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TRAMP: A Relational Memory with an Associative Base

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TRAMP: A RELATIONAL MEMORY WITH AN ASSOCIATIVE BASE

ABSTRACT

This report describes the theory and implementation of an experimental language called TRAMP, which is a software simulation of a content-addressable memory. The system consists of an associative data structure embedded in an interpretive language, allowing great flexibility and strong recursive power. The system has further been extended with a logical inference capability by superimposing a relational structure over the associative memory. The resulting language has already proved to be extremely powerful in several applications, and can be termed a language for developing question-answering and interactive communication systems.

This report discusses the theory and design considerations, details of machine implementation, and details of operation with examples.

TABLE OF CONTENTS

LIST OF FIGURES

TRAMP: A RELATIONAL MEMORY WITH AN ASSOCIATIVE BASE

I. INTRODUCTION

In recent years, the need for a content-addressable computer memory has become increasingly clear. Larger and larger programs are being written which require a structured data base to operate with any efficiency. Many of these could well benefit by replacing tedious searches with a fast, efficient, "content addressable" access of the data store. A good example is the "key word" library search. If we ask for a list of the books written by J.von Neumann, we do not expect the system to look at each title in its store and save only those written by von Neumann. And, if there happens to be a catalog prepared, designed to answer this particular question, we do not want to have to do a binary search to find the correct section of the catalog—we want to retrieve the answer directly!

There are many other problems which might find content-addressability advantageous. Examples abound in Artificial Intelligence, where prohibitively large tree searches are encountered; question answering machines; logical inference systems; graphic systems; and most conversational (timeshared) systems, which require immediate, direct access to a large data store to interact effectively. To date, most investigations into content-addressable memories have been concerned with hardware; such memories have not yet proved to be economically feasible. Even if they had, it is not clear that the obvious gain in speed would compensate for the loss in generality and flexibility. For the moment, it can be said that software simulations are a stopgap measure. They are. But it is not certain that they will be completely replaced by hardware in even the relatively distant future.

Another function of an artificial language is to permit the programmer to phrase his problem in a natural manner. For

many problems information is most naturally described as "relational triples"; e.g., in a graphics system, one might want to say: <Picture in> <Window A> is <Line B>;or<Connected to> <Line B> is <Line C>. The associative processor approach to content addressability allows this.

Before proceeding, we shall explain some potentially ambiguous terms.

The essential feature of an associative processor is that it has, in the conventional sense, no explicit addresses. Reference to storage is made by specifying all or any part of an associative cell, and all cells which match this field(s) are referenced. The conventional computer store may be thought of as a special (degenerate) case of an associative memory, in that the association is between the physical address and its contents. However, reference can be made only by specifying the address—one cannot ask directly for all cells which are zero! The true associative memory is accessed by specifying any of the N participants in the association. Associative memories are often referred to as relational data structures. This is because an association between N + 1 "objects" is most easily thought of, talked about, and manipulated by calling it an N-place relation.

The following example demonstrates why an associative processor can effectively be employed as an application of content addressability. Suppose we wish to know the phone number of Clark Kent. It is simple to look it up in the local phone book. It is, however, quite a different matter to find out whose number is 764-6148 (using the same directory). An associative processor would find both tasks equal. In this example, the "association" is between a subscriber's name and his phone number. In translating this to a two-place relation, "phone number of" could be the relation, and using the <R,x,y> format we would say: <Phone number of> <Clark Kent> is <KR 9-8765>. This is a type of associativity wherein we may

now directly reference this triple by any of its content-addressable components or combination thereof. If we use only the first component, phone number, in a search, what will be referenced is the entire book. If we specify two components: phone number and 764-6148, then we are referencing directly all associations containing those two components, viz., the associations containing the name(s) of the person(s) having the phone number 764-6148.

We are, of course, working with a conventional computer memory. The general strategy used to effect the simulation of an associative processor and an approximation to content addressability was that of hash-coding.† For those unfamiliar with the term, hash-coding is simply a technique whereby an arithmetic transformation is applied to an external name to generate an internal address. Hash-coding by itself provides a restricted but significant approximation to content addressability, but hashing alone does not provide any kind of associativy, and there is always the problem of the "collision," i.e., when two distinct names hash to the same internal address: $X \neq Y$; $H(X) = H(Y)$. Hashing partitions the space of names into equivalence classes. Hopefully, each class has only one element, but two or more names may be equivalent under this partition.*

By providing an interpretive language with an associative data structure it is possible to achieve great flexibility. To this end, we decided to use an existing interpreter and give it a new data structure, rather than start at the bottom by designing a special purpose interpreter. Principally, we were concerned with the data structure, and the vehicle for

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† A good survey of this technique may be found in Robert Morris' article "Scatter Storage Techniques," which appears in the January 1968 issue of Communications of the ACM, Vol. 11, No. 1.

* Even restricting names to four characters of the English alphabet, a one-to-one transformation would require a table with 456, 976 entries to guarantee no collisions.

it was initially felt to be unimportant, since the data structure relies on the host only superficially. In considering the question of the interpreter, we were faced with very little choice. A major consideration was that of availability; fortunately this consideration led us to TRAC* T-64 Language. It has proven to be a most elegant host, and credit for the power of the resulting system must be shared by both the interpreter and the associative memory given to it. However, we feel that the additional primitives are excellent vehicles which change the original processor into an efficient language for writing man-machine and machine-machine communication systems. Familiarity with the TRAC language may be helpful in reading this article, but it is not prerequisite. A brief summary of the basic components of the language is found in Appendix A.

II. BACKGROUND

An associative processor is one possible tool for information storage and retrieval, and its history should be discussed relative to such systems. Unfortunately, adequate comparisons of different types of data systems are difficult to make because they are predicated on different rules. Thus the prime method of storage may vary from cards or paper tape, through magnetic discs and drums, to prime computer memory; at the same time, the storage may be either random or ordered according to some schema; finally, the retrieval of the information may be gross, such as the use of a mechanical sort based on some algorithm, or simple because the data were stored for such answers or because there is a well-developed language to address the stored data.

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* TRAC is the trademark of Rockford Research Institute, Inc., Cambridge, Mass. in connection with their standard languages. For details on TRAC T-64 language, see References 14 and 15.

Thus we have three possible criteria for comparison of systems: the type of storage, the way of entering data into that storage, and the language for addressing that storage. The spectrum of potential systems is therefore large and varied. We will consider only those which use main computer memory as the storage device (including virtual or paged memory).

One inherent bias of computer design affects the storage of data: the use of sequential storage, where the data are placed in numbered or ordered cells. Because this organization system allows the automatic indexing of information by means of some automatically varied register, the preferred method of storage is tabular. Fortunately, tables are excellent ways of storing information, for the parallel entries are ways of expressing associations between objects (see Figure 1).

ITEM#	NAME	FATHER OF	BROTHER OF	MOTHER OF
1	JOHN	EDITH; ARNOLD	SAM;JOAN	———
2	ARNOLD	JAMES	EDITH	———
3	MARY	———	———	ARNOLD
4	EDITH	———	———	MELISSA

Figure 1. Association by Tables.

Hence an index may carry the association and we can respond to the query: "Who is the mother of Arnold?" by scanning the "mother of" column, picking the Index 3 at the entry "Arnold" and returning "Mary" from the "3 position" of NAME.

Such retrieval systems are obvious and are in general use. What, then, are the faults? Part of the problem lies in the relative paucity of information—the large number of blanks in the tables. Other problems occur at the time of search, for

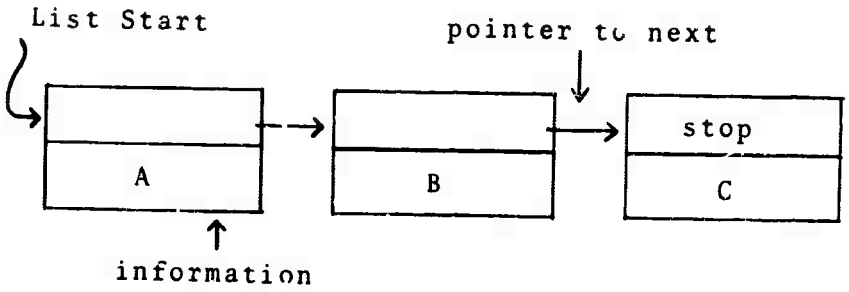
the tables are not properly ordered. In fact, the "best order" depends on what question is expected to be asked. For the question: "Who is the mother of...?" the order 4,3,2,1 is preferred, whereas "Who is the father of...?" prefers the order 2,1,3,4 or 1,2,3,4. Hence there is no order that is optimal for all questions. Another major problem of tabular storage is its size limitation. To be efficient, the table sizes must be pre-specified, and hence a sudden request for extra space is potentially catastrophic.

The need for easy addition and deletion led to the list processor, and many information systems stem from the ideas of IPL-V [16] and SLIP [21]. The former elucidated and refined the method of pointers and lists, and the ideas of association lists (Figure 2). The use of lists makes possible dynamically extended tables. A second use of lists is with association explicitly defined for certain objects. Thus the illustration of Figure 2b could be written:

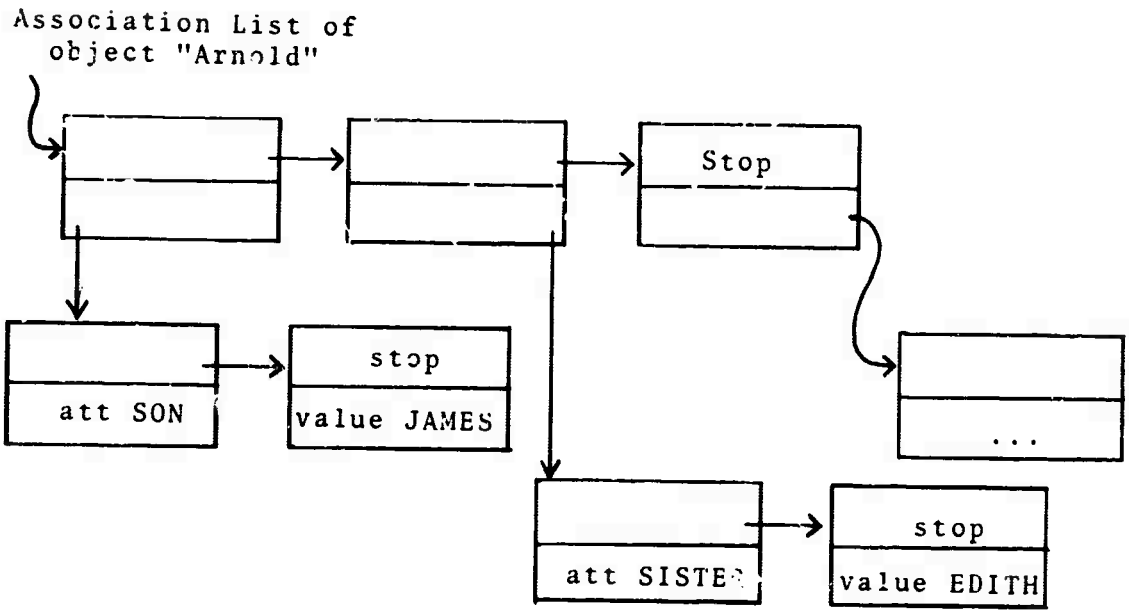
<Attribute A> of <object α> = <value A>
<Son> of <Arnold> is <James> etc.

Here we see that the question "Who is the mother of Arnold?" is difficult to answer, because it was not explicitly stored on Arnold's association list. This question may be answered by searching all association lists, until one is found which has the pair {Mother, Arnold}.

SLIP was the first embedding of a list-processing capability within a higher-level language and was a formative ring structure. The idea of rings was crystalized by Sutherland [20], and Roberts [17], and used with data systems designed primarily for graphics and computer-aided design. Roberts has also developed a language to refer to rings (Class Oriented Ring Associative Language: CORAL). In such languages, the associations are built into the structure by allowing blocks of information to be threaded by rings which carry the associations between the blocks of data. This is illustrated



a. Ordinary, single way list: (A,B,C)



b. One type of paired Association List:
[(att A,val A)(att B,val B) ...

Figure 2. Association by Lists

by Figure 3. Dodd [1] has implemented a similar structure within PL/I. The duality of certain relationships, such as: "defined by" and "defines" or "to the left of" and "to the right of," etc., led to the need for a connector block, here illustrated by the three NUBS.* In essence, the NUB represents a two-way switch for transferring out of one ring and into another. The subroutines or macros pass along the ring until they arrive at a NUB. They "switch" it, and pass into the other ring, passing along the second ring (and others as found) picking up information until they return to the original NUB and re-enter the first ring. This allows answers to questions such as "Who is the mother of Arnold?" as well as "Who is the son of Mary?" One of the major disadvantages of these structures occurs on adding a new, not previously anticipated, association. The operation either is impossible, requiring a complete recompilation, or else clumsy, patching on additional blocks (Figure 4) and requiring sophisticated garbage collectors. A recent survey by Gray [5] describes these and similar structures.

Probably the first conception of a true relational data structure was Kochen's AMNIPS [7,8]. He dealt with the problem of logical inference rather than with data structures, but he recognized that conventional memories were inadequate, and turned to the relational structure, which unfortunately was never fully realized.

A considerable amount of work has been done on various "question-answering machines." Among the better early machines were Lindsay's SAD SAM [11] which can digest English statements about family relationships and construct a family tree, and the BASEBALL program of Green, et al. [6] which answers English queries about facts taken from a stylized

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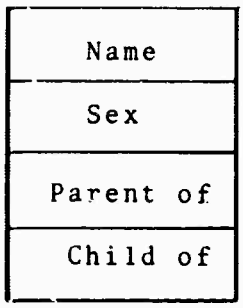
* It is interesting to note that there is no need for NUBS if we are willing to store all inverse and similar relationships explicitly, with separate rings for each.



Generic "Person"
Block

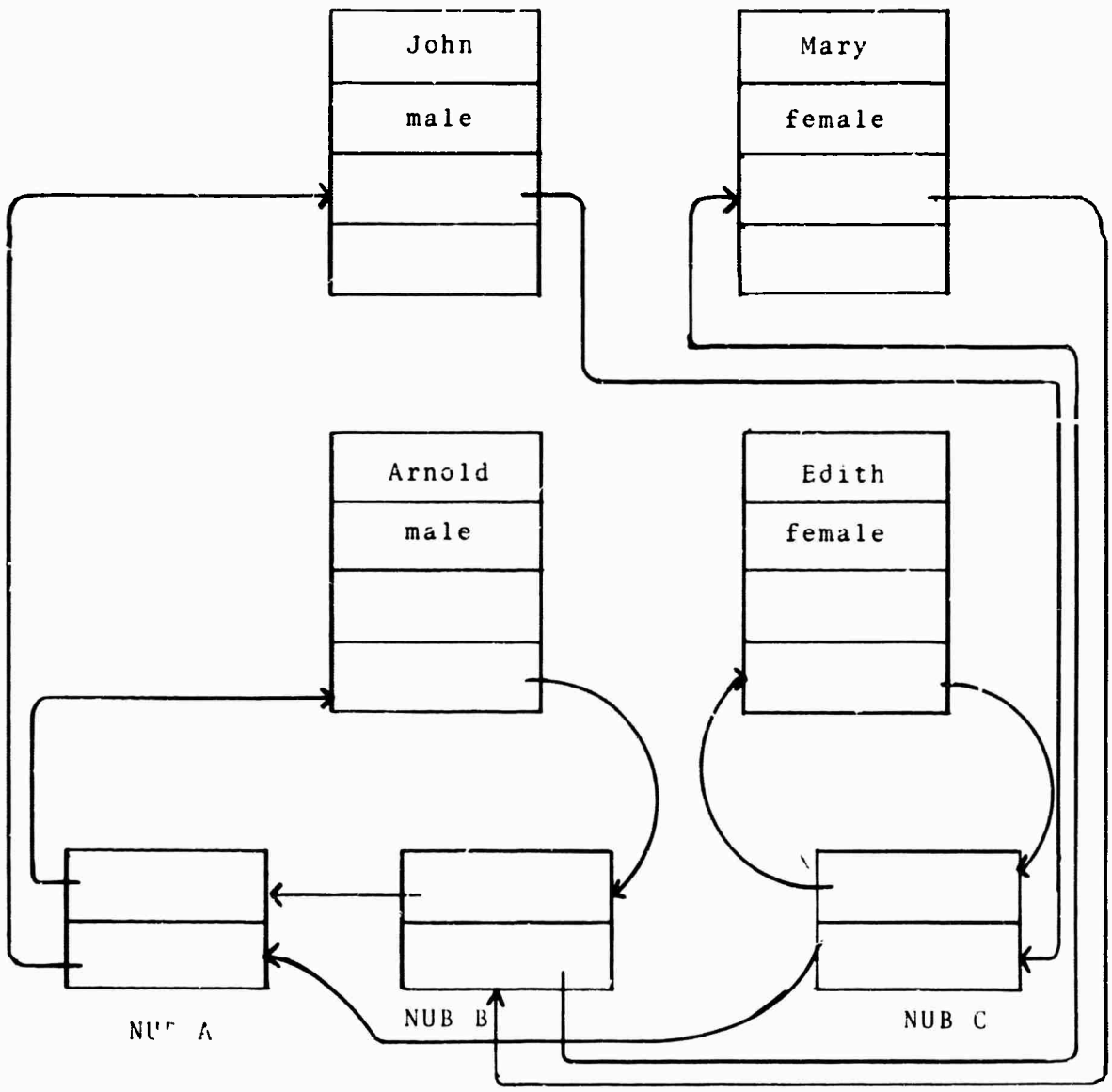


Figure 3. Associations by Rings.

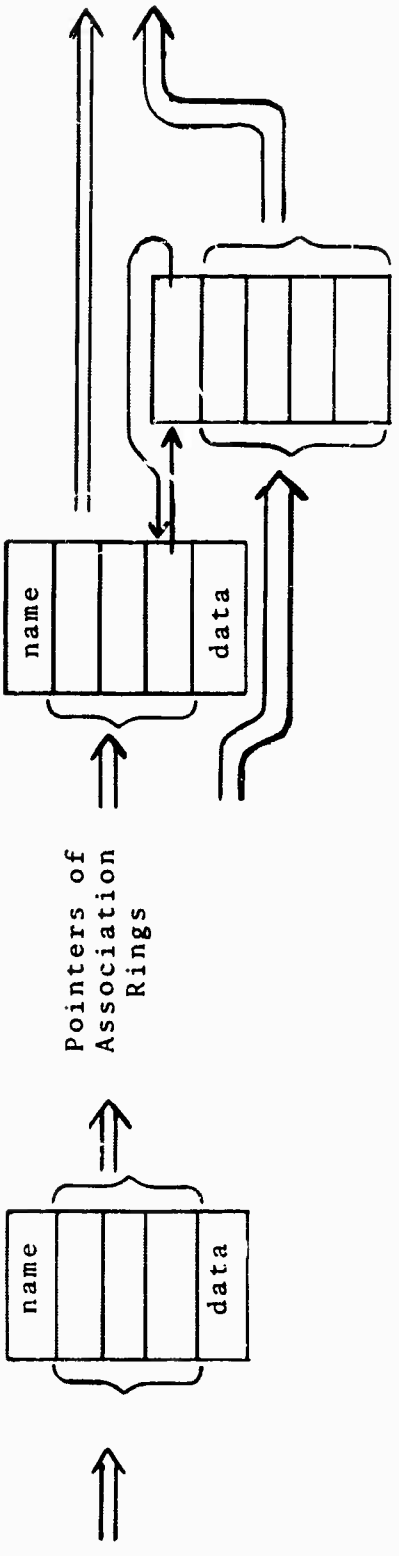


Figure 4. Addition of Association with Rings.

baseball "yearbook." These investigations use conventional data structures, and their real contributions were to the analysis of the English language and logical inference by computer. Simmons [18] provides the most complete survey to date of this work.

Maron and Levien [9,10,12] have designed one of the most extensive and complete systems depending on a relational data file. They deal with binary relations as their building blocks, i.e., each association has three components: one relation and two operands. In addition, they allow the naming of the entire association (triple) giving rise to a fourth component. Reference can be made using any of the four components, and there are four copies of each association—one copy for each word which can reference it.

Feldman has recently used the ideas of hash-coding for association tables [3,4]. The associations are, of course, carried by a new table, referenced by a "double hash" technique. Feldman's language, AL , is designed to be compiled rather than interpreted. AL has been expanded to be three languages in one: a true ALGOL-type algebraic language with full numerical computation facilities; an associative processor; and a language which operates on sets as its basic entities with a full complement of set operations. The language now allows for certain kinds of restricted composition of associations. Specifically, if a sentence is a triple <A,0,V> , then 0 or V may itself be another triple. This allows for generating N-place relations out of the basic binary relations. However, the language has, instead of dynamic inference, a DO loop which is slightly more cumbersome, and far less economical of storage, than are strict logical inference capabilities.

Naturally, the simplicity in using data systems depends on the retrieval language. We have already suggested that the problem is partially a function of explicit versus implicit storage. If the family relationships are taken in

the binary male lineage tree of four generations (Figure 5), we have: 16 great-grandfather–son; 24 grandfather–son; 28 father–son; 14 brother; 24 uncle–nephew; 48 cousins, etc. Obviously, a large number of relationships must be explicitly stored for rapid access, compared with the cost of an implied relationship search with small storage requirement.

The "relational" part of the TRAMP system is the means for retrieving implied relationships, while the "associative" part deals with the explicit relations.

III. TRAMP

TRAMP (Timeshared Relational Associative Memory Program) is two packages of functions: the first–the data structure–may be used to enter, retrieve, and generally manipulate an associative data structure; the second–the relational memory–places an artificial structure on the "associative triples," viz., the relational structure. The relational package allows logical inference to be performed on the data within the associative structure. Specifically, rules may be entered, these will be followed by TRAMP, effectively expanding a "minimal" set of data to a workably large set; the number of associations that must be explicitly stored is thereby drastically reduced. For example: by defining the relation "HUSBAND OF" to be the converse of "WIFE OF," the user need only store marital relations in one direction, while effectively having them available in both directions. More detailed examples and the rules for using the relational package appear later.

These machine-coded functional packages are presently embedded in the UMIST* interpreter on the IBM/360 model 67. Although this existing union has proved most fruitful, the

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* UMIST is closely patterned after the standard TRAC T-64 Language, and was implemented at The University of Michigan with the cooperation of Mr. C.N. Mooers, creator of the TRAC T-64 language.

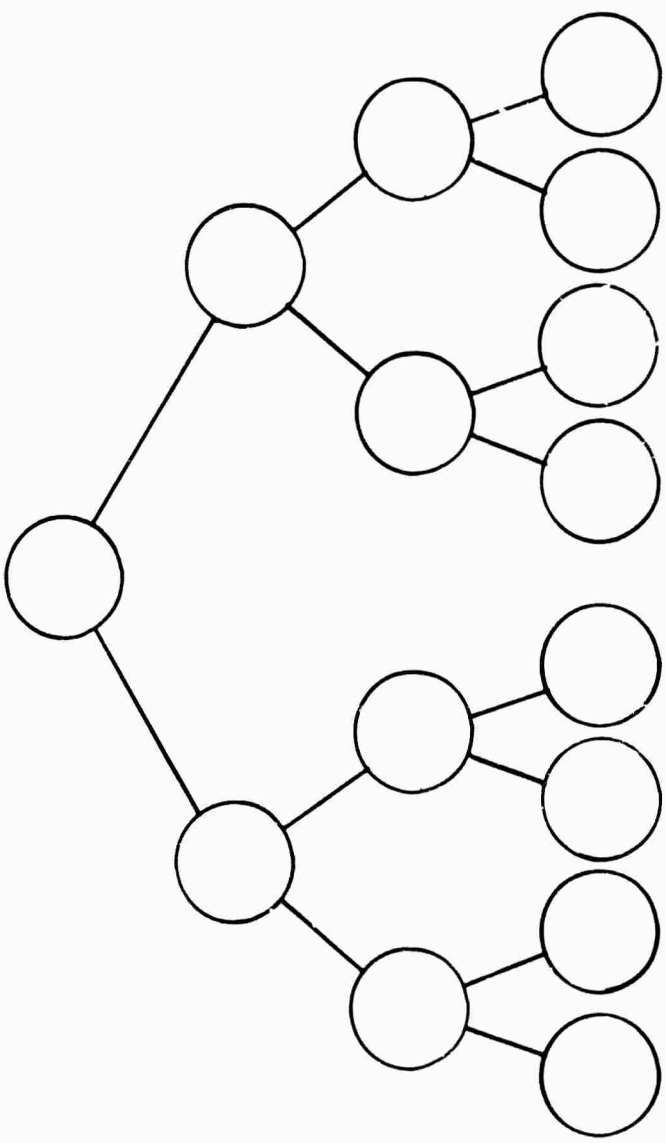


Figure 5. Binary 4 Generation Male Relational Tree

data structure is totally independent of the interpreter and actually relies on it only for I/O. The relational package is also independent, except that it relies on the type of recursion that the interpreter provides. The relational package is totally dependent on the associative data structure.

The Associative Data Structure

Feldman's initial work was a strong motivation in the design of this system, and led us to adopt his notation, viz., the generic entity:

A (O) = V

<Attribute> of <Object> equals <Value>

Thus the Associative Triple is: <A,O,V> . Each of the three components is a non-empty set. To the data structure this is an ordered triple, but no interpretation or meaning is attached to the ordering, and all three are treated equally, giving none a priority.* By appropriately designating the three components as being constant or variable, we can ask eight "questions" of the data structure. Again using Feldman's notation, with a slight re-ordering, they are:

F0	A (O) = V
F1	A (O) = x
F2	A (x) = V
F3	A (x) = y
F4	x (O) = V
F5	x (O) = y
F6	x (y) = V
F7	x (y) = z

* This is in contrast to the relational package which places an artificial structure on the triple, i.e., calling the first component a "relation" and the second and third its arguments.

where [A,0,V] represent constants, and [x,y,z] are variables. Question F7 is not a question at all but a request for a dump of the associative memory, and in TRAMP such a dump is given. Question F0 simply asks: "Does A (0) = V?" and the answer is a kind of truth value. In the case where A, 0, and V are all singletons, the truth value is a straightforward 1 or 0 denoting whether or not the specified association can be verified by the data. The interpretation is slightly ambiguous, however, when one or more of the three sets has cardinality greater than one. To illustrate, assuming that the association

COLOR (CAR) = RED; GREEN*

has been stored, these five questions have the following truth values:

1.	COLOR (CAR) = BLUE	0
2.	COLOR (CAR) = RED; GREEN	1
3.	COLOR (CAR) = RED; BLUE	?
4.	COLOR (CAR) = RED	1
5.	COLOR (CAR) = RED;GREEN; BLUE	?

Questions 1 and 2 are clearly false and true respectively, but questions 3 and 5 are each partially true and partially false; question 4 is only half true. The interpretation which seemed most natural, and the one adopted by TRAMP, gives the truth values as shown, namely:

> if ALL associations implied by the question are resident in memory, or derivable therefrom, the value is "1"
>
> if none, the value is "0"
>
> if some, but not all, the value returned is "?"

---

* Since the comma already plays an important role as a TRAC language meta character, it is unavailable as a set element delimiter. Therefore the semi-colon (;) plays that role in TRAMP.

Questions F1-F6 simply ask the system to "fill in the blank(s)," i.e., to replace the variable with the set that is the answer to the question. For example, Question F1 asks for the set of all Vs that A (0) equals. Question F3 asks for the sets of all Os and Vs that have a first component "A." Because of the recursive nature of TRAC, questions F1-F6 may be nested in any way, to any desired depth. One may ask: "How many fingers on a hand?"; "What figures are pointed to by the arrows in Window Q?"; "How old are the fathers of the wives of Mary's brothers?"; or any questions composed in any way compatible with the stored data, nested to any level.

For those totally unfamiliar with TRAC language, for this section it is necessary to know only the syntax of a function call. The sharp sign (#) signals the start of a function call, with the call itself enclosed in an immediately following pair of parentheses. The arguments are separated by commas, and the first argument is the name of the function.

```
#(sub,ARG)
```

is therefore analagous to the FORTRAN

```
CALL    SUB(ARG)
```

Data Structure Storage

The name of the storage function is dr and the syntax of the call is: #(dr,A,0,V) . Again, the three arguments to dr are each non-empty sets. Each point in the cartesian product of the three sets is stored, i.e., each element of each set is grouped with each pair of elements of the other two sets, and the resulting triple is stored. Thus a single call on dr stores as many associations as the product of the cardinalities of the three sets. The storage declaration:

```
#(dr,AGE,JOHN;MARY,64)
```

would therefore store:

AGE (JOHN) = 64

AGE (MARY) = 64

The actual storage is accomplished by pairing each A and O to point to a list of Vs ; each A and V point to a list of Os , etc. These "answer" lists are, strictly speaking, unordered, except that they retain the order in which they were stored. That is, asking the question:

"Whose age is 64?"

would yield the answer:

JOHN; MARY not MARY; JOHN

It should be noted that this is a pure data structure, and it does not deal with semantics; dr simply inserts associations into memory in a way that they can be quickly retrieved. TRAMP is not a question-answering system that checks for redundancies or inconsistencies of data.

Data Retrieval

The primary retrieval function has the name rl . The syntax of the function call is identical to that of dr except for variable specification. A variable in TRAMP is denoted by enclosing a name, possibly null, within asterisks (*) . Thus, #(rl,A,O,V) has no variables and asks whether A (O) = V ; #(rl,A,O,*X*) asks: "What does A (O) equal?" If the variable is Named, i.e., there is a name within the asterisks, then the function is Null Valued and the answer is stored in TRAC language form storage labeled by the Name. #(rl,A,O,*ANS*) would store the set of Vs which A (O) equals, under the label "ANS." If the variable is not Named, #(rl,A,O,**) , then the answer is the Value of the function. #(rl,A,*SETO*,**)

an example of a two-variable question with one Named and one Unnamed variable. The result in this case would be that the set of Os is placed in form storage under the label "SETO" while the set of Vs is returned as the Value of the function.

The two-variable questions (F3, F5, F6) simply use the Name table of one of the variables and index through that table, internally always asking the one-variable questions. Since the data structure does not assign any priority to the three components, questions F3, F5, and F6, although considerably slower that the one-variable questions, are all equal among themselves. The process of answering a two-variable question is less efficient because it must iterate on the one-variable questions, the number of iterations being a linear function of the size of memory.* The speed with which the one-variable questions are answered is not significantly affected by the size of memory! The three-variable question, #(r1,**,**,**) , is, of course, the slowest of all and it is a full dump of the associative memory. Alternatively, one can call: #(dump).

Going back to the earlier example of N and MARY, the question: #(r1,AGE,JOHN;MARY,**) should have as its value: 64;64. That is, redundancies can be valid and should be reported. But there are certain times, particularly in the two-variable questions, when redundancies become quite a nuisance (and even threaten to overflow the interpreter). Therefore, the function r1 will always return an answer set with all redundancies deleted. A second entry point is provided, with the name r1r , which is identical except that it does not check for redundancies but returns the answer set as it finds it.

---

* Here, and subsequently, "size of memory" refers to the amount of data in the structure, rather than the physical extent of the system.

rl generates the union of the answer sets. That is, the question: #(rl,AGE,JOHN;MARY,**) has two answer sets: the AGE of JOHN and the AGE of MARY. rl simply forms the union of however many sets there might be. int is the function (yet another entry point to the same routine) which generates the intersection of the several answer sets. Thus, #(int,SOUTH;WEST,AUGUSTA,**) generates the set of all things both south and west of Augusta. #(rl,SOUTH;WEST, AUGUSTA,**) , on the other hand, would generate the set of all things either south or west of Augusta.

Data Structure-General Strategy

As stated in the introduction, hash-coding is the technique most basic to the data structure design. A brief description of the use of hash-coding in TRAMP follows. Section V gives a more technical and detailed description.

The data structure uses three Name tables and three Association tables, one each for each of the three components of the association. When the declaration: #(dr,WIFE,JOHN, MARY) is made, each name that appears must be stored somewhere in memory. The full name must be present so that it can be retrieved, and so that, when it is referenced, a collision can be identified and resolved. The first hash, H_1 , then is applied to the "A" component, "WIFE," to generate a displacement from the A Name Table. The designated table entry is then inspected. If the entry is zero, then there is no collision and WIFE has never appeared before as an "A" component. Accordingly, the table entry is now made to point to the Header for the name WIFE, see Figure 6. If the table entry is not zero, the Header to which it points is inspected to see if it is the Header for WIFE. If so, the A name has been processed and we move on to the 0 component, otherwise there is a collision. For a collision, instead of a single Header, there is an alphabetical list of Headers.

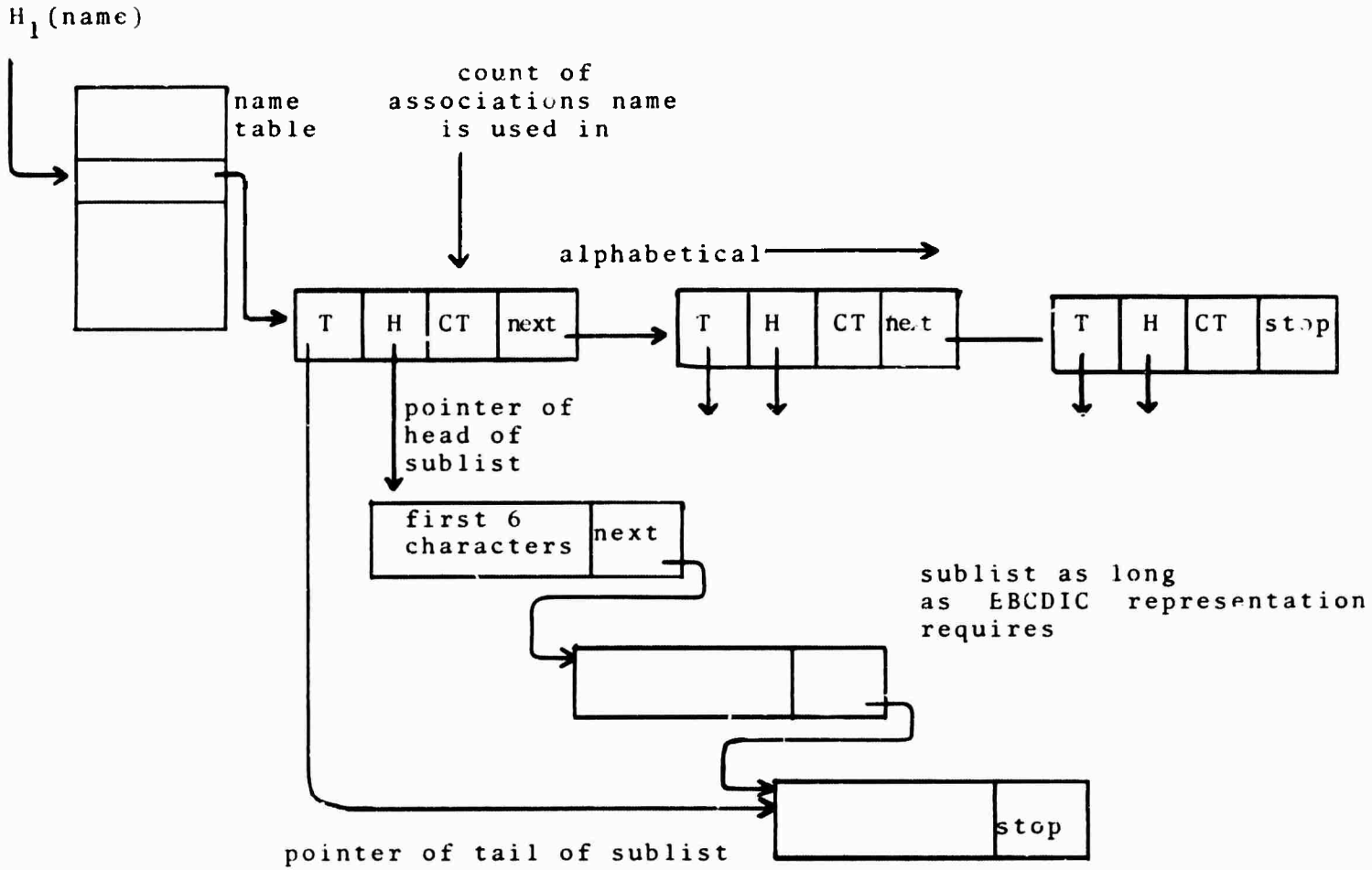


Figure 6. Name Table Structure

Thus, Name Table collisions are not really special cases: if there is no collision, then there is a list consisting of a single Header, otherwise the list contains two or more Headers in alphabetical order.

If the above process did not find the name, before it is actually placed in storage, a further check is made on the other Name Tables, thus avoiding redundant storage. Any name will appear at most once in memory, with up to three Headers pointing to it.

The same procedure is applied to "JOHN" and "MARY," the O and V of this example, on their respective Name Tables. As a result of the Name Table processing, a unique pointer is associated with each of A, O, and V, namely the pointer in the Header which points to the location of the actual name. It is this unique pointer that will be used for the second hash, H_2. "WIFE" must now be placed on the A Association Table. To do this, the O and V pointers are hashed together to generate a displacement from the Association Table. To be able to identify collisions, both pointers that were used to generate the hash are stored in the table entry designated by the hash. Collisions are again resolved by ordered lists. The Association Table entry has three pointers: the first two are the pointers used to generate the displacement; the third points to the Answer List, i.e., the list of A's (in this case) with which O and V have been associated. Thus, "WIFE" is appended to the Answer List by placing the unique pointer to it at the end of the list. Note that H_1 is a function of the actual name, while H_2 is only a function of where the name is stored and is independent of the name itself. Figure 7 shows the Association Tables, both for the collision case [7b], and for the normal case [7a].

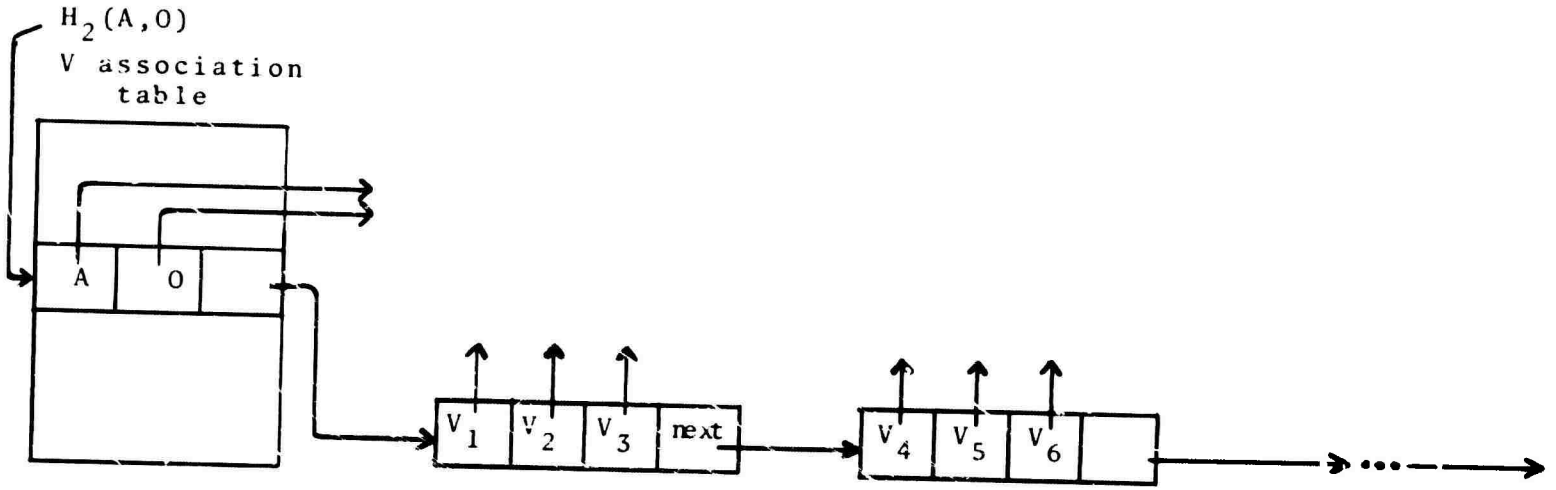


Figure 7a. Normal Case: No Collision.

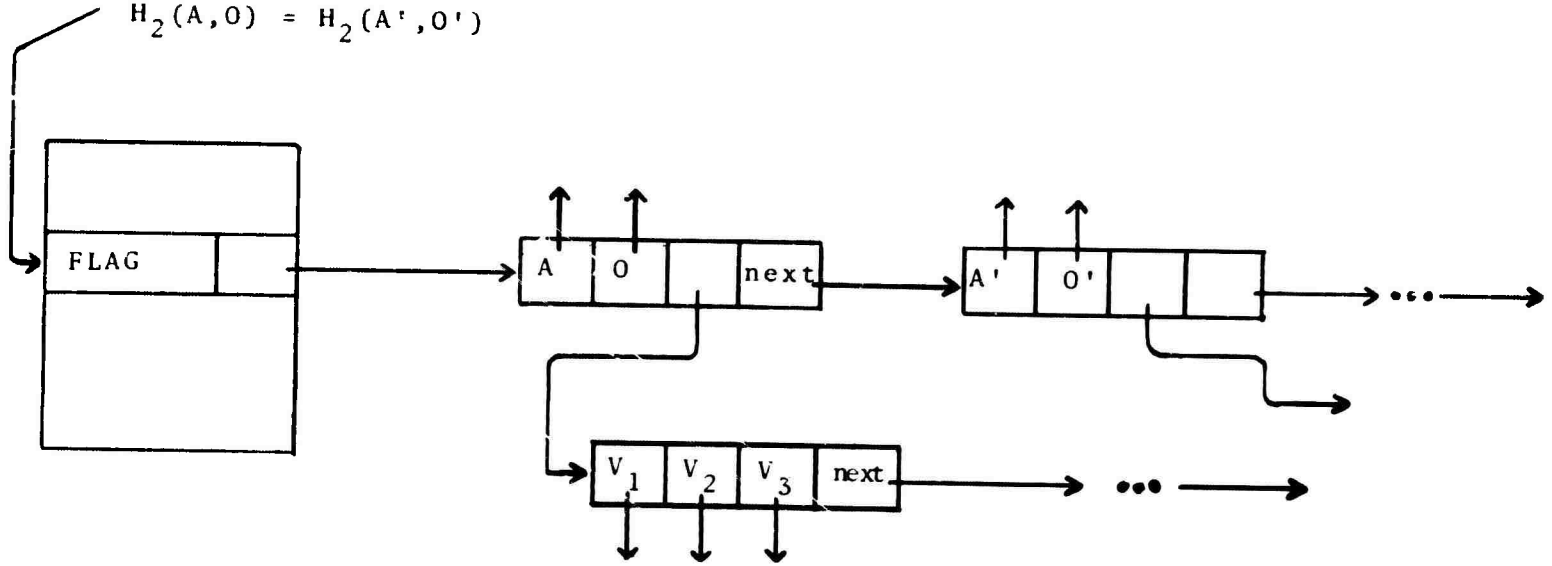


Figure 7b. Collision.

FIGURE 7. ASSOCIATED TABLES.

IV. LOGICAL INFERENCE PACKAGE

The associative memory accomplishes a kind of content addressability by using two quick hashes to address data, and the access time is essentially independent of the size of storage.* But for most, if not all, applications, many associations will be implied by a single associative sentence. This poses two real problems:

1. The user must make sure that all associations that apply are actually inserted into the structure. This is extremely tedious and prone to error and omissions.
2. Explicit storage results in gross inefficiency.

To alleviate this, TRAMP provides the facility to define, in a characteristic way, what other associations may be derived from a given association. This permits all of the information that might be contained in a single association or sequence of associations to be utilized instead of having to enter the same information redundantly in each of the several ways that it might be referenced. The name of the function which makes the definition is ddr . The syntax of the function call is: #(ddr,(R = EXP)) , where R is the relation ("A" component) to be defined, and "EXP" is a logical expression which is the definition.

Before presenting examples of the use of ddr , two relational operators must be defined:

The first is converse, denoted in TRAMP by ".CON." Converse simply inverts the order of the two rela-

---

* As the size of storage increases, there are more collisions, but they are quickly resolved, and do not cause a significant delay. Even in extreme pathological cases, they involve only relatively minor list searches.

tional arguments:†

$$R(x,y) \leftrightarrow .CON.\ R(y,x)$$

Thus "CHILD OF" is the converse of "PARENT OF"; "WIFE OF" is the converse of "HUSBAND OF"; "SPOUSE" is its own converse; any symmetric relation is its own converse.

Relative Product: The relative product or composition of two relations is commonly denoted by R_1/R_2, and this is the notation used by TRAMP.

$$\forall x \forall y \exists z\ [(R_1/R_2)(x,y) \leftrightarrow R_1(x,z) \wedge R_2(z,y)]$$

Less rigorously, but more specifically,

$$\#(ddr,(R_3 = R_1/R_2))$$

would tell TRAMP that $R_3(x,y)$ if a "z" can be found such that $R_1(x,z)$ and $R_2(z,y)$.

Besides these two relational operators, three logical operators are available: .A. (conjunction); .V. (disjunction); .N. (negation). Finally, there are six equality operators: .EQ.; .NE.; .GE.; .LE.; .GT.; .LT., with obvious meanings.

Examples of TRAMP relational definitions are:

```
#(ddr,(BIGGER = BIGGER / BIGGER))  Bigger is transitive

#(ddr,(BIGGER(A,B) = BIGGER(A,Q) .A. BIGGER(Q,B)))
                    exact same definition using expanded
                    format—specifying dummy arguments.

#(ddr,(SIB = BRO .V. SIS  V. .CON.SIB))
                    a sibling is a brother or a sister and it
                    is symmetric.
```

† The relational notation used by TRAMP is derived from the format "R,x,y" by enclosing the relational arguments in parentheses. This is a slight distortion of the associative notation: A(0) = V, but the order is preserved: R(x,y) means that R(x) = y.

```
#(ddr,(HUSBAND = .CON.WIFE))    Husband is the converse of Wife.

#(ddr,(BIGGER = LARGER)    Bigger and Larger are synonomous.

#(ddr,(BRO(CAIN,ABEL) = SIB(CAIN,ABEL) .A. SEX(ABEL,"MALE")))
                        a brother is a male sibling.  Note that
                        constants are denoted by enclosing them
                        within double quotes.

#(ddr,(MALE(X) = SEX(X,"MALE")))    defined the unary relation
                                    MALE

#(ddr,(BRO(X,Y) = FATHER(X,Z) .A. FATHER(Y,Z) .A. MALE(Y)
                                                .A. X.NE.Y))
                    a brother is a male offspring of the same
                    father, other than oneself.

#(ddr,(STEPMOTHER = FATHER / SPOUSE .A. .N.MOTHER))
                    a stepmother is the spouse of the father
                    who is not the mother.

#(ddr,(NEPHEW = SIBLING / SON))    a nephew is the composition
                    of sibling and son.

#(ddr,(UNCLE = .CON.(SIBLING/SON)))    in a male world, uncle
                    is the converse of nephew and may be de-
                    fined as the converse of the definition
                    of nephew.

#(ddr,(UNCLE = .CON.NEPHEW))    or simply as the converse of
                    nephew.
```

More complex examples will arise, and TRAMP is prepared to handle definitions of the above form to a level of complexity virtually unlimited. One major constraint is placed on the definitions: relations must be defined so that at least one set is <u>generated.</u> This generated set can then be intersected with or joined with another set, or otherwise manipulated. The intent of this constraint is that there be at least one <u>reference</u> set. The "whole space" may never be used as a reference set.

#(ddr,(R_3 = .N.R_1 .V. R_2)) is illegal since it specifies a global complement (of R_1), i.e., it references the "whole space."

#(ddr,(R_3 = .N.R_1 .A. R_2)) is legal because it specifies a relative rather than a global complement, i.e., R_1 places a constraint on R_2 not on the whole space.

Implementation of Inference

The purpose of the inference mechanism is to allow the user to define under what conditions an implied association may be derived from data explicitly in memory. This is accomplished by generating where necessary (where defined) a more complex retrieval call from a simple one. Specifically, if the following definition had been entered:

#(ddr,(STEPMOTHER = FATHER/SPOUSE .A. .N.MOTHER))

then the following simple retrieval call:

#(r1,STEPMOTHER,JOHN,**)

which asks for the stepmother of John, would be expanded by the system to be the following:

#(rcom,#(r1,SPOUSE,#(r1,FATHER,JOHN,**),**),#(r1,MOTHER,JOHN,**))
#(r1,STEPMOTHER,JOHN,**)

The exact call generated would be slightly different, but that is a technicality, irrelevant at this point. The final retrieval call in the sequence generated asks if the desired association was entered explicitly. It is always assumed that a relation that has been given a definition may also appear explicitly. The rest of the expanded call will find the answer if it is present implicitly. This expanded call is then returned to the UMIST processor, which in turn makes the actual calls to the data structure. The importance of this is that relations need be expanded only one level at a time, with the UMIST recursion automatically taking care of the possibility that any relation is defined in terms of more complex relations,

etc. (this is the major difference between the call as it actually would be generated, and as it appears above—the above, taken literally, would specify an infinite recursion!) Thus the inference compiler generates TRAMP procedures--they operate only within the TRAMP language—not at a lower, machine level. The definition, entered by #(ddr), specifies what information the procedure is to derive and what rules may be used to derive it; the compiler accordingly constructs such a procedure; and the interpreter (TRAMP inference interpreter—rather than UMIST) expands the procedure at retrieval time, filling in information specific to the call.

At retrieval time, a retrieval "preprocessor" looks to see if the "relation" ("A" component) has been given a definition. If not, the preprocessor exits and retrieval proceeds as described earlier. If the name is found to have been defined, then the "interpreter" is called in to interpret the program generated by the compiler at the time it was defined. This program tells the interpreter what TRAMP function calls are to be made, and what the function arguments are to be.

It should be noted that the compiler actually puts out two programs: one which, given x of R(x,y), builds a chain to generate y; the other builds the appropriate chain in the opposite direction, from y to x. Thus question F1: #(r1,A,O,**) generates a different sequence of function calls than F2: #(r1,A,**,V). It may not be immediately obvious why this is necessary, but, in general, the two programs will be quite different. This is always the case for composition. Still, the compiler would only have to output one program, and the interpreter could decide how to interpret it. Since the compiler will usually be called only once or twice for each relation, or certainly fewer times than the interpreter, it is most efficient to let the compiler do as much of the work as possible.

The compiler is prepared to handle definitions which are circular in the sense that a relation is defined in terms of itself. That is, symmetric and transitive relations are perfectly acceptable. However, the sequence:

```
#(ddr,(PPP = QQQ .V. ... ))  #(ddr,(QQQ = PPP .V. ... ))
```

is invalid because of its circularity. Were the compiler to attempt to generate code for that sequence, the code would specify an infinite recursion. This situation is checked for and flagged if detected.

V. TRAMP INTERNAL ORGANIZATION

In effect, TRAMP employs a triple storage technique to be able to reference an association in three different ways. Thus, the association A (0) = V is stored on each of the A , 0 , and V Association Tables. This makes the answers to questions F1, F2, and F4 equally accessible and optimizes retrieval time.

TRAMP uses eight principal blocks of core. Though it is designed to run under a timesharing supervisor which continually swaps TRAMP on and off a drum, TRAMP itself makes no explicit use of drums, discs, or other secondary storage devices; that is, such use by the system is transparent to TRAMP as well as to the user. The blocks of virtual core are: four Name Tables [A, O, V, and a Name Table for Defined Relations]; three Association Tables; and a General Storage list [GS] (commonly called "Available Space" in many list processors). GS provides all the working space for TRAMP and is by far the largest of the eight. In addition to storing all of the information indexed by the seven tables, GS resolves any overflow (via collisions) from the tables.

For purposes of illustration, let us follow the interpretation of:

```
#(dr,HUSBAND,EVE,ADAM)
```

First the Name Tables are processed. "HUSBAND" is hashed to produce a displacement from the "A" Name Table. The actual

hashing scheme for H_1 is to form a full word (4 bytes) by concatenating the first, last, and middle two characters of the name, in that order. A single character may play only one of those roles, i.e., a name consisting of one character has no last or middle characters. Any missing components are filled with hexadecimal zeroes. Thus HUSBAND yields "HDBA"; EVE yields "E\Vo" and ADAM yields "AMDA." The full word so generated is then transformed, with the transformation being little more than squaring and masking.

A list is generated in GS to hold the EBCDIC representation of the name: 6 characters (bytes) per double word and a 2-byte pointer to the next unit in the list. All units in GS are double words (64 bits). Each name list is terminated with a stop meta character. All lists in TRAMP are terminated with a stop pointer, though the stop pointer is superfluous in the name lists because of the stop meta. In the case of HUSBAND, two double word units will be needed: the first will hold the 6 characters H-U-S-B-A-N, and a two-byte pointer to the next unit which will hold the character "D," the stop meta character, and the stop pointer, with four bytes left over. Since HUSBAND is used here as an "attribute," we are concerned with the A Name Table. We look at the entry in this table designated by the hash. If this entry is empty, i.e., zero, there is no collision, and HUSBAND has not been used previously as an attribute. If not empty, we look at the list of Headers pointed to by the entry. This list is alphabetical, so we need look only until we find HUSBAND or its proper alphabetical position on the list. Proceeding down this list of Headers, we compare the list generated above with the sublists pointed to by the headers. If a match is found, simply return this temporary list to GS and increment the USE count for HUSBAND in its header. If it is not found, insert it ... after checking the O and V tables for its occurrence. Previously HUSBAND may have been used as, say, an

"object" #(d1,SEX,HUSBAND,MALE) . In this case the HUSBAND name list would already be resident in GS. We therefore return the copy of it generated above, and insert a pointer to the first list on the A table header list. Thus a name never appears in core more than once, though many pointers may point to it, including up to four headers if a name appears on all four Name Tables.

The above process is done for each HUSBAND, EVE, and ADAM. The final pointer to the one name sublist of each is saved to generate the Association Table hash—H_2 . Let us follow the processing of the O Association Table. HUSBAND and ADAM (A and V) are hashed together (multiplied and masked) to produce a displacement in the Association Table. The actual hash is performed on the two unique pointers found during Name Table processing. The designated Association Table entry is examined. If zero, there is no collision, and HUSBAND and ADAM have never appeared together with another value. The unique pointer to HUSBAND is placed in the first 2 bytes of the 6-byte entry. The pointer to ADAM is inserted in the middle 2 bytes. A double word unit is picked off GS to be the start of the "Answer List," and the pointer to this Answer List is placed in the last 2 bytes of the table entry. The Answer List elements consist of three 2-byte pointers to name sublists, the answers, and a 2-byte pointer to the next list element. Accordingly, the pointer to EVE is inserted in the Answer List.

If the table entry was not zero, compare the first 4 bytes of it with the two pointers that would go there. If a match is made, then just add EVE to the end of the already started Answer List (polygamy is fine here), starting a new unit if necessary. This is a simple unordered list, with new elements always being added to the right-hand end. If the first four bytes of the table entry do not match the pointers, is there a collision flag in the entry? If not, a collision list is begun. This is an ordered list, with the ordering being

the numerical value of the full word obtained by concatenation of the A and V pointers (the first 4 bytes of the table entry). Each element of the list is a double word as always. The first 6 bytes of this double word are identical to the 6-byte table entry. The last 2 bytes point to the next element on the list. When a collision occurs, the first 4 bytes of the table entry are so flagged and the last two bytes point to the list which resolves it.

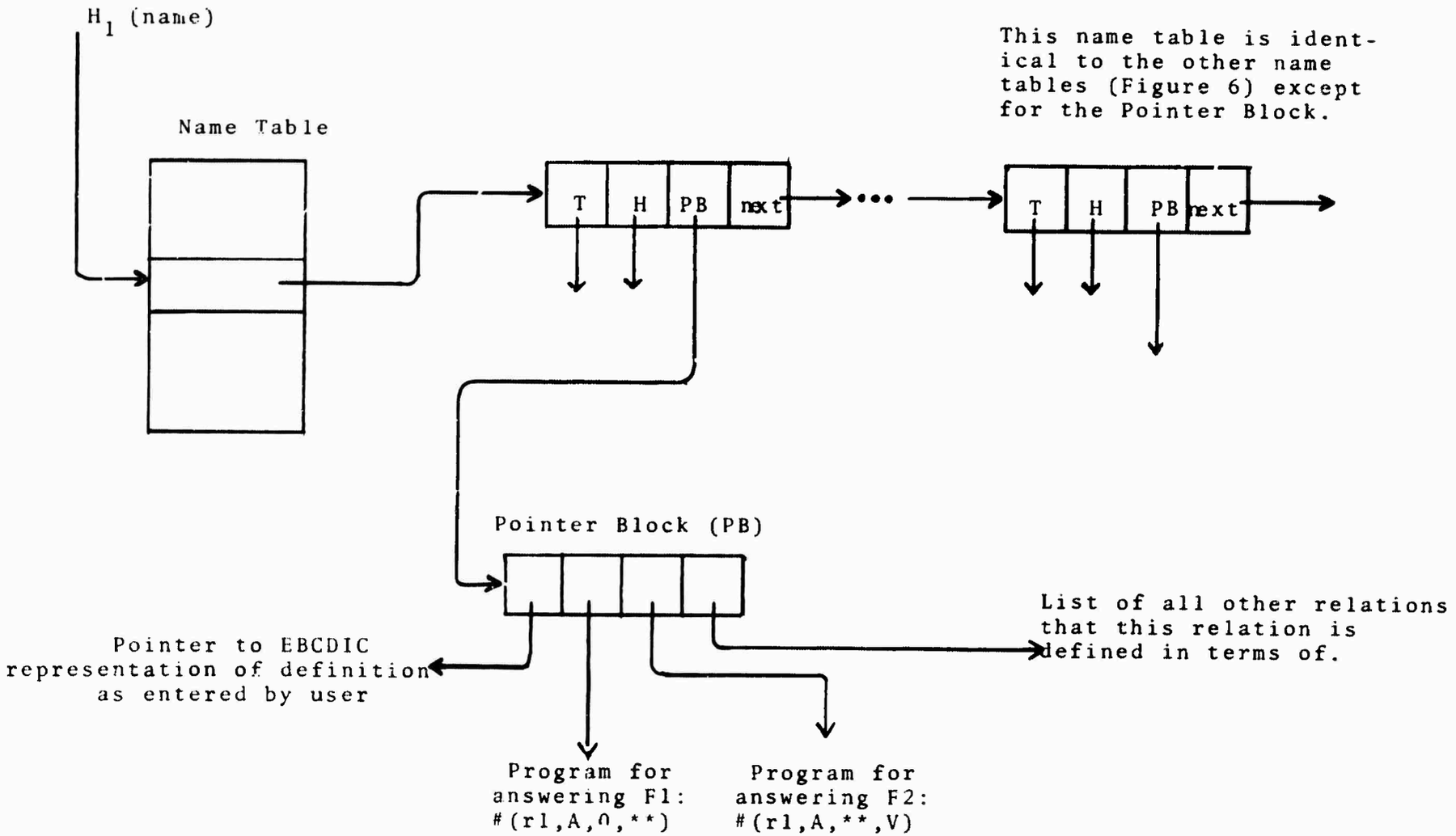
The entries of all the tables, as well as all list pointers within GS , point to double word units in GS . All pointers are 2 bytes long (16 bits), but are capable of addressing 128 pages of GS . (1 page = 4096 bytes; 128 pages = 2^{19} bytes.) For some applications this size is more than adequate,and for others (e.g., artificial intelligence) not nearly enough. With its present scheme (addressing 2^{19} bytes with only 16 bits) TRAMP has an upper limit of 128 pages, which is a usable size for the majority of cases, including many AI applications. There is obviously a trade-off here since the more core that a pointer can address, the less percentage (though not proportionately less) of that core is available! There is a second trade-off because the size of the units which must be addressed determines the number of bits needed to address them—the larger the unit, the fewer bits required, but generally, the less efficiently it is used. We arbitrarily decided that the half-word pointers that TRAMP uses to address double words are, in a sense, optimal. Should more experience prove us wrong, or if some special application should require much greater capacity, the structure could be augmented, e.g., to incorporate full 32-bit addresses, with little more trouble than alteration of an assembly parameter. At this time it is not anticipated that explicit use will be made of any peripheral storage devices, other than the transparent swapping performed by the timesharing supervisor.

The sizes of the various Name and Association tables are another assembly parameter. Currently the 7 tables occupy 4 pages of core. This figure was arrived at arbitrarily and will remain in force pending feedback which indicates that it is inappropriate.

TRAMP is initially loaded into core with all of its tables, a one-page PSECT and 8 pages of GS . Thereafter, when more space is needed (GS is the only unit that will require more space, since overflow from the tables is placed in GS), TRAMP requests it of the system in blocks of 8 pages until the maximum of 128 is reached, or the system is unable to comply with the request.

TRAMP is continually generating temporary lists which are immediately returned to GS when no longer needed. As well, when an association is destroyed, or a relational definition erased (KR and KDR , Appendix B), as much storage as is being released is at that time returned to GS . Thus, unused units are never left lying about core: a unit is returned, not discarded, eliminating formal garbage collections by ensuring that garbage is never created.

Figure 8. Defined Relation Name Table



APPENDIX A

UMIST

APPENDIX A

UMIST

The following excerpts from the UMIST manual are reproduced with the permission of Mr. Tad Pinkerton, whose work it is. What follows is partial and incomplete and is intended only to familiarize the reader with the structure of the language and enable him to follow the TRAMP definitions and examples. A complete description of the UMIST language may be found in The University of Michigan Terminal System Manual: MTS, 2nd Ed., Vol II, The University of Michigan Computing Center, December 1967.

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A level of the TRAC language called "TRAC 64" is described in [14]. It is the basic standard and point of reference for UMIST. A good discussion of TRAC 64's design goals and principles is given in reference [15]. Much of the motivation for the development of the TRAC language came from the work of Eastwood and McIroy [2,13] at Bell Laboratories. A system similar to the TRAC language which was developed independently in Great Britain is described by Strachey [19].

MODE OF OPERATION

There are two kind of functions: primitives, or machine-language subroutines that support the system in its environment. The primitives are the basis for the second type of function, called forms, or named procedures in UMIST storage, which are character strings written like macro definitions and expanded, interpretively, when called. When writing a function call, one specifies whether its value (replacing the call) is to be processed again as part of the input string (active call), or whether processing is to continue starting with the portion of the string to the right of the value returned (neutral call).

A single processing cycle is completed when the scanning and evaluating process reaches the right-hand end of the string.

Sequencing and evaluation in UMIST are inherently recursive: function calls are evaluated from left to right, but may be nested to any depth in the arguments of other calls. Each function call is evaluated when, and only when, all of its arguments have been completely processed. Thus the string being processed is divided logically into two parts: the active string, consisting of input text (possibly preceded by inserted functional values) which is yet to be scanned, and evaluated arguments of function calls which are not completely ready for evaluation. This mode of operation, based on the completely interpretive execution of function calls, eliminates the distinction between program and data.

SYNTAX

Each function call in UMIST has the form of a specially delimited argument list, in which the name of the function is always the first argument. Calls may be open (a variable number of arguments) or closed. A function call may be protected from evaluation by the use of literal delimiters. Another delimiter signals the right-hand end of the input string. These considerations lead to a syntax in which there are seven special symbols, whose occurrences are deleted from the string during syntax scanning and whose presence indicates the beginning or end of a substring. The character strings enclosed in brackets below are the UMIST special symbols:

1. Beginning of neutral function call [##(]
2. Beginning of active function call [#(]
3. End of argument [,]
4. End of call [)]
5. Beginning of literal [(]
6. End of literal [)]
7. End of input string [']

Note that the three beginning-of-substring symbols ##(and #(and (are terminated by the occurrence of the same end-of-substring character,). UMIST has a "parenthesis balanced" syntax, in the sense that an occurrence of the right parenthesis matches only the last previous occurrence of any one of the beginning-of-substring special symbols. Whenever a literal substring is encountered, the UMIST processor removes the enclosing parentheses, but only the outer set is removed if more than one matching pair occurs. Thus a string initially protected from evaluation may be evaluated if scanned a second time, and, in general, evaluation can be controlled to occur the n-th time the substring is scanned.

READ STRING AND PRINT STRING

The value of a 'read string' function call

#(RS)

is an input string accepted from the current input device. The 'print string' function

#(PS,X)

causes the display of the second argument, here symbolized by X , on the current output device, and has a null value.

When the UMIST processor is first given control, and at the end of every processing cycle, the idling procedure

##(PS,#(RS))

is automatically loaded as an input string. This procedure first causes a read from the input device, with the input string becoming the second argument of the 'print string' call. Thus the string, if any, remaining when the input string has been completely processed, is finally printed before the idling

procedure is again loaded. For example, if the input string is

#(PS,ABC)'

then after the 'read string' has been evaluated the processor is scanning the string

##(PS,#(PS,ABC))

and the inner call produces the output ABC ; the outer call nothing, since the inner 'print string' has a null value.

DEFINE, CALL, AND SEGMENT STRING

Any character string in UMIST can be given a name and placed in storage, from whence it can be called by using its name. The null-valued 'define string' function

#(DS,A,B)

places the string B in storage with the name A . A is called a form with value B . At most one string can be defined with a given name at any one time: use of the same name replaces a former definition. The value is retrieved with the 'call string' function

#(CL,A) .

A form name, like a value, is any character string. The only restriction on length is that of the total string capacity of the processor.

The occurrence of strings in storage is deleted with the 'delete definition' function

#(DD,N1,N2,...) .

This null-valued function removes the names N1,N2,... as forms and discards their values.

Once defined, a form can be "parameterized," or segmented, using the 'segment string' function:

#(SS,A,X1,X2,...)

This null-valued function scans the form A , searching for an occurrence of the string X1 as a substring. If X1 matches a part of A , that part is excluded from further matching, creating a "formal variable," or segment gap. The rest of the form is also compared with X1 to create, if possible, more segment gaps, all of which are assigned the ordinal value one, identifying the argument matched. The (separate) substrings of the form not already taken for segment gaps are next scanned with respect to the string X2 , and any occurrences of the latter substring in A create segment gaps of ordinal value two, etc.

Thus, the 'define string' and 'segment string' functions together create a "macro" in which the segment gaps locate the "formal parameters." The "macro" is expanded by supplying the "actual parameters" in a call on the 'call string' function mentioned above:

#(CL,A,Y1,Y2,...) .

The value of the 'call' is generated by returning the form A with all the segment gaps of ordinal value 1,2,... replaced by Y1,Y2,... respectively. If extra arguments are given in a CL , they are ignored. If some are missing, null strings are used as their values.

THE EQUAL FUNCTION

A decision function is provided for character strings:

#(EQ,A,B,T,F) .

If the string A is identical to the string B , then the value of this function is the fourth argument, T ; otherwise the value is the fifth argument, F . Since the strings T and F may be any UMIST procedures, this primitive is the one normally used for branching.

APPENDIX B

TRAMP FUNCTIONS

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APPENDIX B

TRAMP FUNCTIONS

I. This appendix is intended as a reference manual for TRAMP and provides full specifications for using the various functions available in it. This section assumes a working knowledge of UMIST (Appendix A), as well as familiarity with the design goals of TRAMP as set forth in the body of this paper.

II. Running TRAMP in MTS (Michigan Terminal System)

TRAMP is invoked in the normal way be specifying it as the object file of a "RUN" command. The input is taken from the logical device SCARDS; output is put on the logical device SPRINT; and error comments (TRAMP, not UMIST) appear on the logical device SERCOM. While all three are global run parameters, the active input/output devices may be switched from SCARDS/SPRINT to some other logical device, dynamically within UMIST, via the #(par, function.

The "RUN" command can accept, besides these keyword parameters, a parameter "list" (via "PAR=") consisting of the following three global parameters, whose default values are underscored:

a. NOPRIME or PRIME

This parameter specifies whether or not the prime (') will be required to terminate TRAMP input lines. If PAR=PRIME , then the program is in the normal UMIST mode of operation: an input line is not terminated until the prime is encountered. Otherwise, a prime will automatically be appended to the end of each input line (if not already there), as delineated by a carriage return or other device-dependent end-of-record signal, by TRAMP before it is passed on to UMIST, which is still

operating in the normal mode. If an input record has as its last character an ampersand (&) , then that is taken to be a continuation mark: the ampersand is deleted from the line, which is passed on to UMIST without a prime. If the ampersand is followed by a blank, then it is not a continuation mark; it must be the last character, not just the last non-blank character!

The mode of operation is initially set with this parameter, but may be dynamically altered during execution via the PRIME function, fully described in this Appendix.

b. *UMISTL or *UMIST

This parameter specifies which version of UMIST is to be used as the host interpreter. Presently the above two files are the two versions of UMIST available. These two, and any other that might become available, may be used.

c. NOW or LATER

This parameter specifies when the TRAMP functions are to be loaded. If PAR=LATER , then only UMIST will be loaded initially, with the loading of TRAMP being deferred until a call on #(tramp), further explained below.

NAME: DR

PROTOTYPE: #(DR,A,Ø,V)

PURPOSE: This is the associative storage function—the function that inserts the data into the structure.

DESCRIPTION: The three arguments, A, Ø , and V , are each non-empty sets. The set element delimiter in TRAMP is the semicolon (;) because of the important role played by the comma in UMIST. The triple is ordered and interpreted as meaning: A (Ø) = V . Each element of each set is grouped with each pair of elements of the other two sets, and the resulting triple is stored, i.e., each point in the cartesian product is stored. The three sets are ordered sets only inasmuch as the order in which they appear in the storage declaration is retained.

DR simply inserts the data into the structure in a way in which it can be efficiently retrieved. No check is made for inconsistency of data or for redundancies.

EXAMPLES: #(DR,COLOR,CAR,RED;GREEN)

#(DR,AGE,MABLE;EUNICE,39)

this would store: AGE (MABLE) = 39
AGE (EUNICE) = 39

NAME: KR

PROTOTYPE: #(KR,A,Ø,V)

PURPOSE: To undo what DR did—to erase an association from memory.

DESCRIPTION: The syntax of this function is exactly the same, and the effect exactly the opposite, of DR .

EXAMPLES: #(KR,COLOR,CAR,CHARTREUSE)

#(KR,AGE,#(RLR,AGE,**,*X*),#(X))

This would delete ALL associations containing "AGE" as the "A" component [see RLR , below].

NAME: RL

PROTOTYPE: #(RL,A,Ø,V)

PURPOSE: This is the associative retrieval function. "Questions" are asked of the data structure by calling RL and specifying which, if any, among A, Ø , and V are variables.

DESCRIPTION: Variables are denoted by enclosing a name, possibly null, within asteriks (*) . To ask the question: "What color is the car?" , one would write: #(RL,COLOR,CAR,**) or #(RL,COLOR,CAR, *NAME*) . The "answer set" in this example is the set of all third components of associations having "COLOR" as the first component and "CAR" as the second. In the first instance above, the variable is not Named [nothing between the asterisks]. In this case, the answer set is the Value of the function. In the second instance, the variable is Named, which results in the function being Null Valued, and the answer set being stored in UMIST form storage labeled by the Name within the asterisks. Thus, the following two statements are exactly equivalent:

#(DS,ANS,#(RL,COLOR,CAR,**))

#(RL,COLOR,CAR,*ANS*)

If there are no variables, e.g., #(RL,COLOR, CAR,RED) , then the question being asked is: "Does A(Ø) = V?", or in this case, "Is the car colored red?" No answer set is generated, rather a "truth value" is returned as the value of the function. If the specified association is in fact resident in the structure, or

derivable thereof, then the value is "1"; if not, the value is "0." An ambiguity arises when one or more of the three sets has cardinality greater than one. Suppose #(DR,COLOR, CAR,RED) had been entered. Then,

#(RL,COLOR,CAR,RED) would have the value "1"

#(RL,COLOR,CAR,BLUE) " " " " "0"

#(RL,COLOR,CAR,RED;BLUE)" " " " "?"

That is, the first association is found in storage, and the answer is "1." The second is not found, and the answer is "0." But two associations are specified by the last example, one is verified, the other not, and TRAMP returns the value "?"

If there is one variable, then TRAMP is being asked to "fill in the blank." The one variable may be in any of the three positions of the triple. The variable may be either Named or Unnamed, with the respective consequences described above.

If there are two variables, then two answer sets are generated. One of the variables is picked as the index variable, and values are one-by-one substituted for it, internally iterating on the one-variable question. The one constant may again be in any of the three positions of the triple. If both variables are named, the function is Null Valued, and the two answer sets are stored and labeled by their respective names. If one is Named and the other Unnamed, then the set corresponding to the Named variable is stored and the other answer set is the Value

of the function. It is syntactically valid for both variables to be Unnamed, but this should not be done since then the Value of the function would be the concatenation, not union, of the two answer sets.

The two-variable questions generate two answer sets—not a set of ordered pairs! Soon a variation of this function may be offered which will allow the generation of ordered pairs. In the meantime, if this is desired, the user will have to write a short UMIST procedure to pick out the proper subset of the cartesian product of the two answer sets.

The present form of the two-variable questions—generating two answer sets—is very often used to find <u>all</u> "objects" associated with some other "objects," without regard for the third component of the triple. For example, to find all those who have sons, one could say:

```
#(r1,SON,**,*X*)
```

with the set of all sons now being stored in the form "X." In general, this generated set, here the set X , will not be further used and is not wanted. TRAMP recognizes one special Named Variable for <u>two-variable questions</u>: "@," as denoting that the corresponding answer set is not to be generated. Thus,

```
#(r1,SON,**,*SONS*)
```

would return the set of all those who have sons, and store the set of all Sons in the form "SONS"

#(r1,SON,**,*@*) would likewise return the set of all those who have sons, but would discard the set of Sons.

If there are three variables it is interpreted as being a request for a dump of the associative memory. If any of the three variables are Named, the names are ignored. Alternatively, one can simply call: #(DUMP).

EXAMPLES:

#(RL,*REL*,JOHN,HARVEY) put the set of all relations that associate John with Harvey in the string "REL."

#(RL,SON,CLYDE,**) return the set of Clyde's sons.

#(RL,COLOR,**,*COLOR*) return the set of all objects that have the attribute "COLOR," and place the set of all colors in the string "COLOR."

#(RL,*X*,*Y*,*Z*) give a dump of the associative memory. The three names are ignored.

#(RL,AGE,#(RL,FA,#(RL,WIFE,#(RL,BRO,MARY,**),
WIVES)#(WIVES),**),**) recursively asks the question: "How old are the fathers of the wives of Mary's brothers?" Also, the set of the wives of Mary's brothers is now in the string, "WIVES."

#(r1,COLOR,**,*@*) return the set of all objects that have the attribute "COLOR," but do not generate the set of colors.

#(r1,COLOR,CAR,*@*)	put the set of the colors of the car in the string "@." "@" is a special symbol only in the two-variable questions.

NAME: RLR

PROTOTYPE: #(RLR,A,Ø,V)

PURPOSE: To retrieve answer sets that may contain redundancies.

DESCRIPTION: This function is identical to RL except that any redundancies are reported. RL returns non-redundant answer sets, while RLR does not check for redundancies, and is therefore significantly faster.

EXAMPLES: #(RLR,AGE,EUNICE;GLADYS,**)

if they are both 31, then the value will be: "31;31."

NAME: INT

PROTOTYPE: #(INT,A,O,V)

PURPOSE: To generate intersections of answer sets.

DESCRIPTION: This function has the same syntax as the one-variable question of RL . RL generates the union of the answer sets, while INT generates the intersection

#(rl,SOUTH;WEST,TOLEDO,**) generates the set of all things either south or west of Toledo.

#(int,SOUTH;WEST,TOLEDO**) generates the set of all things both south and west of Toledo.

If both constant sets are singletons, INT and RL will yield identical answer sets. The variable may again be in any of the three positions and may be either Named or Unnamed. This function must have exactly one variable.

EXAMPLES: #(int,NORTH;EAST,CHICAGO,*NE*)

place the set of everything both north and east of Chicago in the string "NE."

#(int,**,JOHN;MARY,CLARA)

return the set of all relations that John and Mary commonly share with Clara.

NAME: RCOM

PROTOTYPE: #(RCOM,SET1,SET2,NAME)

PURPOSE: To compute the relative complement of two TRAMP sets.

DESCRIPTION: The third argument is logically subtracted from the second argument, with the disposition of the resulting set determined by the fourth argument: if it is present, the function is null valued and the set is stored in UMIST form storage labeled by the name; if the fourth argument is omitted, the relative complement of the other two arguments is returned as the value of the function. The set computed consists of all elements of "SET1" that are not elements of "SET2."

EXAMPLE: #(RCOM,#(RL,AGE,**,40),#(RL,SPOUSE,**,*@*),SPINSTER)

this would store in the string "SPINSTER" all those who are 40 years old and not married.

NAME: SYMD

PROTOTYPE: #(SYMD,SET1,SET2,NAME)

PURPOSE: To compute the symmetric difference of two sets.

DESCRIPTION: The symmetric difference of two sets is defined to be the set of all things that are in either of the two sets, but not in both (exclusive OR). The syntax of SYMD is identical to that of RCOM, with the fourth argument determining what will be done with the generated set.

EXAMPLE: #(SYMD,#(RL,BRO,**,*@*),#(RL,SIS,**,*@*))

this would return the set of all those who have siblings, but siblings of only one sex.

NAME: INT

PROTOTYPE: #(INT,SET1,SET2,NAME)

PURPOSE: To intersect two TRAMP sets.

DESCRIPTION: This function has the same syntax as the other two set operators: RCOM and SYMD: the two operands are the second and third arguments (SET1 and SET2) and the fourth argument specifies the disposition of the result: if it is present, it will be used as the name of the form into which the answer will be placed; if omitted, the answer will be returned as the value of the function. The answer is a straight set intersection, except that any redundancies (e.g., introduced by a call on RLR) are deleted.

Note that this function has the same name as the retrieval function INT. There is no ambiguity and there should be no confusion, since the two functions have dissimilar syntax! The retrieval function INT is called by specifying exactly three functional arguments, of which exactly one is a Variable; the Set Operation INT is invoked by giving either two or three functional arguments, of which <u>exactly zero</u> are Variables! I.e., a variable specifies retrieval—if there is no variable then a question is <u>not</u> being asked.

EXAMPLES:

```
#(int,#(int,NORTH;EAST,CHICAGO,**),
      #(int,SOUTH;WEST,MAINE,**),UNHUH)
```

recursively uses both forms of INT to place the set of all things both northeast of Chicago and southwest of Maine in the string "UNHUH."

`#(int,#(X),#(X),X)` remove all redundancies from the string "X."

`#(int,#(r1,AUTHOR,**,GEORGE),#(r1,SUBJECT,**,SEA))`

return the set of everything George wrote about the sea.

NAME: DUMP

PROTOTYPE: #(DUMP) or #(RL,**,**,**)

PURPOSE: To obtain a complete listing of everything that is explicitly stored in the data structure.

DESCRIPTION: All associations explicitly stored are printed out, using the "A (Ø) = V" format. A and Ø are singletons and V is the set of all "values" associated with the A/Ø pair. Any redundancies in the V set are printed. Implied associations are not listed in the dump. After all of the associations are listed, all of the current relational definitions [entered by DFR , below] are displayed.

EXAMPLES: #(DUMP)

#(RL,**,** **)

#(RLR,*X*,**,**)

NAME: ERM

PROTOTYPE: #(ERM)

PURPOSE: To completely erase the memory for a fresh restart.

DESCRIPTION: It is not anticipated that this fucntion will be called very often, if ever, and to prevent its being invoked unintentionally, via misspelling, etc., confirmation is required by TRAMP before it actually erases the structure. This is similar in form and in content to the confirmation that MTS requires before EMPTYing a file: an exclamation point (!), or the two letters "ØK" are positive confirmation. Anything else cancels the request.

NAME: USE

PROTOTYPE: #(USE,NAME)

PURPOSE: To obtain the number of explicit associations that the NAME is used in.

DESCRIPTION: The value of the function is the total number of associations that the name in the argument is used in. Any implied associations are not included in the USE count. There is no breakdown as to how the name is used within the associations, simply a count of the triples in which it appears.

EXAMPLES: #(USE,JOHN)

#(USE,COLOR)

How many objects have the attribute color?

NAME: CT

PROTOTYPE: #(CT,SET)

PURPOSE: To determine the cardinality of a TRAMP set.

DESCRIPTION: This is a very simple function that is significantly faster and more convenient than a UMIST procedure that would do the same thing. It distinguishes between: a missing argument; a null set; and a singleton (set with no semicolons); but otherwise is simply an efficient way to count semicolons.

EXAMPLES: #(CT,#(SET)) what is the cardinality of "SET?"

#(CT,#(RL,SON;DAUGHTER,SHERMAN,**))

How many children does Sherman have?

NAME: TABLE

PROTOTYPE: #(TABLE,X)

PURPOSE: To obtain the contents of one of the Name Tables.

DESCRIPTION: The argument, X , specifies which of the four Name Tables is desired:

A - attribute
Ø - object
V - value
D - defined relation

The set of names found on the particular table is returned as the value of the function.

EXAMPLES: #(TABLE,A)

#(TABLE,D)

#(rcom,#(table,A),#(table,D))

return the set of all names that have been used as "attributes" but have not been given definitions. The Defined Relation Name Table is <u>always</u> a subset of the "A Name Table!"

#(int,#(int,#(table,A),#(table,0)),#(table,V))

return the set of all things that have been used at some time in each of the three positions of the associative triple.

#(symd,#(table,A),#(table,V))

return the set of all names used as either "attributes" or "values" but not as both.

NAME: PRIME

PROTOTYPE: #(PRIME,[ON,OFF])

PURPOSE: To set or invert the mode of operation regarding the prime that terminates all UMIST input lines.

DESCRIPTION: An internal switch in TRAMP determines whether or not a prime is required to terminate an input line. This switch is initially set by the parameter in the RUN command. The function PRIME may be used to alter dynamically the setting of this switch during execution.

The argument to PRIME may specify that this switch is to be turned ON or OFF, or simply inverted from its present setting. #(PRIME,ON) turns the prime ON, i.e., it specifies that a prime will be required to mark the end of a line. #(PRIME,OFF) sets the switch the other way; equivalent to: PAR=NOPRIME. Full details of operation with the switch off appear in the introduction to this Appendix.

EXAMPLES: #(PRIME,OFF)

#(PRIME)

#(PRIME,ON)

#(PRIME,X) an unrecognizable argument inverts the switch.

NAME: TRAMP

PROTOTYPE: #(TRAMP)

PURPOSE: To load TRAMP if PAR specified that loading was to be delayed.

DESCRIPTION: If PAR=LATER, then only UMIST will be loaded initially. When ready for TRAMP, the user issues this function call which loads and links up all the TRAMP functions.

The function "TRAMP" is defined only when PAR=LATER, and then only until it has been called.

NAME: SAVE

PROTOTYPE: #(SAVE,FDNAME,RLNG,ID)

PURPOSE: To save the current state of the data structure on an auxiliary device so that at a later date the structure can be initialized to contain the present data.

DESCRIPTION: FDNAME is the name of the file or device onto which the data are to be SAVEd. RLNG is an optional argument specifying the record lengths to be written. If this argument is either omitted or specifies too large a record length for the particular device, the following default values, which are the respective physical maximums, will be used:

PUNCH	80
FILE	255
TAPE	32,760

If RLNG = 80, either explicitly or by default, then each record will contain 72 bytes of information and 8 characters of sequential identification, the first 4 of which may optionally be specified in the last argument, ID. If more than 4 characters are given, extra characters on the right will be truncated. If less than 4, trailing blanks will be appended. If RLNG=80 and this argument is omitted, the 4-character MTS signon ID will be used. If RLNG = λ , $\lambda \neq 80$, then there will be λ bytes of information with no identification.

EXAMPLES:

#(SAVE,MYFILE)

write 255-byte records into the file

#(SAVE,MYFILE,80,IDX)

write 80-byte records into the file with the specified ID. Can now be copied to a card punch.

#(SAVE,*PUNCH*,,IDZ)

punch the data onto cards with "IDZ" ID.

#(SAVE,*PDN1*,80)

write 80-byte records onto tape using MTS ID.

#(SAVE,*PDN2*,255)

write records on tape that can be copied into a file.

NAME: COPY

PROTOTYPE: #(COPY,FDNAME)

PURPOSE: To read back in what has previously been SAVEd.

DESCRIPTION: COPYing in a new structure completely erases anything that might be in the structure at the time the COPY is called. There is no direct way to merge two TRAMP data files. (See Appendix C.)

NAME: PAGE

PROTOTYPE: #(PAGE)

PURPOSE: To ascertain what size file will be required to SAVE in and/or how much core the data structure is occupying.

DESCRIPTION: PAGE is a null-valued printing function which prints on the current output device. The output is the number of pages currently in core that will have to be saved, and how many extensions have been made to TRAMP. The sizes of the various tables used by TRAMP are assembly parameters and are likely to change. Presently the tables occupy a total of 4 pages of core. The information printed by PAGE is the amount of core being used in addition to the tables (tables cannot grow during execution).

TRAMP is initially loaded with an Available Storage List 8 pages long (32, 768 bytes). As this is used up, more is acquired from the system in blocks of 8 pages, called extensions. There can be up to 16 extensions (presently meaning that a maximum of 132 pages = 540,672 bytes would have to be SAVEd). These 8-page blocks are never broken up—SAVEing requires that the entire block(s) be written. In summary, (assumming 4 pages for tables) there is a minimum of 12 pages (= 49,152 bytes) and a maximum of 132 pages (= 540,672 bytes), with the minimum approaching the maximum in steps of 32,768 bytes.

NAME: DDR

PROTOTYPE: #(DDR,(REL = EXP)) or #(DDR,(REL := EXP))

PURPOSE: To define a relation in terms of other relations, thereby creating implicit associations in the data structure.

DESCRIPTION: REL is the relation being defined, and EXP is an expression which is the definition. The equal sign is the delimiter and must be present. In the prototype the entire argument to DDR is enclosed in parentheses, i.e., a UMIST "literal." Depending on the particular definition, this may or may not be necessary, but it will never hurt, and it is good practice always to parenthesize the argument.

EXP is composed of one or more relations joined by the logical connectives: .A. conjunction; .V. disjunction; .N. negation; two relational operators: / (slash) relative product or composition; .CON. converse; and six equality operators: .EQ.; .NE.; .GE.; .LE.; .GT.; .LT.; with obvious meanings.

The "R(x,y)" format is the relational format adopted by TRAMP and is interpreted to mean that R (x) = y .

"Converse" simply inverts the order of the two relational arguments: R(x,y) ↔ .CON.R(y,x) . Thus, "child of" is the converse of "parent of," any symmetric relation is its own converse, etc.

Composition is defined: $\forall x \forall y \exists z[(S/T)(x,y) \leftrightarrow S(x,z) \wedge T(z,y)]$. Specifically, the declaration: #(DDR,(R:= S/T)) would tell TRAMP that R(x,y) if for some z: S(x,z) and T(z,y).

DDR is the only TRAMP function that allows spurious blanks. Before compiling the definition, all blanks are removed. In all other functions (except EDIT, below, which is another entry to this function), blanks are valid EBCDIC characters and are treated like any other. Definitions may be either abbreviated: #(DDR,(R1 = R2 .V. R3)) ; or in an expanded form: #(DDR,(R1(X,Y) = R2(X,Y) .V. R3(X,Y))). There is the restriction that any one definition be consistent. #(DDR,(R1 = R2(X,Y))) is not legal. The two relational operators, composition and converse, may be used only in abbreviated definitions where there are no explicit relational arguments. On the other hand, the equality operators may only be used with relational arguments as their operands. A constant which is to be used as a relational argument is denoted by enclosing the name of the constant in double quotes (").

Precedence of operators: The precedence ordering of the various operators is as follows:

/	composition
.CON.	converse
.EQ. etc.	all equality operators have the same precedence
.N.	negation
.A.	conjunction
.V.	disjunction

The above precedence ordering may be altered in the usual way by the appropriate use of parentheses.

One major constraint is placed on the argument to DDR: relations must be defined so that at least one set is <u>generated</u>. The intent of this constraint is that there be at least one <u>reference</u> set. The "whole space" may never be the reference set!

#(DDR,(R = .N. S))	is illegal, since it specifies a global complement, i.e., it references the "whole space."

#(DDR,(R = .N. S .A. T)) is legal, since it first generates a reference set via T , and then places a constraint on that reference set, not on the whole space.

Besides the choice of using the "expanded" vs "abbreviated" notation for defining a relation, the user has the option of specifying whether or not the implication is one way, or specifies an if and only if condition.

Husband = .CON. Wife

is an iff condition whereby it is implicit that:

Wife = .CON. Husband

the equal sign will be used to denote this kind of equivalence which can be interpreted as meaning iff.

On the other hand,

Parent := Father or Mother

is one-way implication, giving information about the relation "parent" while giving none about the relations "father" or "mother." To denote this the "assignment symbol" (:=) is used.

In general, if the assignment symbol is used then no attempt will be made to extract information about the relations on the right side of the equation. If the equality symbol is used, such an attempt will be made. This attempt will not, of course, always be successful:

Parent = Father .V. Mother

gives us no information about "father" or"mother" even through the equality sign is used.

If a relation is defined, and later a new definition is given for that same relation, TRAMP simply OR's the two definitions together. If there is a syntactic error in the second definition, a diagnostic is printed and the earlier definition is retained.

EXAMPLES:

```
#(DDR,(BIGGER = BIGGER / BIGGER))
```

BIGGER is transitive

```
#(DDR,(BIGGER(A,B) = BIGGER(A,C) .A. BIGGER(C,B)))
```

same definition using expanded format.*

```
#(DDR,(SIB = BRO .V. SIS .V. .CON.SIB))
```

a sibling is defined to be a brother or a sister and it is symmetric

```
#(DDR,(HUSBAND = .CON. WIFE))
```

husband is the converse of wife

```
#(DDR,(BRO(CAIN,ABEL) = SIB(CAIN,ABEL) .A. SEX(ABEL,"MALE")))
```

a brother is a male sibling. Constants are enclosed in double quotes

```
#(DDR,(BIGGER = LARGER))
```

bigger and larger are synonymous

```
#(DDR,(MALE(X) = SEX(X,"MALE")))
```

unary relations may be defined

```
#(DDR,(BROTHER(X,Y) = FATHER(X,Z) .A. FATHER(Y,Z) .A. MALE(Y)
                      .A.X.NE.Y))
```

a brother can be defined as a male offspring of the same father, other than oneself

```
#(DDR,(PARENT = FATHER .V. MOTHER))
#(DDR,(NEPHEW = SIBLING / SON))
```

a nephew is the composition of sibling and son.

```
#(DDR,(UNCLE = .CON.(SIBLING / SON)))
```

in a male world, uncle is the converse of nephew and may be defined as the converse of the definition of nephew.

```
#(DDR,(UNCLE = .CON. NEPHEW))
```

or simply as the converse of nephew.

---

* The dummy arguments used in expanded definitions may be up to eight characters long.

#(DDR,(STEPMOTHER = FATHER / SPOUSE .A. .N.MOTHER))

a stepmother is the spouse of the father who is not the mother.

NAME: KDR

PROTOTYPE: #(KDR,REL1,REL2, ...,RELn)

PURPOSE: To erase definitions made by DDR .

DESCRIPTION: KDR may have any number of arguments. The definition for each of the relation names given as arguments is deleted.

EXAMPLES: #(KDR,SIBLING)

#(KDR,NEPHEW,UNCLE,SPOUSE)

#(DS,X,#(TABLE,D))#(SS,X,;)#(KDR,#(X,(,)))

would erase ALL definitions

NAME: SHOW

PROTOTYPE: #(SHOW,RELATION)

PURPOSE: To display the current definition of a relation.

DESCRIPTION: SHOW will display the definition of the relation specified by its argument exactly as it was entered by the user, except that blanks will have been removed. If more than one definition has been given for the r lation, they will all be concatenated, separated by a break character, and displayed in a continuous line. Three actions may be taken by SHOW : if the relation has been successfully defined, its definition will be displayed on the current output device; if TRAMP has never heard of the relation, the comment: "RELATION XXX HAS NOT BEEN DEFINED." will be printed; if the relation was unsuccessfully defined, or was erased, via KDR, the comment: "RELATION XXX IS UNDEFINED." will be printed.

NAME: EDIT

PROTOTYPE: #(EDIT,RELATION,PATTERN,REPLACEMENT)

PURPOSE: To correct or alter a relational definition made by DDR .

DESCRIPTION: The second argument is the name of the relation that is to be EDITed. The third argument is the pattern within the definition, as displayed by SHOW, that is to be altered. If this argument is null, it matches the void immediately to the right of the relation name in the definition string. The last argument is the string that replaces the pattern specified by the third argument. Any blanks in the PATTERN or REPLACEMENT will be ignored. If the last argument is omitted, the pattern is simply deleted. If the string specified by the third argument occurs more than once in the definition, only the first occurrence is changed.

Calling EDIT implicitly calls SHOW to display the EDITed definition.

EXAMPLES: #(EDIT,SIB,(.V.),(.A.))

change the first OR to AND in the definition of SIB . Like DDR , it is good practice to enclose the argument in parentheses.

#(EDIT,REL,(.A. R4))

delete the string ".A.R4" from the definition of REL.

NAME: DDEF

PROTOTYPE: #(DDEF)

PURPOSE: To display all current relational definitions.

DESCRIPTION: DDEF iteratively calls on SHOW for each name found in the Name Table of Defined Relations. DDEF is an entry to the second half of DUMP, which bypasses the listing of the associations.

TRAMP in no way alters anything internal to UMIST. There are three UMIST functions that cannot be called within TRAMP since they would render it unusable:

#(DSS)	Define Special Symbol
#(DA)	Delete All (including TRAMP)
#(RES)	Restart - contains #(DA) as a subset.

With these three exceptions, the full facilities of UMIST are available to the user.

APPENDIX C

EXAMPLES OF TRAMP

APPENDIX C

EXAMPLES OF TRAMP

This Appendix gives both simple and more complicated examples of the use of TRAMP. The most relevant information about UMIST necessary to understanding the examples is found in Appendix A. Complete understanding of the more complicated example of the question-answering program (Fig. 11b) requires more detailed knowledge of UMIST, which may be found in the cited references.

The first set of examples (Fig. 9) show the "F0" questions of Part III. First, we define the COLOR of CAR to be RED and GREEN. Then the various Boolean questions are asked; the answers given by the system are on the line immediately following the "question."

The next examples (Fig. 10a) describe the family tree information of Fig. 1. Two relatively complicated questions are then asked. The first may be stated as: "Who are the people who have brothers whose age is 64?" To illustrate this in depth, we first ask "Who is aged 64?", then "Who are the people who can call this 64-year-old 'brother'?" Obviously, for one of these people (Mary), there is no answer, for no one calls her "brother." The second question asks: "What is the age of the father of the brother of Melissa's mother?" Store the answer (this age) in the form called "NUM." Now Melissa's mother is Edith, Edith's brother is Arnold, Arnold's father is John, who is 64 years old. Hence, a call for the string NUM prints "64."

```
#(DR, COLOR, CAR, RED; GREEN)'
#(RL, COLOR, CAR, BLUE)'
0
#(RL, COLOR, CAR, RED; GREEN)'
1
 #(RL, COLOR, CAR, GREEN; RED)'
1
#(RL, COLOR, CAR, RED; BLUE)'
?
#(RL, COLOR, CAR, RED)'
1
#(RL, COLOR, CAR, RED; BLUE; GREEN)'
?
#(RL, COLOR, CAR, YELLOW; BLUE)'
0
```

Figure 9. "F0" Questions.

```
#(DR,FATHER,ARNOLD,JOHN)
#(DR,FATHER,JAMES,ARNOLD)
#(DR,BROTHER,SAM;JOAN,JOHN)
#(DR,BROTHER,EDITH,ARNOLD)
#(DR,MOTHER,ARNOLD,MARY)
#(DR,MOTHER,MELISSA,EDITH)
#(DR,AGE,JOHN;MARY,64)
#(DR,AGE,ARNOLD,39)
#(DR,AGE,EDITH,33)'
#(RL,BROTHER,**,#(RL,AGE,**,64))'
SAM;JOAN
#(RL,AGE,**,64)'
JOHN;MARY
#(RL,BROTHER,**,JOHN)'
SAM;JOAN
#(RL,BROTHER,**,MARY)'

#(RL,AGE,#(RL,FATHER,#(RL,BROTHER,#(RL,MOTHER,MELISSA,**),**),
**),*NUM*)'
#(CL,NUM)'
64
```

Figure 10a. Family Relationships / Nested Questions.

```
#(DR,SISTER,JOAN,ALICE)'
#(DDR,(SIB = BROTHER .V. SISTER .V. .CON.SIB))'
#(RL,SIB,ALICE,**)'
JOAN
#(DDR,(SIB(X,Y) = SIB(X,Z) .A. SIB(Y,Z) .A. X.NE.Y))'
#(RL,SIB,ALICE,**)'
JOAN;JOHN;SAM
```

Figure 10b. Relational Example, Associations Between Siblings.

The examples of Fig. 10b show the first use of ddr, where we add to the family of Fig. 10a the sisterhood of Joan and Alice. The first definition of Sibling now allows the retrieval of one of Alice's siblings, though Sibling has never appeared explicitly in an association. The second definition entered completes the job, and TRAMP is now able to return all of Alice's siblings.

As a more complicated example of the use of TRAMP, a rudimentary "question-answering system," with thesaurus, was coded. It should be noted that this illustration is not intended to constitute a good system—in fact, it represents a total of less than one hour's coding and debugging time.

The job of the system is to parse input commands and, from them, generate TRAMP statements. In this regard the system is grossly incomplete, i.e., it uses a most unsophisticated parsing algorithm. The generated TRAMP calls are realistic, nonetheless. The complete program, used as the question-answering system (QAS), is shown in Fig. 11b.* The output from an actual session is shown in Fig. 11a.

To enable the reader easily to follow the dialogue, each statement issued by the QAS is initiated by the word: "ANSWER." Everything else was typed at the terminal by the user. QAS has been given a thesaurus to relax the format of

---

* The code for the question-answering program is shown as it would appear for a processor for the standard TRAC T-64 language, rather than for the locally used dialect UMIST, but the differences are very slight indeed.

```
INPUT AUTHOR OF HUCKFINN WAS MARKTWAIN'
SYNONYM MARKTWAIN IS SAMCLEMENS'
WHAT DID SAMCLEMENS WRITE ?'
 ANSWER:
SYNONYM WRITE = AUTHOR'
WHAT DID SAMCLEMENS WRITE ?'
 ANSWER: HUCKFINN
DID TWAIN WRITE HUCKFINN ?'
 ANSWER: NO
SYNONYM MARKTWAIN AND TWAIN'
DID TWAIN WRITE HUCKFINN ?'
 ANSWER: YES
INPUT AUTHOR OF TOMSAWYER IS TWAIN'
INPUT AUTHOR OF THESTRANGER WAS SAMCLEMENS'
HOWMANY BOOKS DID MARKTWAIN WRITE ?'
 ANSWER: 3
WHAT DID TWAIN WRITE ?'
 ANSWER: HUCKFINN;TOMSAWYER;THESTRANGER
INPUT MODEL OF /360 IS 67'
SYNONYM /360 IS IBM'
WHICH MODEL OF IBM DO WE HAVE ?'
 ANSWER: 67
```

Figure 11a. Output of Question-Answering Program.

QUESTION-ANSWERING PROGRAM

```
#(DS,START,(#(DS,FF,#(RS))#(SS,FF, )#(CL,##(CS,FF))#(CL,START)))'

#(DS,SYN,(#(DS,0,X)#(EQ,##(CC,0),*,X.(##(RL,SYN,X,**)))))#(SS,SYN,X)'

#(DS,CK,(##(RL,SYN,X,*0*)#(EQ,##(CL,0),,(#(DR,SYN,X,X)X),
   (##(CL,0)))))#(SS,CK,X)'

#(DS,DR,(#(DR,#(CL,CK,A),#(CL,CK,O),#(CL,CK,V))))#(SS,DR,A,O,V)'

#(DS,RL,(#(RL,#(CL,SYN,A),#(CL,SYN,O),#(CL,SYN,V))))#(SS,RL,A,O,V)'

#(DS,INPUT,(#(CL,DR,##(CS,FF),#(PS,,##(CS,FF))##(CS,FF),
   #(PS,,##(CS,FF))##(CS,FF))))'

#(DS,SYNONYM,(#(DS,0,##(CS,FF))#(PS,,##(CS,FF))#(DR,SYN,##(CS,FF)
   ,##(CL,0))#(DR,SYN,##(CL,0),##(CL,0))))'

#(DS,WHAT,(#(PS, ANSWER: #(PS,,##(CS,FF))#(DS,0,##(CS,FF))
   #(CL,RL,##(CS,FF),**,##(CL,0)))))'

#(DS,WHO,(#(PS, ANSWER: #(PS,,##(CS,FF))#(CL,RL,##(CS,FF),
   #(PS,,##(CS,FF))##(CS,FF),**))))'

#(DS,HOWMANY,(#(PS, ANSWER: #(PS,,##(CS,FF)##(CS,FF))
   #(CT,#(CL,RL,#(DS,0,##(CS,FF))##(CS,FF),**,##(CL,0))))))'

#(DS,IS,(#(PS, ANSWER: #(EQ,#(CL,RL,##(CS,FF),#(PS,,##(CS,FF))
   ##(CS,FF),##(CS,FF)),0,NO,YES))))'

#(DS,DID,(#(PS, ANSWER: #(DS,0,##(CS,FF))#(EQ,#(CL,RL,##(CS,FF),
   ##(CS,FF),##(CL,0)),0,NO,YES))))'

#(DS,WHICH,(#(PS, ANSWER: #(CL,RL,##(CS,FF),#(PS,,##(CS,FF))
   ##(CS,FF),**))))'

#(CL,START)'
```

Figure 11b. Question-Answering Program.

statements. This thesaurus, as well as all data, is held in the TRAMP structure. To make a thesaurus entry, the user types the command "SYNONYM" followed by the two synonymous names. A datum is entered by the command "INPUT." The questions are self-explanatory.

Merging TRAMP Data Files

The following procedure shows one way that two TRAMP data files can be merged. This sort of thing is necessary because the COPY function erases the current memory while it is writing in a new one. Thus, assume that files DATA1 and DATA2 are two TRAMP data files that are to be merged:

```
$RUN TRAMP PAR=NOPRIME
#(copy,DATA1)
#(par,FDO,SCRATCH)#(dump)#(par,FDO,*SINK*)
#(copy,DATA2)
#(ds,PARSE,(#(ds,X,##(rs))#(eq,##(cc,X), ,(#(ss,X, )&
#(dr,##(cs,X),#(cs,X),#(nl,##(cs,X))##(cs,X))#(PARSE)),&
(#(par,FDI,*SOURCE*)))))
#(par,FDI,SCRATCH((2)))#(PARSE)
```

By way of a superficial explanation: the procedure "PARSE" simply reads in the "dumped" information and parses those lines to extract the three arguments to DR. The process must start at line #2 because the first line of a dump is always a label. The procedure recursively calls on itself until another "label" is encountered, signaled by not having a blank

in the first column. Segmenting the dumped line for blanks, the first segment will be the "A" component; the second segment will be the "O" component (stripped of the parentheses by calling CS actively); the next segment will be the equal sign and is discarded via the NL (null) function; the last segment is the "V" component. Note that PAR must equal NOPRIME (default case) in order for PARSE to be able to read the dumped lines in sequence, since they do not have primes on the end.

An analogous procedure could be written and called by PARSE to read in the rest of the dump, which would contain the relational definitions, and make those definitions via generated calls on DDR.

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13. ABSTRACT

This report describes the theory and implementation of an experimental language called TRAMP, which is a software simulation of a content-addressable memory. The system consists of an associative data structure embedded in an interpretive language, allowing great flexibility and strong recursive power. The system has further been extended with a logical inference capability by superimposing a relational structure over the associative memory. The resulting language has already proved to be extremely powerful in several applications, and can be termed a language for developing question-answering and interactive communication systems.

This report discusses the theory and design considerations, details of machine implementation, and details of operation with examples.

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