(THE REPLY - .)
(THE SUB-FUNCTION USED IS - .)
SETRS
(BUZZ COFFEE-HOUSE-CUSTOMER)
(ITS REPLY . .)
(I UNDERSTAND THE ELEMENTS RELATION BETWEEN BUZZ AND COFFEE-HOUSE-CUSTOMER)
(I UNDERSTAND THE MEMBER RELATION BETWEEN COFFEE-HOUSE-CUSTOMER AND BUZZ)
(THE NEXT SENTENCE IS . .)
(IS A BEARD PART OF BUZZ Q)
(THE FUNCTION USED IS . .)
(THE FUNCTION USED IS . .)
PARTRY—SELECT
((GENERIC - BEARD) (UNIQUE - BUZZ))
(THE KEPLY - .)
(THE SUB-FUNCTION USED IS . .)
PARTRGUQ
(BEARD BUZZ)
(ITS REPLY . .)
YES
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(THE NEXT SENTENCE IS . .)
 (A BOY IS A PERSON)
 (THE FUNCTION USED IS . .)
SETR-SELECT
(IGENERIC . BOY) (GENERIC . PERSON))
THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
 SETR
 (BOY PERSON)
(ITS REPLY . .)
II UNDERSTAND THE SUPERSET RELATION BETWEEN PERSON AND BOY)
 11 UNDERSTAND THE SUBSET RELATION BETWEEN BOY AND PERSON)
 (THE NEXT SENTENCE IS . .)
 (THE FUNCTION USED IS . .)
 SETH-SELECT
(TUNIQUE . JOHN) (GENERIC . BOY))
SETHS
(JOHN BOY)
(I UNDERSTAND THE ELEMENTS RELATION BETWEEN JOHN AND BOY)
II UNDERSTAND THE NEWBER RELATION BETWEEN BOY AND JOHN)
(THE NEXT SENTENCE IS . .)
 THE PUNCTION USED IS - - 1
II UNDERSTAND THE SUPERPART-DE-EACH RELATION BETWEEN HAND AND FINGER)
 ITHE MEXT SENTENCE IS ... )
IHOW MANY FINGER'S DOES JOHN HAVE UP
 THE FUNCTION USED IS . .)
 HAVE-RESOLVE
 (FINGER CUMIQUE . JOHN) 1
 (THE REPLY : 1)
(THE ABOVE SENTENCE IS ANUIGUOUS .. BUT I ASSUME (HAS) MEANS (HAS AS PARTS))
 II DON'T KNOW WHETHER FINGER IS PART OF JOHN!
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ITHE NEXT SENTENCE IS . . .
 (THERE IS ONE HAND ON EACH ARM).
 (THE FUNCTION USED IS . .)
 PARTEN-SELECT
 (IGENER&C . ARMY II . HAND!)
 II REALIZE THE NUMBER RELATION BETWEEN 1 AND (PLIST NAME ARM))
 II UNDERSTAND THE SUBPART-DE-EACH RELATION BETWEEN HAND AND ARM)
 (I REALIZE THE NUMBER RELATION BETWEEN 1 AND (PLIST NAME HAND))
 (THE MENT SEAFENCE IS . .)
 ITHERE ARE THO ARMS ON A PERSON!
 ITHE FUNCTION USED IS . . .
 PARTON-SELECT
 ((GENERIC . PERSON) (2 . ARM))
 (THE MENT SENTENCE IS . .)
 THOW MANY FINGERS DOES JOHN HAVE Q)
 (THE PANCETERN USED IS ...)
HAVE-RESULPE
(FINGER SURTEDE ... JOHN))
 (THE REPLY TO A
 ITHE MOONE SENTENCE IS AMBIGUOUS ** BUT I ASSUME (HAS) MEANS (HAS AS PARTS))
(I KNOW THE SUMPHINAT OF EACH RELATION BETWEEN HAND AND FINGER)
((HON UNINFERMINE) FOR MAND G))
(THE PUNCTION USED IS . .)
 HASN-RESOLVE
            211942-28181 C
 (15 . FINGER) (GENERIC . HAND))
 (THE REPLY . .)
THE ABOVE SENTENCE IS AMMIGUOUS TO BUT I ASSUME (HAST MEANS (HAS AS PARTS))
II KNOW THE BUT ART OF EACH RELATION BETWEEN HAND AND FINGER)
II REALIZE THE NUMBER RELATION BETWEEN S.AMB. (PLIST NAME HAND))
II KNOW THE BUT ART OF THE STATE OF 
 (THE NEXT SENTENCE 15". .)
 (THE FUNCTION USED IS . .)
 HAVE-MESOLVE
 (FINGER TUNIQUE . JOHN))
 ITHE MEPLY 2 .)
ITHE ABOVE SENTENCE IS AMBIGUOUS .. BUT I ASSUME (HAS) MEANS (HAS AS MARTS))
 II KNUM THE SUPERPART-OF-EACH RELATION BETWEEN HAND AND FINGER!
 (I KNOW THE SUPERPART-OF-EACH RELATION BETWEEN ARM AND HAND)
(I KNOW THE SUPERPART-OF-EACH RELATION BETWEEN PERSON AND ARM)
 (THE ANSMER IS 10)
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(THE NEXT SENTENCE IS . .)
THE FELEPHONE IS JUST TO THE RIGHT OF THE BOOK)
                                                  (THE FUNCTION USED IS . .)
                                                  JRIGHT-SELECT
                                                  ((SPECIFIC . TELEPHONE) (SPECIFIC . BOOK))
                                                 (THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
PATCH!
(TELEPHONE BOOK)
                                                  (115 REPLY . .)
                                                 TI UNDERSTAND THE ELEMENTS RELATION BETWEEN GUZSAO AND TELEPHONE)
                                                 (GO284) 15. A BOOK!
11 DIMERSTAND THE ELEMENTS RELATION BETWEEN GO2841 AND BOOK)
11 DIMERSTAND THE MEMBER RELATION BETWEEN BOOK AND GO2841
                                                (I REALIZE THE JRIGHT RELATION BETWEEN TELEPHUNE AND BUCK)
                                       DEANG NAME SUBPRANTO OF MALL AT FIDE OF MARK FIRST AND STATE OF THE ST
      (THE NEXT SENTENCE IS . .)
                                              (THE FUNCTION USED IS . .)

JATIGHT-SELECT

(ISHERIT . . RAD) (SPECIFIC . TELEPHONE))

LINE REPLY . .)
                                                THE SUB-RUNCTION USED IS . . )
           JATGAT

LAA IELEEMONEJ

(15 ABAL)

(G02842 IS A PAO)

(I UNDERSTAND THE ELEMENTS RELATION BETWEEN G02842 AND PAO)

(L UNDERSTAND THE HAMMER RELATION: BETWEEN PAO AND G02842)

(L REALIE IME BREAK RELATION: BETWEEN PAO AND FELEPHONE)

(L REALIE THE JEFT RELATION BETWEEN FACAND AND FELEPHONE)
                        THE MEXT SENTENCE 45 . .)
SENTENCE THE MUNICIPAL LISED IS ...
                        TISPECIFIC PAD (SPECIFIC . BOOK))
                THE REPLY . .)
THE SUB-FUNCTION USED IS . .)
                                                  (PAD BOOK)
   ET BETTER HET THE THE THE THE THE STREET WET TO LOCK THE STREET HE STREET WET WELL THE STREET HE STREET WET WELL THE STREET HE STREET HE
                            With The Table
                                 TYNE NEXT SENTENCE IS . .)
ILS THE BOOK TO THE PAD Q)
                                THE FUNCTION USED IS. ... 1
1 AIGHTO-SELECT
1 CSPECIFIC ... RADA (SPECIFIC . 800K))
(THE REPLY ...)
                                           (THE SUB-FUNCTION USED IS . .)
RECHTSED
THE BOOK)
                                                  IITS REPLY . .)
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THE PAD IS TO THE RIGHT OF THE TELEMONE!
                           TTHE FUNCTION USED IS . .)
                                                                                                                                                                                                                                                                                                                                                                                                       and was a street
                              TESPECIFIC . PADI (SPECIFIC . IELEPHONE))
                           14319
                             IPAD TELEPHONE
                           The function used is
                         · * fileson i forme (for the feetate
                              RIGHT-SELECT
                              ((SPECIFIC . TELEPHONE) (SPECIFIC . PAD))
                             (THE KEPLY . .)
                           AFONT IN
                              (TELEPHONE PAD)
                             PATE MENT TO THE STATEMENT IS INPUSSIBLE!
             AND TARM AND IS IN THE FEEL OF THE BONK)
                  (The function used is ...)

Althoughter adort (Specific - Ash-Tray))

(The function of the fun
     COORDS IS A SH-IRAYI COORDS IS A SH-IRAY SHOULD COORDS IN A SH-IRAY SHOULD COORDS IS A SH-IRAY SHOULD COORDS IN A SH-IRAY SHOULD COO
THE PADE
   " "FORME PUNCTION USED IS ...
     I I'M BEHM - SELLET
                             (ISPECIFIC . PAD) (SPECIFIC . PENCIL))
 THE REPLY ... I THE REPLY ... I THE PROPERTY OF USED IS ... IN THE PROPERTY OF THE PROPERTY OF
 ### THE PRINCE | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 |
                           (I UNDERSTAND THE LEFT RELATION BETWEEN PENCIL AND PAG)
     1224 4 12 (ME 16 4)
```

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THE NEXT SENTENCE IS . . )
                                                                                     INHAT IS THE POSITION OF THE PAD Q1
(THE NEXT SENTENCE IS . .)
(THE PAPER IS TO THE RIGHT OF THE TELEPHONE)
                                                                                     THE FUNCTION USED IS . .)
                                                                                     LOC-SELECT
THE FUNCTION USED IS . . )
                                                                                     [[SPECIFIC . PAD]]
RIGHT-SELECT
                                                                                     ITHE REPLY . . .
((SPECIFIC . PAPER) (SPECIFIC . TELEPHONE))
                                                                                     TIME SUB-FUNCTION USED IS . .)
(THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
                                                                                     LUCATES
                                                                                     (PAD)
RIGHT
                                                                                     IIIS REPLY . .)
(PAPER TELEPHONE)
(ITS REPLY . .)
(GO2845 IS A PAPER)
(I UNDERSTAND THE ELEMENTS RELATION BETWEEN GUZ845 AND PAPER)
(I UNDERSTAND THE MEMBER RELATION BETWEEN PAPER AND GOZBAS)
(I UNDERSTAND THE RIGHT RELATION BETHEEN PAPER AND TELEPHONE)
                                                                                     (THE LEFT-TU-RIGHT URDER IS AS FOLLOWS)
                                                                                     (PENCIL (ASH-TRAY BOOK TELEPHONE PAD) PAPER)
(I UNDERSTAND THE LEFT RELATION BETWEEN TELEPHONE AND PAPER)
                                                                                     (THE NEXT SENTENCE IS . .)
                                                                                     (A TELEPHONE IS AN AUDID-TRANSDUCER)
(THE NEXT SENTENCE IS . .)
(WHERE IS THE PAD Q)
                                                                                     (THE FUNCTION USED IS . .)
                                                                                     SETR-SELECT
(THE FUNCTION USED IS . .)
                                                                                     (IGENERIC . TELEPHONE) (GENERIC . AUDIO-TRANSDUCER))
WHERE-SELECT
                                                                                     THE REPLY . .!
((SPECIFIC . PAD))
                                                                                     (THE SUB-FUNCTION USED (S . .)
(THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
                                                                                     (IELEPHONE AUDIO-TRANSDUCER)
MHERES
(PAD)
                                                                                     (ITS REPLY . .)
(ITS REPLY . .)
(JUST TO THE RIGHT OF THE TELEPHONE)
                                                                                     (I UNDERSTAND THE SUPERSET RELATION BETWEEN AUDIO-TRANSDUCER AND TELEPHONE)
                                                                                     II UNDERSTAND THE SUBSET RELATION BETWEEN TELEPHONE AND AUDIO-TRANSDUCER)
(SOMEWHERE TO THE RIGHT OF THE FOLLOWING . . (PENCILI)
                                                                                     (THE MEXT SENTENCE IS . .)
(THE NEXT SENTENCE IS . .)
                                                                                     IA DIAPHRAGM IS PART UF AN AUDIO-TRANSDUCER)
INHAT IS THE POSITION OF THE PAD Q)
                                                                                     (THE FUNCTION USED IS . .)
                                                                                     PARTA-SELECT
(THE FUNCTION USED IS . .)
                                                                                     (IGENERIC . DIAPHRAGM) (GENERIC . AUDIG-THANSDUCER))
LOC-SELECT
                                                                                     (THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
((SPECIFIC . PAD))
(THE REPLY . .)
(THE SUB-FUNCTION USED IS . .)
                                                                                     PARTE
                                                                                     (DIAPHRAGE AUDIO-TRANSDUCER)
LOCATES
                                                                                     (ITS REPLY . .)
(PAD)
(ITS REPLY . .)
(THE LEFT-TO-RIGHT ORDER IS AS FOLLOWS)
                                                                                     II UNDERSTAND THE SUBPART-OF-EACH RELATION BETWEEN DIAPHRAGE AND AUDIG-TRANSDUCER)
                                                                                     (I UNDERSTAND THE SUPERPART-OF-EACH RELATION BETWEEN AUDIO-TRANSDUCER AND DIAPHRAGA)
(ASH-TRAY (BOOK TELEPHONE PAD) PAPER)
(TO FURTHER SPECIFY THE PUSITIONS YOU MUST INDICATE WHERE THE PENCIL IS WITH RESPECT TO THE ASH-THAY)
                                                                                     (THE NEXT SENTENCE IS . .)
(THE NEXT SENTENCE IS . .)
                                                                                     (WHERE IS A DIAPHRAGE O)
(THE BOOK IS JUST TO THE RIGHT OF THE ASH-TRAY)
                                                                                     (THE FUNCTION USED IS . .)
(THE FUNCTION USED IS . .)
                                                                                     WHERE-SELECT
                                                                                     (IGENERIC . DIAPHRAGH))
JAIGHT-SELECT
((SPECIFIC . BOOK) (SPECIFIC . ASH-TRAY))
                                                                                     (THE REPLY . .)
                                                                                     THE SUB-FUNCTION USED IS . . )
(THE REPLY . .)
THE SUB-FUNCTION USED IS . . )
                                                                                     WHEKEG
JHIGHT
                                                                                     (DIAPHRAGM)
(BOOK ASH-TRAY)
                                                                                     (ITS REPLY . .)
(ITS REPLY . .)
                                                                                     (JUST TO THE LEFT OF THE PAD)
(I REALIZE THE JRIGHT RELATION BETWEEN BOOK AND ASH-TRAY)
                                                                                     IJUST TO THE RIGHT OF THE BUCK!
II REALIZE THE JEEFT RELATION BETHEEN ASH-TRAY AND BOOK)
                                                                                     (SUMEWHERE TO THE LEFT OF THE FOLLOWING . . (PAPER))
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### Biographical Note

Bertram Raphael was born in New York City on November 16, 1936. He attended the Bronx High School of Science, received a B.S. degree in Physics from Rensselaer Polytechnic Institute in 1957, and received an M.S. degree in Applied Mathematics from Brown University in 1959.

Mr. Raphael held several scholarships at RPI from 1953 to 1957, and the Universal Match Foundation fellowship at Brown University in 1958. He received an NSF honorable mention and was elected to the Society of Sigma Xi in 1957.

Mr. Raphael has been interested in automatic computation since 1959 and has worked in that field for RCA, Moorestown, New Jersey; for Bolt, Beranek and Newman, Inc., Cambridge, Massachusetts; and for the RAND Corporation, Santa Monica, California, for whom he is presently a consultant. He taught at RAND summer institutes for Heuristic Programming (1962) and Simulation of Cognitive Processes (1963), and lectured at UCLA during the summers of 1963 and 1964. He has recently accepted an appointment as Assistant Research Scientist at the Center for Research in Management Science, University of California at Berkeley, effective June, 1964.

His publications include:

- "Multiple Scattering of Elastic Waves Involving Mode Conversion," with R. Truell, AFOSR TN 59-399, Metals Research Laboratory, Brown University, May, 1959.
- "A Computer Representation for Semantic Information," paper presented at 1963 meeting of AMTCL, abstract in <u>Mechanical Translation</u> 7 (2), October, 1963.
- "A Comparison of List-Processing Computer Languages," with D. G. Bobrow, Comm. ACM, expected publication May, 1964.
- "LISP as the Language for an Incremental Computer," with L. Lombardi, in The LISP Programming Language: Its Operation and Applications, (Eu C. Berkeley, ed.), Information International, Maynard, Massachusetts, expected publication May, 1964.

His hobbies include mountain climbing and square dance calling.

Mr. Raphael is currently a member of the Association for Computing Machinery, the Association for Machine Translation and Computational Linguistics, and the American Mathematics Society.

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