A COMPUTER MODEL OF INFORMATION PROCESSING IN CHILDREN

BY

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Abstract

A model of cognitive information processing has been constructed on the basis of a protocol gathered from a child taking an object association test. The basic elements of the model are a graph-like data base and strategy. The data base contains facts that relate objects in the experiment. The graph distance that separates two objects in the data base is the measure of how well a relation is known. The strategy used in searching for facts that relate two objects is sequential in nature.

The model has been programmed for computer testing in the LISP programming language. The responses of the computer model and the original subject are compared. To aid in the model evaluation a revised test was defined and administered to two children. The results were modeled and the correspondence of model and subject performance is discussed.

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1. Introduction

In this paper we describe a computer model of human cognitive **processes.** The subjects are children from five to six years of age. A portion of the Illinois Test of Psycholinguistic Abilities [6] has been administered and protocols gathered. In the'basic test, the child is shown pictures of objects. **One** object is designated as the key object and the child is asked to point to the object in the remaining group that'he feel is best "related" **to** the key. A sequence of these trials constitutes the basic **experiment.** Prom **the protocol,** a model of the type of information processing believed to be used by the child has been **constructed.** This model has been **programmed** in the LISP **programming** language [7]. **It** is possible to test the effectiveness of-the model **by presenting** it with the test objects and observing which objects it selects as being most closely related. Subject and model performance are compared and the model modified until agreement is obtained. The basic elements of the model are the data base and the strategy. The data base reflects what the model or child knows about the objects in the test sequence. The strategy dictates how the data base is to be **examined** to determine the appropriate related **pairs.**

In spirit this work is related to the work of Abelson and Colby [1,4]. We differ in that we examine the behavior of children where they have concentrated on adults, Cur hope is that the **phenomena** are simpler and hence more **susceptable** to modeling. We would like to establish one point on a development scale of cognitive processing; in this area, we look to the work of Piaget and Bruner [5,2,3]. Bruner's work has been important in showing the value of finding strategies that people use in performing various tasks. Piaget has written extensively on the development of our information processing abilities. We will attempt to place the abilities that we have detected in perspective with those he proposes. Our techniques for gathering protocols and for protocol analysis have been aided by the work of Newell at Carnegie Mellon University [8].

The goal of the research is to create a model of the performance of one particular individual. We are not interested in whether the responses are correct but rather in why they were made. Nor are we interested in constructing the best possible model for determining relations among objects. This is a basic difference between this research and that directed at producing computer programs to play chess. Chess playing programs are generally written to play the best possible game by whatever means available. Strategies and data bases are common to both types of study.

A difficulty in the evaluation of models such as we propose .is the determination of whether the model actually reflects-the human behavior. This is often referred to as the verification problem. We have approached this problem by constructing a second series of tests based on the objects present in the original series. In the second series, the objects are rearranged so as to elicit different responses from the model given the strategy derived to explain the performance on the first test series. Human subjects are then tested with the revised sequence to see if they also give different responses. This provides a check on the model and how well it explains behavior.

In the next section, we describe the test sequence used in constructing the model. We also describe how the tests were modified for the verification experiments. This is followed by a discussion of the model including a description of the types of relations that may be represented,' how the model "learns", how the model "recognizes" objects, and the basic strategy that is used to determine which pair of objects is most closely related. The learning and object recognition behavior of the model are not intended to correspond in detail to human behavior. These processes play very important roles, particularly object recognition since we assume that the objects are recognized before any attempt to relate them is made, The protocols obtained from the child and from the model are compared and evaluated and the results of the verifications experiments are also discussed. We conclude with a discussion of the findings and some suggestions for possible extensions to this work.

2. Test Description

The Illinois Test of Psycholinguistic Abilities is a battery of tests designed to give a measure of the language proficiency of children between the ages of 2 1/2 and 9 1/2 years of age. We have selected a particular portion of the test for study, namely that designed to measure the visual-motor association ability of the child. The child is shown pictures of familiar objects such as "car", "ball", "man", etc.. A typical trial has the objects "shoe", "sock", and "ball", The shoe is designated as the key object and the child is asked to point to either the sock or the ball as being most closely related to the shoe. A copy of the test pictures for this example is given in Figure 1. The key object (shoe) is placed on the right side of the page separated from the possible choices by a vertical line. In this paper we will describe such a trial using the form:

relate (a-shoe (a-sock a-ball))

The hyphenation is used since "a-ball" will represent a distinct object in our model.

The-authors of the test claim that it is constructed to minimize the encoding problems presentinrecognizing objects. Once a match is obtained the decoding process is minimized by allowing the subject to pointto the response. The complete test consists of about twenty trials. The responses are graded and scored according to results obtained by testing 1000 normal children. We art; not interested in the scoring of the experiment; thus

Typical Trial in Original Test

Demonstration II

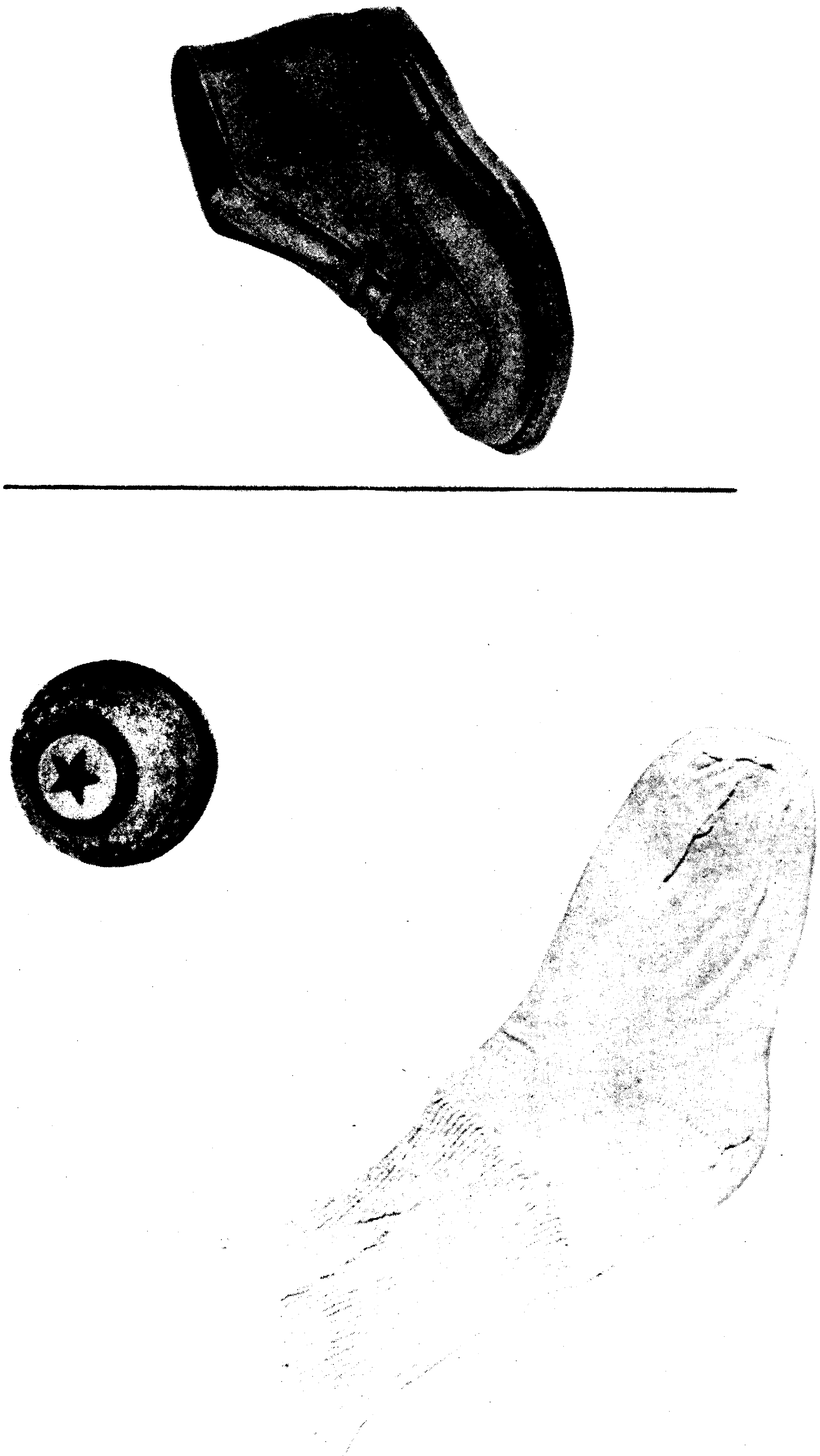

Figure 1

we omit any discussion of how well the child or model does. Our findings on the actual performance of children taking the test cast doubt as to whether the test really serves the function it was intended to serve. This matter will be treated further in the discussion of the main subject protocol.

For the purposes of our study, the administration of the test has been modified slightly. When the pictures are shown to the child he is asked to identify each object. This provides a check that the objects are recognized as intended. When the child has made his choice of a pair of objects, he is then asked why he made that choice, His response to this question provides the basis on which insight as to the information processing performed is obtained.

Since we are interested in studying the behavior of a particular individual, we have not gathered data on large numbers of subjects. Our feeling is that it is better to make a detailed analysis of the performance of a single individual than to gather volumes of statistics on how groups respond to the test. The test was administered by an experimenter who was seated facing the child with the pictures displayed on a table between them. The sessions were recorded either by a human recorder or on tape and then transcribed for analysis.

The first time the test was administered to a child it was apparent that two different types of information processing were being used. In the first and most elementary, the subject would pick items as being related simply on the basis of important visual characteristics of the objects.

Thus for example, "a-drum" and "a-tunafish-can" would be said to be related because "a-drum looks like a-tunafish-can". The second type of response was apparently higher level. Here the choice was justified by facts that showed a knowledge of what the objects were and how they were used, For example, "a-lamp" and "an-end-table" are related because "you put a-lamp on an-endtable". Since the second type of association seemed to be of a more "cognitive" nature and since it was more independent of the perceptual processes, it was decided to attempt to model only responses in this category. One further difficulty was encountered with the test. In many cases the subject did not recognize the objects that were to be related. This contradicted the original assumptions upon which the test was constructed. The difficulty here is in providing a suitable picture that will evoke the proper object recognition. Sometimes the objects were not recognized even when the subject was given the object name (a life preserver such as found on a ship was not known to the subject).

These difficulties led to the selection of a subset of the trials in the test. The model was constructed from this subset. In Appendix A we give the ten trials used along with the protocol obtained from the child for these trials.

verification testing

When satisfactory model performance was achieved on the test sequence, it was suggested that the trials be revised in order to attempt to verify that the model actually did reflect the information processing that the child had **used.** ' A new test sequence was defined that included trials from the first sequence with some additions. The original subject used in the first trial sequence was no longer available for testing, so two new subjects were obtained. The first was female, age 5 years; the second, male, age 6 years. . Detailed discussion of the **results** of the verification testing will be given after we have defined the model and compared its performance with the first protocol obtained, The general approach in making verification trials was to substitute a new object in one of the old trials and then to observe subject and model performance,. The model, Using **its** Strategy, might now prefer that the new object be paired with the key. If the model is correct then the subject should also make the same choice. In effect we are introducing a form of differential testing in which we ask the subject and model to make finer and finer distinctions among the trial objects. Note that since we are now dealing with three subjects we in effect have three different models, one for each subject, This makes evaluation more difficult since each model (subject) will in general have slightly differentdata bases and possibly strategies. It has the advantage of providing additional model construction and evaluation **opportunities.**

In Figure 2, the twelve trials that made up the verification test **sequence** are given. For this test sequence, new object pictures were used since we felt that in **some** cases the pictures in the original test were difficult to identify. Each picture was placed on a small card and the cards were placed on **a** table between the subject and the **experimenter.** The key object was separated from the possible choices as in the first sequence.

Verification Test Sequence

1. relate (a-shoe (a-sock a-ball))
2. relate (a-shoe (a-sock a-foot))
3. relate (a-hand (a-stove a-glove a-star a-flower))
4. relate (a-spoon (a-cup a-car))
5. relate (a-spoon (a-cup a-knife))
6. relate (a-hammer (a-screwdriver a-nail a-pin))
7. relate (a-girl (a-chair a-couch a-mother))
8. relate (a-window (a-clock a-button the-sun))
9. (female subject)

   relate (a-window (a-clock a-house the-sun))

9. (male subject)

   relate (a-window (a-house a-button the-sun))

10. relate (a-bottle (a-book some-blocks a-box))
11. relate (a-truck (a-horse a-giraffe a-zebra a-cow))
12. relate (a-truck (a-horse a-man a-zebra a-cow))

Figure2

3. Model Description

The major elements of the model are the data base and the strategy invoked to relate objects. In addition there are components for the input of facts into the data base (learning) and for recognizing objects when presented with a list of object characteristics such as round, metallic, etc..

the data base

The data base for these experiments is intended to reflect only a small portion of the information that the child being modeled has in his memory. Only relations between objects are represented and it is assumed that each object is distinct and for the purposes of the test unambiguous. Thus the object "ball" refers to the round, spherical object that bounces rather than the party at the country club on Saturday night. In cases where the label associated with an object has multiple meanings, we distinguish them by adding a number suffix to the label obtaining "ball1", "ball2", etc.. This solution has been used before by Quillian [9].

The data base is a graph-or netlike structure with the objects corresponding to the nodes and the relations between objects represented by the links. The links are of several different types and correspond closely to certain simple sentence types. The links may be thought of as having different colors to represent the type of link. This is a rather visual interpretation of how information is represented in the model, In a human there are many more mechanisms at work for the human data base has a dynamic nature that can be affected by many factors that are poorly understood. The model is intended to correspond to the subject's knowledge of the test objects at one short period in time, when the test was administered.

<u>link types</u>

The link types in the data base correspond to simple sentence types. The link types are:

a. active

form: (object verb object)[1]

example: (a-bat hit a-ball)

b. passive

form: (object IS verb BY object)

example: (a-ball is hit by a-bat)

c. predicate7

form: (object IS verb preposition object)

example: (a-ball is caught with a-glove)

d. predicate2

form: (object IS SOMETHING object IS verb preposition)

example: (a-glove is something a-ball is caught with)

e. instance

form: (object IS (HAS) object)

examples: (a-ball is round)

(a-glove has five-fingers)

1. Sentences will be enclosed in parentheses since this is the notation used in the model.

f. quality

form: (SOMETHING THAT IS (HAS)[2] object IS object)

examples: (something that is round is a-ball)

(something that has five-fingers is a-glove)

Each object in the data base may be connected to other objects by means of links of the above six types. The links are created in pairs so that for every active link there is a corresponding passive link, for every predicate1 link there is a predicate2 link, and for every instance link there is a quality link. All information in the data base is represented in terms of these six links or sentence types,

The link types separate into two classes, the instance and quality links are known as <u>vertical links</u> while the other link types are known as <u>horizontal links</u>. The vertical links will be used in-the object recognition process and the horizontal links will be most important in relating objects. This distinction is very useful in reducing the size of the data base for search when attempting to relate objects and also to recognize objects. The distinction between horizontal and vertical links has been made before by Abelson [1]. He did not use' this distinction as a search heuristic however.

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2. The verb "has" is used here in the sense of "has as an attribute". Raphael [10] notes that there is another sense of "has" that of ownership as in "He has a bicycle.". This sense of the word is represented by horizontal links in the data base.

The size of the data base is an important factor in any experiment such as this. The original test sequence involved about fifty distinct objects. For each of these objects roughly ten links to other objects were defined in the "learning" phase. This resulted in the introduction of additional objects and links, We do not claim to represent all the child knew about the objects, but we do hope that we have represented those facts that are in some sense "closest" to his consciousness and that were a factor in the relational process.

learning

In order for the model to be able to perform its basic function of associating related objects, facts regarding the objects in the experiment must be learned by the model. In the learning phase, facts are supplied in the form of the simple sentence types that correspond to links in the data base. The allowable input formats are sentence types active, predicatel, and instance. The inputs are processed by a LISP function called LEARN, Each sentence results in appropriate links being generated by the program. An instance sentence type results in both an instance link and a quality link being generated. Thus (a-ball is round) generates an instance link from "round" to "a-ball" and a quality link pointing from "a-ball" to "round". An active sentence type has the form (object verb object). This sentence results in four links being generated. They are an active link from the subject object pointing to the predicate object, a passive link pointing from the predicate object to the subject object, a quality link from the predicate object pointing to the verb, and an instance link from the verb to the predicate object of the sentence, That is, the sentence (a-bat hit a-ball) results in an active link from "a-bat" to "a-ball" , a passive link from "a-ball" to "a-bat", an instance link from "hit" to "a-ball", and a quality link from "a-ball" to "hit", A predicate1 sentence type also results in four links being generated. This sentence type has the form (object IS verb preposition object). The subject object and the predicate object receive appropriate predicate1 and predicate2 links. The "object IS verb" portion of the sentence is treated as an instance sentence and the appropriate links are generated, The sentehce (a-ball is caught with a-glove) results in a predicate1 link from "a-ball" to "a-glove", a predicate2 link from "a-glove" to "a-ball", an instance link from "caught" to "a-ball", and a quality link from "a-ball" to "caught".

As implemented in LISP, each object is treated as a LISP atom, The links to other atoms are stored on the property list of the atom.

object recognition

The recognition of the test objects has been modeled in the following manner. Each object is perceived as a list of lists of characteristics of the object. For example the object "a-ball" might be perceived as ((round red) (made-of-rubber)). The sublists are ordered in the order that the characteristics are assumed to be noted, The translation of object to characteristic list is done by lookup in a list with the name OBJECT-CHARACTERISTICS. The characteristics used in recognizing objects are given in Appendix B. No attempt is made to model the perceptual processes that determine the characteristics such as round. The recognition process is performed by a

LISP function called RECOGNIZE. This function takes each sublist of characteristics and forms a list of the objects in the model that have those characteristics. If there are multiple objects with the perceived characteristics, the program processes the remaining sublists until a distinct object is found. The model then gives the response (THAT IS object), If there are no objects in the data base with the noted characteristics, the model will respond (DO NOT KNOW WHAT THAT IS). If all characteristics are processed and there are multiple objects found, the model responds (I THINK THAT IS EITHER object OR object OR . . .).

Only the instance links in the data base are used in the recognition process, This greatly restricts the amount of data that must be examined and makes object recognition an efficient procedure.

association strategy

The association strategy in combination with the content of the data base provide the basis for the association of objects in the experimental trials. The strategy used is quite simple and has a sequential nature. The idea is that certain facts are better known than others; the data base is examined to find the fact that best relates one pair of objects, The types of structures searched for were determined by an examination of the first subject protocol. How well a particular fact is known is reflected in this model by the form in which the information is represented in the data base. If a fact is well known it is represented by a single sentence link, for example (a-bat hit a-ball). If a fact is not so well known, it may be reached by searching through several links via intermediate objects.

For example, the fact that (a-truck carry a-horse) might be represented in the data base by two links, a vertical link (a-horse is an-animal) and a horizontal link (a-truck carry an-animal), If the subject also knows that (a-man drive a-truck) and this was stored as a direct link, then we would say that this fact is "better" known than the fact that (a-truck carry a-horse). Thus, we use the structure of the data base to reflect how well facts are known, An alternative would be to assign weights to the facts and select the fact with the highest weight. Our objection to this approach is that we do not know how to assign the weights for facts nor do we know the factors that affect the weights. We were interested in determining how well a model that did not make use of weights would perform.

Given the philosophy of representing facts in the data base outlined above, the strategy to locate the most closely related object pair is simply to search the data base for the first path that links a pair of objects. The active, passive, predicate1, and predicate2 links are examined, in that order, first for a single link relating the key object and one of the possible choices, If this search is successful it returns the first such fact found and does not continue further, If this search fails, the data base is examined for a pair of facts that relate two objects in the following manner, First two horizontal facts are sought that have the two objects as subjects and identical predicates. For example, if "the-sun" and "a-lamp" are to be related, the fact pattern might be (the-sun give light) and (a-lamp give light). The next search determines if there are two horizontal facts that have a common third object between them. For example, to relate "the-sun" and "a-window", the fact pattern may be (the-sun give light) and (light is shine through a-window). If these attempts fail, the model next looks for a horizontal - vertical fact relationship, That is, the two objects are related through a common intermediate object that is reached by an instance link together with any horizontal link. Thus as in an earlier example, a-truck and a-horse would be related, given the facts (a-horse is an-animal) and (a-truck carry an-animal). If these attempts to find a match are unsuccessful, the model announces (SORRY - NOTHING SEEMS TO GO WITH object).

It is important to note that only particular links in the data base are examined and that they are examined in a particular order, This reduces the amount of information that must be processed in each case. Note also that the model makes no attempt to check on the "reasonableness" of its response. It is very possible that there is contradictory information present in the data base that was not reached in the search process. This approach is in keeping with the ideas of Piaget that children at this age make little or no effort to apply logical processes in their thought [5].

The basic strategy used in relating objects is outlined schematically in Figure 3 using horizontal lines to denote links of type active, passive, predicate1, or predicate2 and vertical links to indicate instance links. The adequacy of this model will be considered after a discussion of the results of the test protocols.

implementation

Computer programs to execute the functions of the model just described have been written in the LISP programming language [7]. The

Search Strategy Used for Object Association

```
1.   A------------>B

2.   A-----//-------->
     BI----//------->            (where predicates are identical)

3.   A-------------->I  and  I-------------->B
                                 (I is some intermediate object)

4.   I    I-------------->B     (I is some intermediate object)
     ^
     |
     A
```

Figure 3

program is currently running on the IBM 360/67 computer at Stanford University. The most important functions in the model are LEARN, which builds the link structure of the data base; RECOGNIZE, which locates an object in the data base given a specification of the characteristics of the object; and RELATE, which given a key object and a list of objects that are possibly related to it, searches for a related pair using the strategy just discussed. To aid in the development of the program, an additional function TELLABOUT was written. This function provides an output listing of all links in the data base for a specified list of objects. A complete listing of the program is given in Appendix C.

In a typical run, the program is defined and then the facts are input to form the data base. Approximately 300 facts relating the fifty trial objects are usually processed. The characteristics that are used to recognize each object are specified next. The trials are then given in the form illustrated by RELATE (A-BAT (A-BALL A-SHOE)). The model identifies the objects, e.g. (THAT IS A-BALL) and then the related pair is designated along with the reason for the choice, e.g. (A-BAT GOES BEST WITH A-BALL BECAUSE (A-BAT HIT A-BALL)). The total running time of the program is usually about .5 minutes. There is no relation between the time it takes the model to make an association and the time it takes a human subject. The model typically takes less than a second to reach a decision.

4. Results

The sentences used to generate the data base for the original test sequence are given in Appendix D. The modifications to the data base for the other subjects will be mentioned in the following discussion, We first give a comparison of the subject and model performance for the original test sequence. This is followed by the results of the verification testing including a comparison of subject and model performance for two different subjects. The original subject was a girl, age 5 years. The verification tests were made with a 5 year old girl and-a 6 year old boy,

<u>original test sequence</u>

Appendix E summarizes the subject and model responses to the original trial sequence. There is a close correspondence betweenthe model responses and the subject responses. In trial 10, the responses are different but this was done purposely to illustrate the effect of leaving one fact (a-truck carry a-horse) out of the data base. If this fact had been present, the model response would have been the same reason as given by the subject. It is interesting that a fixed strategy is able to account for all the responses given by the subject. The frequent appearance of the wprd "you" in the subject protocol is a-lso worthy oi' mention. This is characteristic of the responses of a child in the early stages of cognitive development. One of the problems S-n the design of the data base was how to account- for the node "you". The word is used ambiguously, sometimes referring to a genera3 collection of people performing some action and sometimes referring to only a single person, the child himself, Also the prefix "you" may be attached to almost every fact (you catch a-ball with a-glove), etc.. This would result in the node "you" having links to almost every other node in the data base, which is not a particularly interesting case. For these reasons, the basic sentences for the data base were given a more abstract structure. The prefix "you" could be added by a trivial transformation before output to yield an even closer correspondence between the subject and model responses.

verification test sequences

The problem in asserting that we now have a successful model of the information processing of the child is that we have used the same protocol not only for the construction of the model (although this was not done directly) but also for the evaluation of the model. For these reasons, the verification test sequence was defined (Figure 2). A summary of the results of administering this sequence to the female subject is given in Appendix F, The original subject was no longer available for testing and so could not be used for model verification, However, even if the original subject had been available there could have been differences in the subject responses due to variations in the data base that occurred in the interval between testing. The modeling of how these variations occur in the data base is beyond the scope of this experiment, The changes made in the data base for this subject are given in Figure 4. The results of the test revealed certain differences between the two subjects, Instead of responding that (a-glove is worn on a-hand) in trial 3, the response was

Modifications to Data Base (Appendix D)

for Female Subject

add

(a-shoe warm a-foot)

(a-mother watch a-girl)

(a-truck carry a-cow)

delete

(a-girl belong-to a-mother)

(a-nail hit a-hammer)

(a-nail is a-thing)

(the-sun is shine through a-window)

Figure 4

(a-hand is warm by a-glove) indicating that this fact had precedence in the data base of the second subject. In trial 8, the responses of the subject and model differ. In this case the subject was attracted by the window sill in the picture of the window and made the association between clock and window on the basis of the fact that (a-window has a-sill) and (a-clock sits on a-sill). Note however that when a-house is substituted for a-button as in trial 9, that the subject and the model now both feel that the window and the house are more closely related than their previous choices. In both cases this is due to the presence of the fact (a-window is part of a-house) that is encountered by the search strategy-before the indirect reference, given in trial 8. The search strategy also accounts for the selection of shoe-foot in trial 2 instead of shoe-sock as in trial 1 and the selection of spoon-knife in trial 5 versus spoon-cup in trial 4. In trial 6, the subject -in the verification test gave a different response than the subject in the original test. This is accounted for by the absence of the fact (a-hammer hit a-nail) in the data base of the second subject. Since this fact is absent, the search continues with the result noted in the response, The only difficulties detected in the correspondence of the model and subject performance appear in trial 10 and in the last two trials 11 and 12, In trial 10, the subject gave a string of irrelevant facts in relating the objects. The model is not capable of this type of behavior but could perhaps do this in some random fashion. In trial 11, the model's reason for associating cow-truck is that the data base contains the fact (a-truck carry a-cow). In trial 12, the reason is (a-man drive a-truck). Unfortunately both these facts are of the type looked for first in the search strategy.

Since the model picks the first possible response it can find, there is no reason to prefer one fact over the other, The correspondence of the responses in trial 12 is due to the order in which the facts were encountered,, This suggests that there needs to be a ranking of the facts in the horizontal classes <u>or</u> that the data base has not been properly specified to elicit the responses. If the result in trial 11 had been derived via the reasoning (a-cow is a-thing) and (a-truck carry a-thing), i.e. a vertical link in conjunction with a horizontal link, then the strategy would have yielded the proper response without resort to weights. However if the data base also contains the fact (a-horse is a-thing) then there is no reason to prefer (a-truck carry a-cow) to (a-truck carry a-horse). Difficulties such as these can be resolved by refining the notion of "a-thing".

<u>second verification test</u>

The results of administering the verification test to the male subject are summarized in Appendix G. Modifications to the original data base (Appendix D) are given in Figure 5. In this sequence several interesting phenomena were observed. For the first time a subject felt that both possible choices could be associated with the key object (trial 2). This indicates that this subject did not adhere to the premise that the first possible match be selected without a search for contradictions, Examination of this case (a-shoe (a-sock a-foot)) reveals that it is hard to find a basis for the separation of the objects. We feel that in this case, the subject has two facts both of which are so "close" together in his data base that they were unavoidably encountered by his search mechanism, In the

Modifications to Data Base (Appendix D)

for Male Subject

<u>add</u>

(a-shoe cover a-sock)

(a-shoe cover a-foot)

(a-sock cover a-foot)

(a-mother watch a-girl)

(a-bottle is a-thing2)

<u>delete</u>

(a-bottle is a-thing)

(a-spoon stir a-drink)

(a-girl belong-to a-mother)

(the-sun is shine through a-window)

Figure5

model, we might explain this phenomenon in the following manner. We would modify the search 'strategy slightly so that the model would not search exhaustively for contradictions but would continue to search through the remaining items at the particular strategy level it was currently working on. To illustrate, the first step in the search strategy is to look for a single fact that relates the key object and one of the possible choices, e.g. (a-shoe cover a-sock) , We propose that before giving this as the response, the search process continue until all single horizontal facts (facts at the same level) have been considered. If additional pairs are encountered, the model would announce that more than one of the possible choices was suitable, again if the fact (a-shoe cover a-foot) was present the model would announce that shoe-foot and shoe-sock are possibly related and that it is unable to resolve between them.

Another phenomenon observed for the first time in this test was the inability of the subject to relate any of the object pairs (trial 3, 10, and 11). There are two possible ways to account for this behavior in the model. The first is by altering the subject strategy by eliminating part of it, say levels 3 and 4 in Figure 3. The subject would then be unable to form paths between objects through an intermediate object or to make a path through a vertical link followed by a horizontal link. These portions accounted for the responses in the original test sequence, The other alternative is to selectively restructure the data base so that the required links are not present to make the relations between the object pairs. Without further testing of the subject there is no way to resolve this issue. The second approach (modification of the data base) was used to obtain correspondence between the model performance and the subject performance.

In trial 4, the subject response does not correspond to the model response. In this case, the facts are related but through an intermediate object "food" as in (a-knife cut food) and (food is eaten with a-spoon). If we reorder the strategy for this subject to search for the patterns of level 3 (Figure 3) before the patterns of level 4, we would get the response given by the subject.

5. Discussion

The results of the verification tests indicate that the data base and strategy for association of related objects are adequate to explain the behavior of children in a crude way. The significance of this is not clear, since this work is really only a beginning in learning how to model the thought of a child. We emphasize that we are modeling the thought processes of a single individual. Thus in the preceding section we were really discussing three models, one for each-of-the subjects. The similarity among the subject responses to particular trials is interesting.

A sequential strategy was employed in the search for related object pairs. This does not imply that no parallel processing is done but rather that parallel processing does not appear to he necessary to explain the behavior observed in the subjects.

There is a close interaction between the strategy and the data base portions of the model. It is our feeling that the data base should be structured so that the relevant information can be located quickly and easily. This has been done in our model by using the measure of graph distance as an indication of how well a particular fact is known. The search for the correct response is then reduced to locating the pair of objects with the shortest path between them. This searching is always breadth first rather than depth first. In fact, the search never goes deeper than a distance of two links in the graph. This is no doubt a simplification that was adequate in this case because of the limited scope of this experiment. We do feel that limited depth searches are of value however, Piaget's views on cognitive development are well summarized by Flavell [5]. In the particular age period that we have studied, Piaget discusses two different types of cognitive activity. In the first, known as syncretism, the thought of the child is dominated by environmental properties that attract him. The child fails to relate successive impressions in a logical way. This type of behavior was observed in our first observations of a child (not given here). In several cases, the child would make the association based entirely on a distinguishing characteristic of the objects. This type of behavior seems to depend heavily on the perceptual processes. The second type of thought Piaget describes is characterized by a more stable and coherent approach to problems. He refers to this as the period of concrete operations. While we have not followed Piaget's model in any detail, we do believe that we are modeling behavior that is characteristic of this level of intellectual development .

6. Suggestions for Further Study

There are many questions left unanswered and many that have not even been considered in this study. We mention briefly a few such questions.

Perhaps the least understood portion of the model is the data base. Even hypothesizing that our structure is correct, we have said nothing about how it reaches that state and how it continues to evolve, The 'assimilation of new, possibly contradictory, data, the effect of the subject's environment, the effect of his emotions, are all unaccounted for. It is reasonable to assume that there are "background" processes at work in the mind just as there are in many modern computing systems. It would be interesting to determine the nature of this background processing and to reconcile it with models of cognitive processing.

Another study of interest would be to look at children of different ages and to attempt to create models of the processing techniques used by each. This would lead to a sequence of models with increasingly sophisticated abilities. These models would give insight into the development of human cognitive processes.

If a model is to be truly successful, it must be capable of explaining not only normal behavior but abnormal behavior as well. For example, certain children with a language disability known as aphasia have difficulty in certain word finding situations. They often confuse the names for elbow with-knee, neck with wrist, and so forth. It would appear that they are very close to finding the proper response but fail at some final step in the retrieval of the name. This suggests that a model that fails at the last step in the search and instead of picking the proper response selects one from a closely related class of objects, might exhibit very similar behavior. Hopefully such a model would give insight into the nature of the aphasic person's problem and possibly aid in the treatment of his disability.

7. Acknowledgements

This work has been inspired by the work of my wife, **Polly,** with children with language impairments. Her interest and her understanding of children have been of great aid. I would also like to thank Dr. Kenneth Colby for his advice and encouragement during this study and give sincere appreciation to those parents who allowed their children to participate in this experiment. Of course I thank the children themselves for allowing us to observe their behavior.

Appendix A

Trial Set and Protocol Used for Model Construction

1. relate (a-shoe (a-sock a-ball))

   choice: a-shoe and a-ball

   reason: you wear them sometimes

2. relate (a-spoon (a-cup-and-saucer a-car))

   choice: a-spoon and a-cup-and-saucer

   reason: when you drink, need spoon for sugar

3. relate (a-hand (a-flower a-glove a-star a-stove))

   choice: a-hand and a-glove

   reason: it's the glove you sometimes wear

4. relate (a-baby (a-safety-pin a-nail a-paper clip a-straight-pin))

   choice: a-baby and a-safety-pin

   reason: use for diaper

5. relate (a-hammer (a-straight-pin a-nail a-needle a-knife))

   choice: a-hammer and a-nail

   reason: you nail something on the wall

6. relate (a-lamp (a-book a-flashlight-battery a-pencil an-endtable))

   choice: a-lamp and an-endtable

   reason: you put this (a-lamp) on this (an-endtable)

7. relate (a-girl (a-chair a-sofa a-mother a-cigarette))

   choice: a-girl and a-mother

   reason: a-girl has a-mother

8. relate (a-window (a-clock a-button the-sun a-penny))

choice: a-window and the-sun

reason: the-sun is outdoors

9. relate (a-jar (a-book some-blocks a-brick a-box))

choice: a-jar and a-box

reason: it (jar) is a-box like this (box). you put things in this (jar) and you put things in this (box).

10. relate (a-truck (a-cow a-giraffe a-horse a-zebra))

choice: a-truck and a-horse

reason: you carry a-horse in a-truck sometimes

Appendix B

Characteristics Used for Object Recognition

```
(A-SHOE(A-SOLE L A C E S MADE-OF-LEATHER))
(A-SOCK( MADE-OF-COTTON A-TOE A-HEEL))
(A-BALL(R C U N C MADE-OF-RUBBER))
(A-FOOT(A - H E E L TCES PART-OF-THE-BODY))
(A-CUP-AND-SACCkK(A-HANDLE A-BOWL))
( A-SPCON(A-HANDLE AN-OVAL-END S ILVERWARE))
(J-C A R(WHEELS A-HOOD)(A-T R U N K))
(A-HAND( F I V E - F INGERS PART-OF-THE-BODY))
(A-FLOWER( A - S T E M PETALS))
(A-GLCVE(F I V E - F I N G E R S MADE-OF-COTTON))
(A-S T A R(PCINTS))
(A-STOVE(A - B U R N E R SQUARE))
( A-BABY (HUMAN SMALL) )
(A-SAFETY-PIN(STRANGE-END1 STRANGE-END2))
(A-PAPER-CL I P(STRANGE-SHAPE1))
( A - N A I L(LCNG THIN A-HEAD MADE-OF-METAL))
(A-NEEDLE( A N - E Y E SHARP))
(A-STRAIGHT-PIN(SHARP T H I N SMALL))
(A-HAMMER(A-HEAD2 A - T O O L A-HANDLE))
(A-K N I F E(MADE-OF-METAL SILVERWARE A-B L A D E A-H A N D L E))
(A-LAMP(FURN ITURE A-SHADE A - R A S E))
(AN-ENDTABLE(FURNITURE LEGS A-F L A T - S U R F A C E))
(A-BOOK(A - C O V E R PAGES))
(A-BATTERY(C Y LINDRICAL EVERREADY-WRITTEN-ON-IT))
(A-PENCIL(A-POINT L O N G THIN AN-E R A S E R))
(A-GI RL ( A-DRESS LONG-HAI R A-PERSON) )
( A-CIGARETTE (A-FILTER CYLINDRICAL LONG))
( A-CHAI R ( FOUR-LEGS A-SEAT MADE-OF-WOOD) )
(A-SOFA(F U R N I T U R E LARGE))
( A-HOUSE (A-WINCOW A-DOCR A-ROOF) )
(A-GLASS-BOTTLE ( MADE-OF-GLASS SHAPE4 ))
(A-MOTHER( A - C R E S S OLD A-PERSON))
(A-WINDOW(P A N E S A-F R A M E))
(A-C L O C K(HANDS2 A-f ACE))
(A-BUTTON ( ROUND HOLES ) )
( THE-SUN (BR IGHT ) )
(A-PENNY (MADE-OF-METAL A-PICTURE-OF-LINCCLN-ON-IT))
(A-JAR (MADE-OF-GLASS ROUND A-TOP ))
( A-BLOCK (SQUARE MADE-OF -WOOD PICTURES-ON-IT) )
(A-BRICK (HEAVY SQUARE) )
(A-BOX( A - T O P A-BOTTOM))
(A-T R U C K(WHEELS A-CAB))
(A-COW(A N - U D D E R AN-ANIMAL))
(A-GIRAFFE (NIL))
(A-ZEBRA( A N - A N I M A L STRIPE))
(A-HORSE(AN-ANIMAL A - M A N L BROWN))
(A-MAN ( TALL WORKCLOTHES ))
(A-BOTTLE(MADE-OF-GLASS LIQUID-IN-IT) )
(A-SCREWDR I VER(A-TOCL A-TH I N-END A-H A N D L E))
(A-MILKBOTTLE (MADE-OF-GLASS FILLED-WITH-MILK) )
```

Appendix C

Program Listing

```
(COPY (LAMBDA (X)
    (COND
        ((NULL X) NIL)
        ((ATOM X) X)
        (T (CONS (COPY (CAR X)) (COPY (CDR X)))))))

(LENGTH (LAMBDA (X)
    (COND
        ((ATOM X) 0)
        (T (LEN1 X 0))
    )))

(LEN1 (LAMBDA (X L)
    (COND ((NULL X) L)
        (T (LEN1 (CDR X) (PLUS L 1))))))

(CADDDR (LAMBDA (X)
    (CAR (CDDDR X))))
( CDDDDR (LAMBDA (X)
    ( CDK (CDDDR X ))))

(CADDAR (LAMBDA (X)
    (CAR (CDDAR X)) ))

(PROP (LAMBDA (X Y U)
    (COND ((NULL X)(U NIL))
        ((EQ (CAR X) Y) (CDR X))
        (T (PROP (CDR X) Y U)) )))

( LEARNER (LAMBDA (L )
    (COND
        ((NULL L) (QUOTE (ALL DONE)))
        (T(PROG2 (LEARN(CAR L))(LEARNER(CDR L)))))))

(LEARN(LAMBDA (LIST)
        (PRCG2 (SETUPLIST)(LEARN1 LIST))))
( LEARN1 (LAMBDA (LIST)
    (COND ((GREATERP (LENGTH LIST) 3)
            (LEARN2(CAR LIST)(CADDR LIST)(CADDDR LIST)
                    (CAR(CDDDDR LIS-T))))
        ((OR (EQ (CADR LIST)(QUOTE IS))(EQ (CADR LIST)(QUOTE HAS)))
            (LEARN3(CAR LIST)(CADR LIST)(CADDR LIST)))
        (T(LEARN4(CAR LIST)(CADR LIST)(CADDR LIST)))    )))

(LEARNL (LAMBDA (LIST)
    (COND
        ((NULL LIST) NIL)
        (T (PROG2 ((LAMBDA (A P ATR)
                    (COND ((MEMBER P (GET A ATR)) NIL)
                          (T(DEFLIST(LIST (LIST A(CONS P (GET A ATR))
                                )) ATR))))
                  (CAAR LIST)(CADAR LIST)(CADDAR LIST))
                (LEARNL (CDR LIST)))))))
```

```
SETUP (LAMBDA (LIST)
   (COND ((NULL LIST) NIL)
      ((ATOM (CAR LIST))
         (PROG2(COND((NULL(GET(CAR LIST)(QUOTE CATEGORY)))
                           (ATTRIB(CAR LIST)(COPY(QUOTE
                              (CATEGORY T QUALITY NIL INSTANCE NIL
                              PREDA NIL PREDP NIL PRED1 NIL PRED2 NIL)))))
                        (T NIL))(SETUP(CDR LIST))))
      (T(ERROR(LIST(QUOTE(SETUP- NONATOM))(CAR LIST)))))))

(LEARN2 (LAMBDA (A B C D)
   (LEARNL (LIST
      (LIST A (LIST(QUOTE IS) B)(QUOTE QUALITY))
      (LIST B (LIST A (QUOTE IS))(QUOTE INSTANCE))
      (LIST A (LIST B C D)(QUOTE PRED1))
      (LIST D (LIST A B C)(QUOTE PRED2))))))

(LEARN3 (LAMBDA (A B C)
   (LEARNL (LIST
      (LIST A (LIST B C)(QUOTE QUALITY))
      (LIST C (LIST A B)(QUOTE INSTANCE))))))

(LEARN4 (LAMBDA (A B C)
   (LEARNL (LIST
      (LIST A (LIST B C)(QUOTE PREDA))
      (LIST C (LIST B A)(QUOTE PREDP))
      (LIST C (LIST(QUOTE IS) B) (QUOTE QUALITY))
      (LIST B (LIST C (QUOTE IS)) (QUOTE INSTANCE))
   ))))

(TELLABOUT (LAMBDA (LIST)
   (COND((NULL LIST)(QUOTE(THAT IS ALL I KNOW)))
      (T (PROG2 (TELL1(CAR LIST))(TELLABOUT(CDR LIST)))))))

(TELL1 (LAMBDA (A)
   (TELL2 A (PROP A(QUOTE CATEGORY) (FUNCTION KNOWNOT)))))

(KNOWNOT(LAMBDA(NIL)
   (APPEND(QUOTE(I DO NOT KNOW ABOUT))(LIST A))))

(TELL2(LAMBDA(A LIST)
   (COND((EQ(CAR LIST)(QUOTE I))(PRINT LIST))
      (T(TELL3 A (CDR LIST))))))

(TELL3(LAMBDA(A LIST)
   (COND((NULL LIST)NIL)
      (T(PROG2(TELL4 A (CAR LIST)(CADR LIST))
                     (TELL3 A (CDDR LIST)))))))

(TELL4 (LAMBDA (A ATR VALS)
   (COND ((EQ ATR (QUOTE QUALITY)) (TELL4A VALS))
      ((EQ ATR (QUOTE INSTANCE))(TELL4B VALS))
      ((EQ ATR(QUOTE PREDA))(TELL4C VALS))
      ((EQ ATR(QUOTE PREDP))(TELL4D VALS))
      ((EQ ATR (QUOTE PRED1)) (TELL4E VALS))
      ((EQ ATR (QUOTE PRED2)) (TELL4F VALS))
      (T(PRINT(LIST(QUOTE(STRANGE ATTRIBUTE OF)) A ATR))))))

(MAPPRT (LAMBDA (U FN)
   (COND((NULL U)NIL)
```

```
      (T (PROG2 (PRINT (FN   A   (CAR U))) (MAPPRT (CDR U) FN))) )))

(TELL4A (LAMBDA (VALS)
   (MAPPRT VALS (FUNCTION RESA))))

(TELL4B (LAMBDA (VALS)
   (MAPPRT VALS (FUNCTION RESB))))

(TELL4C (LAMBDA (VALS)
   (MAPPRT VALS (FUNCTION RESC))))

(TELL4D (LAMBDA (VALS)
   (MAPPRT VALS W-UNCTION RESD))))

(TELL4E (LAMBDA (VALS)
   (MAPPRT VALS (FUNCTION RESE))))

(TELL4F (LAMBDA (VALS)
   (MAPPRT VALS (FUNCTION RESF))))

(RESA   (LAMBDA (X Y ) (LIST X (CAR Y) (CADR Y))))

(RESB   (LAMBDA (X Y) (LIST (QUOTE SOMETHING) (QUOTE THAT)   (CADR Y)   X
        (QUOTE IS ) (CAR Y))))

(RESC (LAMBDA (X Y) (APPEND (LIST X) Y)))

(RESD (LAMBDA (X Y)
   (LIST X (QUOTE IS) (CAR Y) (QUOTE BY) (CADR Y))))

(RESE (LAMBDA (X Y)
   (APPEND (LIST  X  (QUOTE IS)) Y)))

(RESF (LAMBDA (X Y)
   (LIST X (QUOTE IS) (QUOTE SOMETHING) (CAR Y) (QUOTE IS) (CADR Y)
      (CADDR Y))))

(RECOGLIST (LAMBDA (INLIST OUTLIST )
   (COND ((NULL INLIST) OUTLIST)
      (T (RECOGLIST (CDR INLIST) (CONS (RECOGNIZE (CHARLIST
                                    (CAR INLIST) OBJECT-CHARACTERISTICS
                                    ) (QUOTE OLIST)) OUTLIST))))))

(CHARLIST (LAMBDA (OBJECT LIST)
   (COND ((NULL LIST) NIL )
      ((EQ OBJECT (CAAR LIST)) (CDAR LIST))
      (T (CHARLIST OBJECT (CDR LIST))) )))

(RECOGNIZE (LAMBDA (CLIST OLIST)
   (COND
      ((EQUAL (LENGTH OLIST) 1) (PROG2 (PRINT (APPEND (QUOTE (THAT IS))
         (LIST (CAR OLIST)))) (CAR OLIST)))
      ((NULL CLIST) (COND ((NULL OLIST) (PROG2 (PRINT (QUOTE
                              (DO NOT KNOW WHAT THAT IS))) NIL))
                  (T (PROG2 (PRINT (APPEND (APPEND (QUOTE (I THINK
                     THAT IS EITHER)) (LIST (CAR OLIST))) (PRETACK
                     (QUOTE OR) (CDR OLIST) NIL))) NIL))))
      (T (RECOGNIZE (CDR CLIST) (RECOG1 (CAR CLIST) OLIST))))))

(RECOG1 (LAMBDA (CHARS OLIST)
   (COND
```

```
      ((NULL CHARS) OLIST)
      (T (RECOG1 (CDR CHARS) (INTERS (REMISHAS (GET (CAR CHARS)
         (QUOTE INSTANCE)) NIL) OLIST)))
   )))

(INTERS (LAMBDA (L1 L2)
   (COND
      ((EQ L2 (QUOTE OLIST)) L1)
      (T (INSECT L1 L2 NIL))
   )))

(INSECT (LAMBDA (A B RES)
   (COND
      ((NULL A) RES)
      ((MEMBER (CAR A) B) (INSECT (CDR A) B (CONS (CAR A) RES)))
      (T (INSECT (CDR A) B RES))
   )))

(REMISHAS (LAMBDA (L R)
   (COND
      ((NULL L) R)
      (T (REMISHAS (CDR L) (CONS (CAAR L) R)))
   )))

(REMISHASQ (LAMBDA (L)
   (MAPCAR L (FUNCTION CADR))
   ))

(RELATE (LAMBDA (OBJ OLIST)
   (RELATE1 (RECOGNIZE (CHARLIST OBJ OBJECT-CHARACTERISTICS)
  -      (QUOTE OLIST)) (REMNIL (RECOGLIST OLIST NIL)) )))

(RELATE1 (LAMBDA (OBJ OLIST)
   (COND
      ((NULL OBJ) (QUOTE (I REALLY CAN'T DO THIS SINCE I DON'T KNOW
         WHAT THAT IS)))
      ((NULL OLIST) (APPEND (QUOTE (SORRY - BUT I DON'T KNOW WHAT
         ANY OF THOSE ARE))
         (LIST OBJ)))
      (T (RELATE1A OBJ OLIST))
   )))

(RELATE1A (LAMBDA (OBJ OBJLST)
   (COND
      ((NULL OBJLST) (REDEEP OBJ (REMNIL OLIST)))
      (T (RELATE2 (CAR OBJLST) GETLST))
   )))

(RELATE2 (LAMBDA (CHOICE GETLIST)
   (COND
      ((NULL GETLIST) (RELATE2A CHOICE GETLST))
      (T (RELATE3 (CAR GETLIST)))
   )))

(RELATE2A (LAMBDA (CHOICE GETLIST)
   (COND
      ((NULL GETLIST) (RELATE1A OBJ (CDR OBJLST)))
      (T (RELATE3A (CAR GETLIST)))
   )))

(RELATE3 (LAMBDA (ATR)
```

```
    (RELATE4(GET CHOICE ATR))
    ))

(RELATE3A (LAMBDA (ATR)
    (RELATE4A (GET CHOICE ATR)(GET OBJ ATR))
    ))

(RELATE4 (LAMBDA(VALS)
    (COND
        ((NULL VALS)(RELATE2 CHOICE(CDR GETLIST)))
        (T (RELATE5 (CAR VALS) ))
    )))

(RELATE4A(LAMBDA(VALS OVALS)
    .(COND
        ((NULL VALS)(RELATE2A CHOICE(CDR GETLIST)))
        (T (RELATE6(CAR VALS)OVALS))
    )))

(RELATES(LAMBDA(VAL)
    (COND·
        .((MEMBER OBJ VAL)(OUTPUT (LIST (RESULT-1 CHOICE VAL ATR))))
        (.T (RELATE4(CDR VALS)))
    )))

(RELATE6 (LAMBDA (VAL OVA)
    (COND
        ((MEMBER VAL OVA)(OUTPUT(RESULT2 OBJ CHOICE VAL ATR)))
        (T(RELATE4A(CDR VALS) OVALS))
    )))

(REDEEP (LAMBDA(OB OBJLST)
    (COND
        ((NULL OBJLST) (UPUPL OB OLIST))
        (T(RED1 GETLST (CAR OBJLST)))
    )))

(RED1(LAMBDA(GETL1 MATCH)
    (COND
        ((NULL GETL1 )(REDEEP of 3(CDR OBJLST) ))
        (T(RED1A(CAR GETL1)(GET MATCH (CAR GETL1))))
    )))

(RED1A (LAMBDA (AT1 VALS1)
    (COND
        ([NULL VALS1)(RED1(CDR GETL1) MATCH))
        (T (RED2 (GETOB( CAR VALS1) AT1) GETLST))
    )))

(RED2 (LAMBDA (OB2 GETL2)
    (COND
        ((NULL GETL2) (RED1A AT1 (CDR VALS1)))
        (T(RED2A(CAR GETL2)(GET OH2 (CAR GETL2))))
    )))

(RED2A(LAMBDA(AT2 VALS2)
    (COND
        ((NULL VALS2)( RED2 OB2(CDR GETL2)))
        ((EQ Of 3(GETOB (CAR VALS2)AT2))(REDOUT OB MATCH(RESULT1 MATCH
            (CAR VALS1) AT1)(RESULT-1 OB2(CAR VALS2)AT2)))
        (T (RED2A AT2(CDR VALS2)))
```

```
    )))

( UPUPL (LAMBDA (OBJ OBJLST)
    ( (LAMBDA (ANS)
        (COND
           ((NULL ANS) (UPUPL2 OBJ OBJLST))
           (T ANS)
        ))
        (UPLOOK OBJ OBJLST)
    )))

(UPLOOK (LAMBDA (OBJ OBJLST)
   (COND
        ( (NULL OBJLST ) NIL )
        ( T (UPLOOK2 GETLST (CAR OBJLST) ))
    )))

(UPLOOK2 (LAMBDA (GETL CHOICE)
   (COND
        ( (NULL GETL) (UPLOOK OBJ (CDR OBJLST )) )
        (T (UPLOOK3 (GET OBJ (CAR GETL)) (REMISHASQ (GET CHOICE
           (QUOTE EQUAL X T Y)))))
    )))

(UPLOOK3 (LAMBDA (OVA CLIST)
    (COND
        ( (NULL OVA) (UPLOOK2 (CDR GETL) CHOICE))
        (T (UPLOOK4 (CAR OVA) CLIST))
    )))

(UPLOOK4 (LAMBDA (OV CHL)
    (COND
        ((NULL CHL) (UPLOOK3 (CDR OVA) CLIST))
        ((EQ (GETOB OV (CAR GETL)) (CAR CHL)) (OUTPUT (LIST (RESULT1 OBJ
           (REPLACE (CAR CHL) CHOICE OV) (CAR GETL)))))
        ( T (UPLOOK4 OV (CDR CHL) ))
    )))

(UPUPL2 (LAMBDA (OBJ OBJLST)
    (COND
        ( (NULL OBJLST) (UPLOOKER OBJ OLIST))
        (T (UPUPL3 (UPLOOK (CAR OBJLST) (LIST OBJ)) (FUNCTION UPUPL2)))
    )))

(UPUPL3 (LAMBDA (ANS FN)
    (COND
        ((NULL ANS) (FN OBJ (CDR OBJLST)))
        (T ANS)
    )))

(UPLOOKER (LAMBDA (OBJ OBJLST)
    (COND
        ( ( NULL OBJLST ) (APPEND (QUOTE ( SORRY -NOTHING SEEMS TO GO WITH))
           (LIST OBJ) ))
        (T (UPUPL3 (PARLOOK OBJ (CAR OBJLST) GETLST) (FUNCTION UPLOOKER)
        ))
    )))

(PARLOOK (LAMBDA (OBJ CHOICE GETL)
    (COND
        ((NULL GETL) NIL)
```

```
        (T (PARLOOKA ( PARLK1 (GET OBJ (CAR GETL ) )
            (GET CHOICE (CAR GETL)) (CAR GETL))))
    )))

(PARLOOKA (LAMBDA (ANS)
    (COND
        ((NULL ANS) (PARLOCK OBJ CHOICE (CDR GETL) ))
        (T ANS)
    )))

(PARLK1 (LAMBDA ( OVALS CVALS ATR)
    (COND
        ((NULL OVALS) NIL)
        (T (PARLK1A (PARLK2 (CAR OVALS) CVALS)))
    )))

(PARLK1A (LAMBDA (MATCHL)
    (COND
        ((NULL MATCHL) (PARLK1 (CDR OVALS) CVALS ATR))
        ( T (PARLK3 MATCHL))
    )))

( PARLK2 (LAMBDA (OVAL CHVALS)
    (COND
        ((NULL CHVALS) NIL)
        (T ((LAMBDA (CKVAL)
            (COND
                ((NULL CKVAL)(PARLK2 OVAL (CDR CHVALS)))
                (T CKVAL)
            ))
            (CHECK QVAL (CAR CHVALS) ATR)
        ))
    )))

(PAKLK3 (LAMBDA (LST)
    ( SPLIT (CAR LST) (CADR LST) (CADDR LST))
    ))

(SPLIT (LAMBDA (V1 C1 O2)
    ((LAMBDA (COMIN)
        (COND
            ((NULL COMIN) NIL)
            (T (OUTPUT (RESULT2 OBJ CHOICE (REPLACE O1 (CAR COMIN) V1)
                ATR)))
        ))
        (REMOVE (GETVB V1 ATR) (INSECT (ISONLY ( GET O1 (QUOTE QUALITY)))
            (ISONLY (GET O2 (QUOTE QUALITY))) NIL))
    )))

(CHECK (LAMBDA (L1 L2 AT)
    (COND
        ((EQ AT (QUOTE PREDA)) (CHECK1 NIL))
        ((EQ AT ( QUOTE PREDP)) (CHECK1 NIL))
        ((EQ AT (QUOTE PRED1)) (CHECK2 NIL))
        ((EQ AT (QUOTE PRED2)) ( CHECK3 NIL))
        (T (PROG2 (PRINT (LIST (QUOTE (CHECK L1 L2 AT)) L1 L2 AT)) NIL))
    )))

(CHECK1 (LAMBDA (NIL)
    (COND
        ((EQ (CAR L1) (CAR L2)) (LIST C1 (CADR L1) (CADR L2)))
```

```
        (T NIL)
    )))

(CHECK2 (LAMBDA (NIL)
    (COND
        ((AND (EQ (CAR L1) (CAR L2)) (EQ (CADR L1) (CADR L2)    (LIST L1
            (CADDR L1) (CADDR L2)))
        (T NIL)
    )))

(CHECK3 (LAMBDA (NIL)
    (COND
        ((EQUAL (CDR L1) (CDR L2)) (LIST L1 (CAR L1) (CAR L2)))
        (T NIL)
    )))

(REDOUT (LAMBDA (OBJ CHOICE R1 R2)
    (OUTPUT (LIST R1 R2))
    ))

(RESULT1 (LAMBDA (A V TY)
    (COND
        ((EQ TY (QUOTE QUALITY)) (RESA A V))
        ((EQ TY (QUOTE INSTANCE)) (RESB A V))
        ((EQ TY (QUOTE PREDA)) (RESC A V))
        ((EQ TY (QUOTE PREDP)) (RESD A V))
        ((EQ TY (QUOTE PRED1)) (RESE A V))
        ((EQ TY (QUOTE PRED2)) (RESF A V))
        (T (ERROR (LIST (QUOTE (WIE GEHTS)) A V TY)))
    )))

(RESULT2 (LAMBDA (A B V TY)
    (LIST
        (RESULT1 A V TY)
        (RESULT1 B V TY)
    )))

(OUTPUT (LAMBDA (L)
    (COND
        ((NULL (CDR L)) (OUT1 (CAR L)))
        (T (APPEND (OUT1 (CAR L)) (PRETACK (QUOTE AND)  (CDR L) NIL)))
    )))

(OUT1 (LAMBDA (X)
    (LIST OBJ (QUOTE GOES) (QUOTE BEST) (QUOTE WITH) CHOICE
        (QUOTE BECAUSE) X )))

(PRETACK (LAMBDA (PRE LIST RSLT)
    (COND
        ((NULL LIST) RSLT)
        (T (PRETACK PRE (CDR LIST) (CONS PRE (CONS (CAR LIST) RSLT))))
    )))

(REMNIL (LAMBDA (L)
    (COND
        ((NULL L) NIL)
        ((NULL (CAR L)) (CDR L))
        (T (CONS (CAR L) (REMNIL (CDR L))))
    )))
```

```
    (COND
       ((EQ A    T(QUOTE INSTANCE))(CAR VAL))
       ((EQ A    T(QUOTE QUALITY))(CADR VAL))
       ((EQ A    T(QUOTE PREDA))(CADR VAL))
       ((EQ A    T(QUOTE PREDP))(CADR VAL))
       ((EQ A    T(QUOTE PRED1))(CADDR VAL))
       ((EQ A    T(QUOTE PRED2))(CAR VAL))
       (T(ERROR( L I S T(QUOTE(WIE GEHTS GETOB))V  A  L AT)))
    )))

( ISONLY ( LAMBDA (L)
    (COND
       ((NULL L) NIL)
       ((EQ (CAAR L) (QUOTE IS)) (CONS (CADAR L) (ISONLY (CDR L))))
       (T (ISONLY (CDR L)))
    )))

( REPLACE (LAMBDA (X  Y  L)
    (COND
       ((NULL L) NIL)
       ((EQUAL (CAR L) X) (CONS  Y  (CDR L)))
       (T (CONS (CAR L) (REPLACE X      Y(CDR L))))
    )))

( REMOVE (LAMBDA (X L)
    (COND
       ((NULL L) NIL)
       ((EQ X (CAR L)) (CDR L))
       (T (CONS (CAR L) (REMOVE  X  (CDR L))))
    )))

(GETVB (LAMBDA (V ATR)
    (COND
       ((EQ A  T  R(QUOTE PRED2))(CADR V))
       (T  (CAR  V))
    )))
```

Appendix D

Sentences for Original Test Sequence

(A-BALL I S BOUNCED)
(A-BALL IS ROUND)
(P-BALL I S CAUGHT WITH A-GLCVE)
(A-BAT H I T A-BALL)
(P-CLOVE HAS FIVE-F INGERS)
(A-GLCVE IS MADE-OF-LEATHER)
(A-HALL IS MADE-OF-RUBBER,)
(A-BOCK IS ON-THE-SHELF)
(THE-SHELF IS FOUND IN THE-LIBRARY)
(THE-LIBRARY IS FOUND IN THE-HCUSE)
(A-SHCE IS WCPN GN A-FOOT)
(A-SHCE I S MADE-OF-LEATHER)
(P-SHOE HAS A-SOLE)
(A-SHCE I-AS LACES)
(A-SHOE I S AN-ARTICLE-OF-CLOTHING)
(AN-ARTICLE-OF-CLOTHING IS PUT-ON IN THE-MORNING)
(AN-ARTICLE-CF-CLOTHING IS TAKEN-GFF AT NIGHT)
(A-SUCK I S WORN ON A-FOCT)
(A-SOCK IS MACE-OF-WOOL)
(A-SOCK IS MACE-OF-COTTCN)
(A-SOCK I S AN-ARTICLE-CF-CLOTHING)
(AN-ARTICLE-CF-CLOTHING I S WASHED I N SOAP-AND-WATER)
(A-SOCK I S SOFT)
(A-BALL IS THROWN)
(P-SOCK HAS P-HEEL)
(A-SOCK HAS A-TOE)
(COFFEE I S A-DRINK)
(CREAM IS PUT I N COFFEE)
(A-SPCON HAS AN-OVAL-END)
(A-SPOON HAS A-HANDLE)
(FCCD IS EATEN WIT): A-SPOON)
(A-SPCON IS FCUND IN A-DRAWER)
(CEREAL I S FOOD)
(A-SPCON I S S ILVERWARE)
(FATHER HAS A-CAR)
(A-CAR HAS WHEELS)
(A-CAR HAS P-TOP).
(P-CAR HAS A-HOCD)
(A-CAR HAS A-TRUNK)
(A-CAR HAS A-COOR)
(A-CAR IS BIG)
(A-CAR USED GASOLINE)
(A-CAR IS RUN ON THE-HIGHWAY)
(P-CAR IS PARKED IN A-GARAGE)
(A-CUP-AliD-SAUCER IS BREAKABLE)
(A-CUP-ANC-SAUCER HOLC A-CR INK)
(A-CUP-AhD-SAUCER HAS A-HANDLE)
(A-CUF-AND-SAUCER HAS A-BOWL)
(A-SPCON STIR A-CRINK)
(A-BOWL I S HOLLCW)
(A-SAUCER I S FLAT)
(A-BOCY HAS A-HAND)
(A-HAND t-AS FIVE-FINGERS)
(A-HAND HAS A-THUMB)
(A-HANC IS PART-OF-THE-BODY)
(A-HAND HAS A-PALM)
(THE-WRIST IS CONNECTED TO A-HAND)
(A-ROSE IS A-FLOWER)
(A-FLOWER HAS A-STEM)
(A-FLOWER HAS PETALS)

(A-GLOVE H A S FIVE-FINGERS)
(A-GLCVE IS MADE-OF-COTTON)
(A-GLCVE I S WCRN U N A-HAND)
(A-GLCVE WARM A-HAND)
(A-STOVE I S HOT)
(MCTHER IS CCCKS O N A-STOVE)
(DINNER I S COCKED ON A-STOVE)
(PEOPLE EAT DINNER)
(A-STCVE I S FCUND I N THE-KITCHEN)
(A-STOVE HAS A-BURNER)
(A-STOVE IS BOUGHT IN A-STORE)
(A-STCVE I S SQUARE)
(A-STOVE BURNED A-PERSON)
(A-PERSON HAS A-HAND)
(P-HOSE HAS THORNS)
(THORNS HURT A-HAND)
(P-BABY IS SMALL)
(A-BABY WEAR A-DIAPER)
(A-BABY I S HUMAN)
(A-BABY I S ALIVE)
(P-STAR t-AS PCINTS)
(A-NAIL IS LONG)
(A-NAIL IS THIN)
(A-NAIL HAS A-HEAD)
(A-HAMMER HIT A-NAIL)
(A-HAMMER HIT A-THING)
(A-NAIL I S A-THING)
(A-NAIL IS SHARP)
(A-NAI L IS MADE-OF-METAL)
IA-FAPEK-CLIP IS MADE-OF-METAL)
(A-PAPER-CLIP IS THIN)
(A-PAPER-CLIP H A S STRANGE-SHAPE1)
(P-PAPER-CLIP HOLD-TOGETHER PAPER)
(A-STRAIGHT-PIN I S SHARP)
(A-STRAIGHT-PIN I S THIN)
(A-STRAIGHT-PIN IS SMALL)
(P-STRAIGHT-? IN IS NARROW)
(A-STRAIGHT-PIN PRICKS A-PERSON)
(A-SAFETY-PIN HOLD-ON A-DIAPER)
(A-SAFETY-P IN I S MADE-OF-METAL)
(A-SAFETY-PIN HAS STRANGE-END1)
(A-SAFETY-PIN HAS STRANGE-END2)
(A-HAMMER I S A-TOOL)
(A-HAMMER H A S A-HEAD2)
(A-HAMMER HAS A-HANDLE)
(A-HAMMER I S FOUND I N A-TOOL-BOX)
(A-HAMMER HURT A-FINGER)
(A-KN/FE I S SHARP)
(A-KNIFE HAS A-HANDLE)
(A-KNIFE HAS C-BLADE)
(A-KNIFE C U T FOOD)
(A-KNIFE S L I C E BREAD)
(P-KNIFE SPREAD BUTTER)
GA-NEEDLE IS SHARP)
(A-KNIFE IS MADE-OF-METAL)
(FOOD IS EATEN WITH A-KNIFE)
(A-KNIFE IS FOUND IN A-DRAWER)
(A-KNIFE IS SILVERWARE)
(SILVERWARE I S MADE-OF-METAL)
(A-NEEDL E IS MADE-OF-METAL)
(A-NEEDLE HAS AN-EYE)

(A-NEEDLE HAS A-POINT)
(A-LAMP GIVE LIGHT)
(A-LAMP HAS A-SHADE)
(P-LAMP HAS A-BASE)
(A-LAMP HAS A-SWITCH)
(A-LAMP IS FURNITURE)
(P-LAMP IS SIT ON AN-ENDTABLE)
(AN-ENDTABLE IS FURNITURE1
(AN-ENDTPBLE HAS k-FLAT-SURFACE)
(AN-ENDTABLE HAS LEGS)
(AN-ENDTABLE IS P-TABLE)
(AN-ENDTABLE IS FOUND IN THE-LIVING-ROOM)
(AN-ENDTABLE IS MADE-CF-WOOD)
(A-BOCK IS MADE-OF-PAPER)
(A-BOCK HAS A-COVER)
(P-ROCK HAS PAGES)
(A-BOOK IS READ)
(A-BOOK IS FOUND ON THE-SHELF)
(A-PENCIL IS LONG)
(A-PENCIL IS THIN)
(A-PENCIL HAS AN-ERASER)
(A-PENCIL HAS A-PCINT)
(A-PENCIL IS USED FOR WRITING)
(A-FLASHLIGHT HAS A-BATTERY)
(A-BATTERY IS CYLINDRICAL).
(A-BATTERY HAS A-KNOB-CN-TOP)
(A-BATTERY HAS EVERREADY-WRITTEN-ON-IT)
(P-GIRL WEAR P-CRESS)
(A-GIRL WEAR SHOES)
(A-GIRL HAS b-DRESS)
(A-GIRL IS A-PERSON)
(A-PERSON HAS ARMS)
(A-PERSON HAS LEGS)
(A-PERSON WEARS CLOTHES)
(A-GIRL HAS LONG-HAIR)
(A-MOTHER HPS A-CRESS)
(A-MOTHER WEAR A-DRESS)
(E-GIRL EELONG-TO A-MOTHER)
(A-MOTHER IS CLD)
(P-MOTHER IS A-PERSON)
(A-MOTHER CARRY A-PURSE)
(A-CIGARETTE IS LONG).
(A-CIGARETTE IS CYLINDRICAL)
(P-CIGARETTE t-AS A-FILTER)
(FATHER SMCKE A-CIGARETTE)
(A-CHAIR IS FURNITURE)
(A-CHAIR IS MADE-OF-WCOD)
(b-CHAIR HAS A-SEAT)
(A-CHAIR HAS A-BACK)
(A-CHAIR HAS FOUR-LEGS)
(A-SOFA IS FURNITURE)
(A-PERSON IS SIT ON A-SOFA)
(A-SOFA IS LARGE)
(A-SOFA IS FOUND IN THE-LIVING-ROOM)
(A-SOFA IS COVERED WITH CLOTH)
(A-WINDOW HAS PPNES)
(A-WINDOW IS FOUND IN A-WALL)
(P-STONE BREAK A-WINDOW)
(A-HOUSE HAS A-WINDOW)
(A-WINDOW IS FRAGILE)
(A-WINCOW HAS A-FRAME)

(P-FRAME IS MADE-OF-WOOD)
(A-CLOCK HAS A-FACE)
(A-CLOCK HAS HANDS2)
(A-CLOCK GIVE THE-TIME)
(THE-SUN IS OUTSIDE)
(THE-SUN IS BRIGHT)
(THE-SUN GIVE LIGHT)
(OUTSIDE IS SEEN THROUGH A-WINDOW)
(THE-SUN IS SHINE THROUGH A-WINDOW)
(A-BUTTON IS ROUND)
(A-BUTTON IS FLAT)
(A-BUTTON HAS HOLES)
(A-BUTTON IS FOUND ON CLOTHES)
(A-PENNY IS MADE-OF-METAL)
(A-PENNY IS ROUND)
(A-PENNY IS FLAT)
(A-PENNY HAS A-PICTURE-OF-C INCCLN-ON-IT)
(A-JAR IS MADE-OF-GLASS)
(A-JAR HOLD JAM)
(A-JAR HOLD A-THING)
(A-JAR IS ROUND)
(A-JAR HAS A-TOP)
(A-BOX HOLD A-THING)
(A-BOX IS MADE-OF-WOOD)
(A-BOX HAS A-TOP)
(A-BOX HAS A-BOTTOM)
(A-THING IS CARRIED IN A-BOX)
(A-BRICK IS HEAVY)
(A-BRICK IS SQUARE)
(A-BRICK IS RED)
(A-BLOCK IS SQUARE)
(A-BLOCK IS MADE-OF-WOOD)
(A-BLOCK HAS PICTURES-ON-IT)
(A-PERSON IS PLAY WITH A-BLOCK)
(A-TRUCK HAS WHEELS)
(A-TRUCK PAS TIRES)
(A-TRUCK CARRY DIRT)
(DIRT IS A-THING)
(A-TRUCK CARRY A-THING)
(A-TRUCK HAS A-HOOD)
(A-TKCCK HAS A-CAB)
(A-COW IS AN-ANIMAL)
(A-COW EAT GRASS)
(A-COW IS LIVE-ON A-FARM)
(AN-ANIMAL HAS LEGS)
(A-COW HAS A-HORN)
(A-COW GIVE MILK)
(A-COW HAS AN-UDDER)
(A-ZEBRA IS AN-ANIMAL)
(A-GIRAFFE IS AN-ANIMAL)
(A-HORSE IS AN-ANIMAL)
(A-ZEBRA HAS STRIPE)
(A-ZEBRA IS LIVE IN AFRICA)
(A-GIRAFFE IS LIVE IN AFRICA)
(A-ZEBRA IS FOUND IN THE-ZOO)
(A-GIRAFFE IS FOUND IN THE-ZOO)
(A-ZEBRA IS WILD)
(A-GIRAFFE IS WILD)
(A-GIRAFFE HAS A-LONG-NECK)
(A-HORSE HAS A-MANE)
(A-HORSE IS BROWN)

```
(A-HORSE CARRY A-PERSON)
(A-PERSON I S A-THING)
(A-FOOT HAS TOES)
(A-FOOT I S PART-OF-THE-BODY)
(A-FOOT HAS A-HEEL)
(A-HOUSE H A S A-WINDOW)
(A-HOUSE HAS A-HOOF)
(A-WINDOW IS PART OF A-HOUSE)
(A-FAMILY IS LIVE IN A-HOUSE)
(A-HOUSE HAS A-DOOR)
(P-GLASS-BOTTLE HAS SHAPE4)
(P-GLASS-BOTTLE IS MADE-OF-GLASS)
(A-GLASS-BOTTLE HOLD A-LIQUID)
(COCA-COLA I S A-LIQUID)
(P-JAR I S MADE-OF-GLASS)
(A-JAR HOLD A-LIQUID)
(A-CAR HAS WHEELS)
(A.-CAR HAS A-HOOD)
(A-CAR HAS A-DOOR)
(A-CAR HAS SHAPE5)
(A-PERSON I S RIDE I N A-CAR)
(FATHER DRIVE A-CAR)
(A-MAN DRIVE A-TRUCK)
(FATHER I S A-MAN)
(A-MAN DRIVE P-CAR)
(A-MAN IS TALL)
(A-MAN I S A-PERSON)
(A-MAN I S OLD)
(A-MAN HAS WORKCLOTHES)
(A-MAN HAS A-SUIT)
(A-SCREWDRIVER I S FOUND I N A-TOOLBOX)
(A-HAMMER IS FOUND I N A-TOOLBOX)
(A-SCREWDRIVER SCREWED A-SCREW)
(A-SCPEWCKIVER HAS A-HANDLE)
(A-SCREWDRIVER I S A-TOOL)
(A-HAMMER I S A-TOOL)
(A-SCREWDRIVER H A S A-THIN-END)
(A-MILKBOTTLE I S FILLED-WITH-MILK)
(A-MILKBOTTLE HOLD MILK)
(A-MILKBOTTLE IS KEPT IN A-FREEZER)
(MILK IS COLD)
(E-FREEZER HOLD MILK)
(A-FREEZER I S COLD)
(MILK I S GOOD)
(A-MILKBOTTLE I S MACE-OF-GLASS)
(A-MILKBOTTLE I S A-THING)
(A-MAN H P S WORKCLOTHES)
(A-BOTTLE IS KACE-OF-GLASS)
(A-BUTTLE HAS LIQUID-IN-IT)
(A-BOTTLE I S BREAKABLE)
(A-MILKBOTTLE I S A-BOTTLE)
(A-BOTTLE I S A-THING)
```

Appendix E

Subject and Model Performance

on Original Test Sequence

1. relate (a-shoe (a-sock a-ball))

   choice: a-shoe and a-sock

   subject: you wear them sometimes

   model: a-shoe is worn on a-foot

2. relate (a-spoon (a-cup-and-saucer a-car))

   choice: a-spoon and a-cup-and-saucer

   subject: when you drink, need spoon for sugar

   model: a-cup-and-saucer hold a-drink and a-drink is stir by a-spoon

3. relate (a-hand (a-flower a-glove a-star a-stove))

   choice: a-hand and a-glove

   subject: it's a-glove you sometimes wear

   model: a-glove is worn on a-hand

4. relate (a-baby (a-safety-pin a-paperclip a-nail a-straight-pin))

   choice: a-baby and a-safety-pin

   subject: use for the diaper

   model: a-safety-pin hold-on a-diaper

5. relate (a-hammer (a-knife a-straight-pin a-nail a-needle))

   choice: a-hammer and a-nail

   subject: you nail something on the wall

   model: a-nail is hit by a-hammer

6. relate (a-lamp (an-endtable a-book a-battery a-pencil))

choice: a-lamp and an-endtable

subject: you put the lamp on the **endtable**

model: an-endtable is something a-lamp is sit-on

7. relate (a-girl (a-cigarette a-chair at-sofa a-mother))

choice: a-girl and a-mother

subject: girls have mothers

model: a-mother is belong-to by a-girl

8. relate (a-wiridow (a-clock a-button the-sun a-penny))

choice: a-window and the-sun

subject: the-sun is outdoors

model: the-sun is shine through a-window

9. relate (a-jar (a-book a-block a-brick a-box))

choice: a-jar and a-box

subject: you put things in a-box and you put **things** in a-jar

model: a-box hold a-thing and a-jar hold a-thing

10. relate (a-truck (a-cow a-giraffe a-horse a-zebra))

choice: a-truck and a-horse

subject: you carry horses in trucks sometimes

model: -a-truck carry **a-thing** and a-horse carry a-thing

Appendix F

Subject and Model Performance

on Verification Test Sequence

(Female Subject)

1. relate (a-shoe (a-sock a-ball))

    choice: a-shoe and a-sock

    subject: put it on your toes then on your foot

    model: a-shoe is worn on a-foot and a-sock is worn on a-foot

2. relate (a-shoe (a-sock a-foot))

    choice: a-shoe and a-foot

    subject: a-shoe makes foot warm

    model: a-foot is warm by a-shoe

3. relate (a-hand (a-stove a-glove a-star a-flower))

    choice: a-hand and a-glove

    subject: glove keeps your hand warm

    model: a-glove warm a-hand

4. relate (a-spoon (a-cup a-car))

    choice: a-spoon and a-cup

    subject: use spoon to stir the cup up

    model: a-cup hold a-drink and a-drink is stir by a-spoon

5. relate (a-spoon (a-cup a-knife))

    choice: a-spoon and a-knife

    subject: they all go in the drawer

    model: a-knife is found in a-drawer and,a-spoon is found-in a-drawer

6. relate (a-hammer (a-screwdriver a-nail **(didn't** recognize at **first)** a-pin))

choice: **a-hammer** and a-screwdriver

subject: **they** all go in the suitcase

model: **a-hammer** is found in a-toolbox and a-screwdriver is found in a-toolbox

7. relate (a-girl (a-chair a-couch a-mother))

choice: a-girl and a-mother

subject: she watches the girl

model: a-mother watch a-girl

8. relate (a-window (a-clock a-button the-sun))

choice:a-window and a-clock

subject: put the clock on there (the window sill)

model:a-window and the-sun because **the-sun** give light and light is come through a-window

9. relate (a-window (a-clock a-house the-sun))

choice; a-window and a-house

subject: the window goes on the house

-model: **a-house** is something **a-window is** part of

10. relate (a-milkbottle (a-book Some-blocks a-box))

choice: a-milkbottle and a-box

subject: carry the bottle in the box up the stairs take milk out and put in the freezer

model: a-box hold a-milkbottle

11. relate (a-truck (a-horse a-giraffe (didn't recognize) a-zebra a-cow))

choice: a-truck and a-cow

subject: truck brings cow to the grass

model: a-cow is carry by a-truck

12. relate (a-truck (a-horse a-man a-zebra a-cow))

choice: a-truck and a-man

subject: the man drives the truck

model: a-man drive a-truck

Appendix G

Subject and Model Performance

on Verification Test Sequence

(Male Subject)

1. relate (a-shoe (a-sock a-ball))

    choice: a-shoe and a-sock

    subject: there's a sock with the shoe

    model: a-sock is cover by a-shoe

2. relate (a-shoe (a-sock a-foot))

    subject choice: both go

        reason: sock goes on this (foot) shoe goes on sock

    model choice: a-shoe and a-foot

        reason: a-foot is cover by a-shoe

3. relate (a-spoon (a-cup a-car))

    choice: (subject) none of them go

    choice: (model) sorry - nothing seems to go with a-spoon

4. relate (a-spoon (a-cup a-knife))

    choice: a-spoon and a-knife

    subject: knife you cut with and a spoon you eat with

    model: a-spoon is found in a-drawer and a-knife is found in a-drawer

5. relate (a-hand (a-flower a-glove a-star a-stove))

    choice: a-hand and a-glove

    subject: a-glove goes on the hand

    model: a-glove is worn on a-hand

6. relate (a-hammer (a-screwdriver a-pin a-nail))

choice: a-hammer and a-nail

subject: a-hammer is used on a-nail

model: a-nail is hit by a-hammer

7. relate (a-girl (a-chair a-couch a-mother))

choice: a-girl and a-mother

subject: the mother takes care of the girl

model: a-mother watch a-girl

8. relate (a-wondow (a-clock a-button the-sun))

choice: a-window and the-sun

subject: see the sun out the window

model: a-window is something the sun is seen through

9. relate (a-window (a-house a-button the-sun))

choice: a-window and a-house

subject: there are windows in the house

model: a-window is part of a-house

10. relate (a-bottle (a-book a-box some-blocks))

subject choice: none go

model choice: sorry - nothing seems to go with a-bottle

11. relate (a-truck (a-cow a-giraffe thought it was a zebra) a-zebra a-horse))

subject choice: none go

model choice: sorry - nothing seems to go with a-truck

12. relate (a-truck (a-cow a-man a-zebra a-horse))

choice: a-truck and a-man

subject: the man drives the truck

model: a-man drive a-truck

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