Maintaining Organization in a Dynamic
Long-Term Memory*

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As new unanticipated items are added to a memory, it must be able to reorganize itself, integrating the new items into its structure. The reorganization process must maintain the memory's structure and also build up the knowledge retrieval strategies need to search that structure. This study will present an algorithm for knowledge-based memory reorganization. Included in that algorithm are processes for directed generalization and generalization refinement. A fact retrieval system called CYRUS which uses the algorithm is also presented. Conclusions are drawn about maintaining accessibility in a conceptual memory, organizing generalized knowledge with respect to specific knowledge, and expected retrieval failures due to change over time in the memory's organization.

1. INTRODUCTION

One interesting aspect of human memories is that they never seem to run out of space. Furthermore, the vast amount of knowledge people have does not interfere significantly with their memory capabilities (Smith, Adams, & Schorr, 1978). Experts, who know a lot about particular subjects, can remember facts in their domain of expertise much more easily than nonexperts, who presumably have fewer facts to remember.

We can explain this by inferring that as people learn new facts, they integrate them with what they already know, reorganizing memory to make the important facts accessible. Previous knowledge aids in deciding where and how to place new inputs in memory.

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The problem of keeping a memory organized is relevant to both psychologists (interested in human memory) and computer scientists (interested in computer memory). Computer science interest in this topic stems from the problem of organizing information in a computer memory. As new information is added to a computer memory, its retrieval processes should remain efficient. This requires automatic reorganization.

This work will describe some of the necessary characteristics of a self-organizing memory, and will present CYRUS, a self-organizing computer program (Kolodner, 1980, 1981, 1984). CYRUS is an intelligent fact-retrieval system designed to store and retrieve day-to-day events in the lives of political dignitaries. It works with either of two data bases—one each for former U.S. Secretaries of State Cyrus Vance and Edmund Muskie. Given a new fact about Vance or Muskie, CYRUS integrates it into its already existing memory organization. It retrieves facts from its memory when queried in English. Following is a dialog with CYRUS:

> When was the last time Vance was in Egypt?
ON DECEMBER 10, 1978.

> Why did he go there?
TO NEGOTIATE THE CAMP DAVID ACCORDS.

> Who did he talk to there?
WITH ANWAR SADAT.

> Where was Muskie three weeks ago?
IN EUROPE.

> Who did he talk to?
TO NATO IN BRUSSELS ON MAY 14 AND TO ANDREI GROMKYO IN VIENNA.

2. PROBLEMS

There are at least two tasks a memory must do: (a) integrating new items into its framework (memory update), and (b) retrieving them, or "remembering." Although this discussion is about memory update, that task cannot be decoupled from retrieval. When a new item is integrated into memory, not only must it be made accessible, but the accessibility of items already in memory must be maintained. The retrieval processes must continue to work efficiently as memory grows.

Memory update is also related to understanding. One aspect of understanding, for example, involves figuring out how a new item is similar to items already in memory. This is necessary in order to choose a frame (Charniak, 1977; Minsky, 1975) or knowledge structure (Schank & Abelson, 1977) for further processing the item. Choosing a frame for an item is also the first step in integrating a new item into memory. As in understanding, once a frame is chosen during memory update, it provides an appropriate
point in memory from which to draw inferences and make assumptions. In fact, the end result of understanding and memory update are the same: the concepts which comprise and are related to an item have been specified, and the place for the item within memory’s knowledge structures has been found.

To understand problems associated with memory update, then, we must look to both the retrieval and understanding processes. In understanding an event, previously made generalizations are used to infer aspects not explicit in the event and to make predictions about what will be true in the future. To make generalized information available for understanding, it must be built up as new items are added to memory. This requires noticing the similarities between a new item being added to memory and items that are already there. As similarities are noticed, generalizations are made based on those similarities. Those generalizations must then be integrated into memory along with the item itself, so that both can be used for later understanding.

In order for similarities to be noticed without enumerating a memory’s contents, similar items must be directed to the same place in memory. When a second item is directed to a place in memory where another item resides, their similarities can be noted. For this to happen, memory must be organized in conceptual categories, categories based on similarities in meaning. Once a generalization is made, it can be used in understanding or predicting aspects of a later similar item. If conceptual categories maintain generalized information extracted from their items, it can be used in understanding later similar items or situations.

Because noticing similarities is an important part of understanding, integration processes must allow similarities to be noticed and must make generalizations based on them. It would not be feasible, however, to have memory notice all similarities and differences. A person going to a meeting, for example, is not likely to connect the weather with the meeting, unless it has some bearing on the meeting (e.g., how hard it is to get there). Generalization and noticing similarities must be directed and controlled.

The second important function of a memory is remembering or retrieval. Conceptual categories and generalized information by themselves will not allow the kinds of retrieval we see people doing. People’s memories do not slow down as they learn new facts (Smith et al., 1978). A memory which does not slow down as it gets larger must never do sequential search. This implies that conceptual categories must have some internal organization that allows retrieval without sequential enumeration.¹

The traditional solution to that problem within computer science has been indexing. If we propose indexing as a solution in conceptual categories, then we must specify (1) which kinds of indices are appropriate,

¹Chase and Simon’s (1973) “Perception in Chess” seems to support this.
and (2) how indices for items added to memory can be chosen. To facilitate retrieval without enumeration, indices should be based on salient features of categories. A salient feature is one which is likely to be used in identifying an item to be retrieved from the category or in describing an event to be added to a category (e.g., destinations of trips, participants and topics of meetings). Consider, for example, the following question:

(Q1): During his meeting with Gromyko last week, what did Vance talk about?

This question requires remembering a "meeting last week between Gromyko and Vance." The item is specified by its conceptual category (diplomatic meeting) and two features: its time (last week) and its participants (Vance and Gromyko). If items are indexed in conceptual categories by features salient to the category, then retrieval will be a process of traversing indices corresponding to features specified in a question. (For more about the retrieval process, see Kolodner, 1983, 1984 in press.)

Indexing serves a number of functions. It is used to discriminate individual events and divide a category into reasonably sized subcategories. Indexing also allows similarities between events to be noticed and generalizations to be made. When two items are indexed in the same way, a subcategory can be formed, indexed in the parent. Relevant similarities between the two items can be extracted and stored as generalized information associated with the new subcategory. That generalized information can then be used during understanding, to guide memory search, and to limit later indexing.

Generalized information is not static, but changes with the addition of new items. Because later information might contradict a previous generalization, and because all generalizations cannot be made on the basis of only two items, memory update must provide for recovery from bad generalizations and control of later generalizations.

The following list summarizes some of the problems involved in creating and maintaining good memory organization:

1. How is a new item entered into a conceptual category, and how are its indices chosen?
2. What is the role of generalization in memory processing?
3. How can generalization be directed?
4. When is it appropriate to create a new subcategory?
5. How are new subcategories created?
6. How can the generalized information associated with a category be derived?
7. How can memory recover from useless subcategories and generalizations?
The answers to these questions will be addressed in the remaining sections. CYRUS will be presented as an implementation of a self-organizing memory.

3. INITIAL MEMORY ORGANIZATION

Before describing how to maintain memory's organization, we must present a viable memory organization. The major conclusion about memory organization that has come out of our observations is the following:

**Memory Principle #1**

Similar items in memory should be organized around the same concept according to their differences.

Organization according to differences serves two purposes. One purpose of an indexing or organizational scheme is to subdivide categories into smaller more workable parts. In a conceptual memory, items in each subcategory must be conceptually similar. Putting all items with the same conceptual difference into the same subcategory ensures that items in a subcategory will be conceptually similar to each other.

In addition to subdividing a category, indexing should serve to make members of a category easily accessible. Through cross-indexing, an item can be referenced in many different ways. Through subindexing, it can be given a unique set of pointers. Indexing, then, should make items discriminable, differentiating them from one another.

One category that a "diplomatic meeting with Begin about the Camp David Accords" might fit into, for example, is "diplomatic meetings." A "diplomatic meeting" has a topic of international concern and its participants are high-ranking diplomats of the countries concerned with the topic. A "diplomatic meeting with Begin about the Camp David Accords" has two obvious differences from the norms of "diplomatic meetings"—its topic (CDA) and participant (Begin). In this case, those differences are specifications of the norms. Indexing the meeting by those two features discriminates it from other meetings in the same category. In addition, as additional meetings with either of those features are added to memory, corresponding indices will eventually index subcategories of "diplomatic meetings," i.e., "meetings about the Camp David Accords" and "meetings with Begin."

Figure 1 illustrates this indexing scheme.

In order to insure directed search of such an organization, we must put a restriction on it. Indices may be traversed only if their labels have been specified. Such an organization prohibits enumeration, and requires directed traversal through memory. The indices act as locks which can only be opened (and thus traversed), if the correct key is available to open them.
"DIPLOMATIC MEETINGS"

(i.e., if the value of the index has been specified). In this way, each conceptual category organizes all of the concepts related to it, but obtaining any of these concepts requires specifying the feature designated as its path "lock" or key. These structures can be thought of as "locked conceptual networks."

Such an organization accounts for many of the reconstructive memory phenomena we observe in people (e.g., forgetting, remembering, false starts). But why use such a restrictive memory organization in a computer system? While it may seem that a locked network requires more work for retrieval, the alternatives require enumerating, and therefore examining, many more items. In a large memory, directed retrieval is preferable to enumeration. A locked memory structure is oriented toward a directed
retrieval process involving incremental specification of possible features of items to be retrieved. Instead of examining a large number of items, extra effort is made during retrieval to direct search to a small number of the most relevant items.³

3.1 E-MOPs

The conceptual categories which organize events in memory will be referred to as Episodic Memory Organization Packets (E-MOPs). E-MOPs organize similar episodes according to their differences and keep track of their similarities (Kolodner, 1984, in press, Schank, 1980). When an event is entered into one of these structures, the features will differentiate it from other items in the E-MOP are extracted and used to index it. To retrieve events from an E-MOP, features of a targeted event are specified, the corresponding arcs are traversed, and the concepts indexed by the specified features are retrieved.

In general, we can expect an event memory to have E-MOPs for each major type of event it knows about. Thus, E-MOPs for day to day events might include "getting up in the morning," "eating in a restaurant," "going to the movies," and "driving to the office." Memory for a diplomat will also include E-MOPs for "diplomatic trips," "diplomatic meetings," "negotiations," "speeches," and other diplomatic activities. The E-MOPs necessary to organize events in the life of a particular person will depend on that person's activities and experiences.¹

An E-MOP is a net in which each node is either an E-MOP or an event. Each E-MOP has two important aspects—(a) generalized information characterizing its episodes (i.e., its norms, also called its content frame), and (b) treelike structures that index its episodes by their differences. An E-MOP's norms include information describing its events. This includes normative event features (e.g., usual participants, locations, and topics) and norma-

¹A more detailed analysis of the memory organization and its psychological support and implications can be found in Kolodner (1983).

³These structures are related to Schank's (1980) MOPs and to Lebowitz's (1980) S-MOPs, but the concerns in defining MOPs and S-MOPs were different than those in defining E-MOPs. In particular, Schank's (1980) concern was with showing the interrelatedness of structures in memory. Thus, in his example domain of professional office visits, he described how visits to doctors, dentists, lawyers, and other professionals are similar, and how the structures they are stored in are related. My concern, on the other hand, is with the processes for access of individual episodes, and the organizational requirements those processes place on memory.

Lebowitz (1980) used S-MOPs to organize terrorism events derived from newspaper stories. E-MOPs are more experientially oriented and hold more detailed information than S-MOPs. As a result of the detail, additional issues that Lebowitz did not address (such as index selection) must be examined.
tive episodic context (i.e., the E-MOP's relationships to other E-MOPs). Figure 2 includes the normative information CYRUS has about diplomatic meetings.

'diplomatic meetings' ($MEET) -- generalized information

larger episodes:
"negotiations" (l-NEGOTIATE)
  participants = diplomats of same nationality as meeting participants, and
  of other countries involved in meeting topic
  topic = generalization of meeting topic
"diplomatic trips" (sM-VIPVISIT)
  destination = country or area involved in meeting topic, or country of
  residence of meeting participant
"conferences" (sM-CONFERENCE)
  participants = diplomats of same nationality as meeting participants, and
  of other countries involved in meeting topic
  location = location of meeting
  topic = generalization of meeting topic

enables:
"treaty signing" ($TREATY)
  sides = sides of meeting topic

sequence of events:
  participants MTRANSing to each other about meeting topic

preceding and following events:
"diplomatic meetings" ($MEET)
  participants = subset of meeting participants
  topic = aspect of meeting topic

more general E-MOPS and classifications:
"political meetings" (sM-MEETING)
  all components correspond
"diplomatic activities" (eM-ACTIVITY)
  all components correspond

role fillers:
  participants: foreign dignitaries of countries involved in contract being
    discussed
  location: conference room in capital city of country of residence of some
    important participant
  topic: international contract
  duration: one to two hours

Figure 2

An E-MOP's indices also correspond to event features, and index either individual events or specialized E-MOPs. When an E-MOP holds only one episode with a particular feature, the corresponding index will point to the individual episode. When two or more episodes in an E-MOP share the same feature, its corresponding index will point to a specialized sub-MOP which organizes the events with that feature. In this way, MOP/sub-MOP hierarchies are formed. The MOP in Fig. 1 is part of CYRUS's 'diplomatic
meetings" E-MOP. "Diplomatic meetings" (MOP1) holds generalized information about "diplomatic meetings," while MOP2 and MOP3 index "meetings with Begin" and "meetings about the Camp David Accords," respectively.

Notice that indexing is two-tiered. The first tier indexes types of features (e.g., participants, topic). The second indexes values for the features (e.g., Dayan, Gromyko, SALT, Jerusalem). By following the index for "participants," and from there following the one for Begin, the sub-MOP organizing "meetings with Begin" is found. Following the index for "topic" and from there the index for "SALT," one arrives at the individual event EV2, the only meeting about SALT indexed in this MOP.

This organization provides a rich cross-indexing of events in memory. Specification of any discriminating set of features within an E-MOP allows retrieval of the event with those features. In a richly indexed organization such as this, enumeration of a memory category should never be necessary for retrieval. Instead, search keys specifying a conceptual category and indices to be traversed are created from question concepts. Retrieval strategies are used to elaborate inadequate search keys, thereby inferring plausible event features and relevant paths through the memory structures. In this way, search is directed only to categories and subcategories whose events are relevant to a retrieval cue.

4. MAINTAINING ORGANIZATION OVER TIME

In the remaining sections, a process for automatically adding new items to memory while maintaining its organization will be described. Extending what we know about memory organization, we can lay out the following algorithm for adding new items to memory: When a new item is added to memory, conceptual categories must be chosen for it. Its differences from the norms of those categories must then be decided and features for indexing chosen. After that, the item must be indexed. As part of the process, indexing must be controlled to avoid combinatorial explosion of indices. In addition, as new conceptual categories are created through indexing, the generalized information that memory needs for understanding and retrieval must be added to each one.

5. AUTOMATIC INDEXING

The first step in adding a new event to an E-MOP is to choose appropriate features of the event for indexing. Recall that this means choosing features which differentiate it from other events indexed in the same E-MOP. Con-
sider, for example, how the following event should be indexed in memory under each of the following circumstances:

**EV1**: Cyrus Vance has a meeting with Andrei Gromyko in Russia about the Afghanistan invasion.

Case 1: Vance has met many times before with Gromyko, but never in Russia, and never about the Afghanistan invasion.

Case 2: Vance has been in Russia for the past two weeks meeting with Gromyko every day about the Afghanistan situation.

In the first case, the topic and location of EV1 can distinguish it from other meetings in memory. Therefore, either of those features would be reasonable indices for EV1 in a "diplomatic meetings" MOP. In the second case, however, its location and topic cannot distinguish this meeting from other meetings already indexed in that E-MOP. Indexing on those features will not be helpful in discriminating this meeting from others.

There are two major problems to address in discussing index selection: (a) what characterizes a good E-MOP index? and (b) how can E-MOP indices be chosen?

### 5.1 What is a Difference from a Norm?

We have already stated that maintaining discriminability requires unusual aspects of a situation to be indexed. Unusual aspects of a situation are those that differ from the norms of the conceptual category the situation fits into. We identify four types of differences from norms:

1. a violation of the norm.
2. a variation of a norm (e.g., the norm plus additional features).
3. a specialization of the norm.
4. a generalization of the norm.

In CYRUS, for example, the E-MOP "summit conference" has the norms which are shown in Fig. 3.

Taking these into consideration, consider how the "Camp David Summit" would be indexed in the "summit conference" E-MOP. Its purpose was to negotiate an accord between Israel and Egypt, an important international contract. Its participants were the heads of state of Israel, Egypt, and the United States, plus their advisers. Its location was the U.S. president's private resort complex in the United States (not quite a neutral country). It lasted almost two weeks. Figure 4 illustrates a portion of CYRUS's "summit conference" MOP after adding the Camp David Summit and indexing it as just described.
summit conference

norms:
- topic is an international contract
- participants are heads of state of countries involved in contract and a group of their advisors
- location is a resort area in neutral country
- purpose is negotiations
- includes many diplomatic meetings
- duration is a few days

Figure 3

SUMMIT CONFERENCE

norms:
- topic is an international contract
- participants are heads of state of countries involved in contract and a group of their advisors
- location is a resort area in neutral country
- purpose is negotiations
- includes many diplomatic meetings
- duration is a few days

Because the topic of the conference is better specified than the normalized topic specification, this conference is indexed according to its topic. The participants are a more general case than the E-MOP's norms for participants (there is an addition), and that difference is indexed. The conference's location is indexed because it violates the norm. Because the purpose of the summit matches the norm (i.e., negotiation of its major topic), it does not get indexed. Finally, because this summit was longer than the norm (another violation), an index for its length is appropriate.

5.2 What Makes a Good Index?

Not all event properties make good indices. Consider, for example, the following two situations:
An employer is interviewing a prospective employee for a job as a computer programmer.

An employer is interviewing a prospective employee for a job as a fashion model.

Because these are both interviews, it would be reasonable to index each using relevant features of the prospective employees. The features of the prospective employees that would make reasonable indices, however, differ greatly. It would be reasonable for the employer interviewing a prospective computer programmer to index the interview according to the interviewee's educational background. It would be less reasonable, however, for him to index the experience according to the color of the interviewee's hair (unless his hair is a weird color). On the other hand, it would be more reasonable for the employer interviewing a prospective model to index the experience according to the person's hair color and what he is wearing, rather than by his education.

The amount of detail that should be indexed for each feature of a situation depends upon the context in which the event is taking place. We must therefore explain what regulates the number and relevancy of specific details for indexing.

Because indices should divide a category into smaller pieces and differentiate events, unique features of events make good indices. A unique feature is one for which there is not already an index. If the only diplomatic meeting Vance has ever had with Dobrynin is indexed as a meeting with Dobrynin, then it will be retrievable through that unique feature.

All aspects of unique features of an event need not be indexed, however, but only the most general description of a unique feature. One description is more general than a second if it can be used to describe the second, i.e., if all of its aspects are also aspects of the second.

The more general a unique feature used as an index, the more retrievable the event being indexed will be.

A more general description of a feature will make a better index because it will be accessible in more cases. An index based on nationality, for example, will be traversable in more cases than an index for a particular person.

Perhaps the most important property indices should have is predictive power. A feature which is predictive often co-occurs with some other event feature. It is the one which a useful generalization can be based on. The nationality of participants in a diplomatic meeting, for example, is usually the same as one side of the contract being discussed. Thus, in a "diplomatic meetings" MOP, the nationality of participants is usually predictive of...
another feature, and actual nationalities of participants are good predictive features for indexing.

An predictive feature is one which, if it indexed an E-MOP instead of an event, would correlate with other E-MOP features. It is important to index individual events by features which are potentially predictive so that, if additional similar events are added to memory, a new E-MOP with useful generalizations can be formed based on the similarities between events with that feature.

The first time we see a particular feature, however, we cannot be sure whether or not it will be predictive later. Predictiveness of features can be judged by previous experience. If a type of index (e.g., appearance of participants, nationality of participants, sides of a contract) has been useful previously for similar events, then there is a good chance it will be useful for a new event. If nationalities of participants have been predictive in indexing other “diplomatic meetings” or “diplomatic activities,” then “nationality of participants is Canadian” will probably be predictive.

Indices should have predictive power or potential predictive power.

This implies that as new events are added to memory, the relative predictive power of different types of indices must be tracked. The process of refining the knowledge used for indexing will be explained in a later section.

To further constrain the notion of predictive power in a MOP, we must place the following constraint on E-MOP predictions: E-MOP indices should not only have potential predictive power, but they should make context-related predictions. A context-related prediction is one which predicts MOP-specific features.

The usefulness of an index depends on its context; a good index should make context-related predictions.

5.3 Choosing Indices

These criteria for discriminability suggest an algorithm for index selection (see Fig. 5).

Since only features with predictive power should be indexed, the actual process of choosing indices must first use information about predictability to select possible indices for an event. Each of those possibilities can then be checked to make sure (a) that it has not been marked as nonpredictive, and (b) that it is not an E-MOP norm. In addition, each feature chosen as a potential index must be checked to see if there is a unique way of describing
Select types of features from event that have been predictive previously

Get rid of
(1) particular features known to be non-predictive
(2) E-MOP norms

Choose most general way of describing those features which are unique

Figure 5

it. If so, the most general unique way of describing it should be used as an index.

In addition to presenting an algorithm, we must also describe the knowledge necessary to make the process work. In order for predictive power to be used in choosing indices, each E-MOP must keep track of types of indices which have been useful, and actual features which have not been useful and should no longer be used as indices. Similarly, in order to compute differences from a MOP's norms, its norms must be specified.

Consider, for example, CYRUS's "diplomatic meeting" MOP after enough meetings have been added to it for it to know some of its nonpredictive features. Figure 6 contains some of its predictive aspects, its norms, and the features it knows to be nonpredictive at that time.

Using predictive information associated with this E-MOP, the first step of the index selection process would choose the following as potentially predictive features of EV2:

EV2: Cyrus Vance has a meeting with Andrei Gromyko in Russia about SALT.

*Note the CYRUS does not really have all of this information on the "diplomatic meetings" MOP itself. In order that features common to many of its MOPs do not have to be duplicated on each MOP, CYRUS has major MOP classifications which include most of the information about predictive features and some norms. Some of those classifications are "occupational activities," "political activities," "social activities," and "meetings." Information lives on the most general E-MOP or MOP classification to which it belongs.
'diplomatic meetings'

norms:
- participants: diplomats of countries involved in contract being discussed
- location: conference room in capital city of country of an important participant
- topic: international contract
- duration: one to two hours

predictive:
- political roles of the participants
- classes those roles fit into
- nationalities of the participants
- occupations of the participants
- political leanings of participants
- topic, place, participant
- sides of the topic
- issue underlying the topic (e.g., peace)

non predictive features:
- participants' occupation is foreign minister
- participants' occupation is head of state

Figure 6

1. the meeting is with a foreign minister
2. the meeting is with a diplomat
3. the meeting is with a Russian
4. the meeting is with a Communist
5. the meeting is about SALT
6. the topic concerns the U.S. and Russia
7. the underlying topic is arms limitations
8. the meeting is with Gromyko
9. the meeting is in Russia

In the second step of the process, those features known to be nonpredictive or norms of the E-MOP are deleted from the set of potential indices. Taking into account the norms and nonpredictive aspects of the "diplomatic meetings" MOP cited, features 3 through 9 would remain as plausible indices for EV2.

One potential problem with multiple indexing is combinatorial explosion of indices in memory. This problem is controlled by indexing only differences which are predictive of other features. In the next section we shall see that generalization is the tool that builds up norms and controls indexing.

6. CREATING NEW E-MOPS

After choosing features for indexing, events are indexed in E-MOPs by the chosen features. A feature chosen for indexing can have one of three relationships to the E-MOP (Kolodner, 1980):
1. There is nothing yet indexed in the E-MOP with that feature.
2. There is one other item with that feature indexed in the E-MOP.
3. There is an E-MOP indexed by that feature.

6.1 Index Creation

If there is not already an index for a feature (case 1), then one is created for it. Any time an event is indexed by a feature unique to an E-MOP, it can be retrieved from that E-MOP by specifying that feature. Thus, the more features an event has that are unique to an E-MOP, the more ways there will be of retrieving it uniquely. The rule in Fig. 7 summarizes the process of creating a new index.

**Index Creation**

IF there is no prior index for a relevant feature of an event

THEN

(1) construct an index
(2) index the event's description there

Figure 7

6.2 E-MOP Creation

The second time an event with a particular feature is added to an E-MOP, a new sub-MOP can be created. When a second event is indexed at a point where there is just one other event, the previous event is remembered. This is called reminding (Schank, 1980). Reminding triggers the creation of a new E-MOP. The current and previous events are compared for common aspects. Similarities between the two events are extracted, and a new E-MOP with generalized information based on those two occurrences is created (see Fig. 8).

**E-MOP Creation**

IF there is one event indexed at an index point for a new event

THEN

(1) create a new E-MOP at that point
(2) extract the similarities of the two events and add those as norms of the new E-MOP
(3) index the two events in that E-MOP according to their differences from its norms

Figure 8
When CYRUS indexes a second event where a first is already indexed, it examines the first episode, notices similarities between the two episodes and creates a new E-MOP. Suppose, for example, that CYRUS’s “diplomatic meetings” MOP held one meeting about military aid. The second time Vance meets about military aid, CYRUS is reminded of its prior meeting because both have the same topic. It checks the descriptions of both to see what other similarities they have. Since both were with defense ministers, CYRUS concludes that “meetings about military aid are usually with defense ministers.” It also creates a new “meetings about military aid” MOP and indexes the two meetings within that E-MOP. Figure 9 contains CYRUS’s response to a second meeting about military aid, this one with the defense minister of Israel in Jerusalem.

Adding $\text{SMEET} \quad \text{actor (Vance)}$
\text{others (defense minister of Israel)}
\text{topic (Military aid to Israel)}
\text{place (Jerusalem)}
to memory...

Reminded of $\text{SMEET} \quad \text{actor (Vance)}$
\text{others (defense minister of Pakistan)}
\text{topic (Military aid to Pakistan)}
\text{place (Washington)}

because both are “diplomatic meetings”
both have contract topic “military aid”

creating new MOP, meetings about military aid
generalizing that when
Vance meets about military aid, often he meets with a defense minister

Figure 9

After adding this meeting to memory, the “diplomatic meetings” MOP will look the same as before adding the event except that a new E-MOP will have been created at its index for “underlying topic is military aid.” Major changes in organization will occur in the new E-MOP and in other sub-MOPS this event was added to. The newly created E-MOP, “diplomatic meetings about military aid,” is a specialization of “diplomatic meetings,” and its norms include only those features that are more specialized or different from the parent MOP. The new E-MOP has the norms and indices contained in Fig. 10.

Later, if CYRUS hears about a third meeting whose topic is military aid, it will assume that the meeting is with the defense minister of the country requesting aid unless given contrary information. If asked for the participants of that third event, it will be able to answer “probably the defense minister.”
6.3 E-MOP Refinement

When there is already a sub-MOP at the point where an event is being indexed (case 3), the new event is indexed in the sub-MOP by the same procedure used to index it in the more general E-MOP. In addition, the new event is compared against the generalized information of both the parent E-MOP and the sub-MOP, and the validity of previous generalizations is checked and refined (see Fig. 11).

**E-MOP Refinement**

**IF there is an E-MOP at an index point for a new event**

**THEN**

1. Index the event in that E-MOP
2. Check the validity of its generalization
3. Update its generalizations as necessary

On entering another meeting about military aid to memory, for example, CYRUS will index it among other events already indexed there. In this way, reminding, generalization, and new E-MOP creation occur within newly created E-MOPs. If a new meeting about military aid to Pakistan is added to the E-MOP “meetings about military aid,” illustrated in Fig. 10, CYRUS will be reminded of the first because both will be indexed as “Pakistan was one side of the contract discussed,” and a new E-MOP, “diplomatic meetings about military aid to Pakistan” will be formed as a specialization.
of "diplomatic meetings about military aid." The processes that go into confirming and denying generalizations will be explained in the next section.

7. GENERALIZATION

In CYRUS, two types of generalization are done—initial generalization and generalization refinement. Initial generalization happens when the second event with a particular feature is added to an E-MOP. It has already been described as a process of feature extraction and comparison. Common features of the current event and the one already in memory are extracted and added to the norms of the new E-MOP. The events are then indexed in that MOP by their differences.

Because initial generalizations made in creating an E-MOP might be incomplete, inaccurate, or wrong, the update process must be able to monitor the correctness of generalized information in newly created E-MOPs. Checking the correctness of generalizations requires monitoring both the norms and indices in an E-MOP. Undergeneralization or incomplete generalization is recognized when a particular feature indexes most of the events in an E-MOP. In that case, the corresponding sub-MOP is collapsed and its norms added to those of the parent MOP. A feature is overgeneralized if it is an E-MOP norm but does not correspond to later events added to the E-MOP. When an E-MOP's norm fails to correspond to new events, that norm must be removed and an E-MOP built for it.

Index monitoring is also necessary as a way of keeping track of a feature's predictive power. If a particular feature does not correlate with other features, it should be marked as nonpredictive so it will no longer be indexed. In this section, the processes of recovery from overgeneralization or false generalization, generalization beyond the initial ones, and recovery from nonpredictive indices will be discussed in detail.

7.1 Generalization Refinement

The first two events added to an E-MOP are special. They initiate the set of generalizations that will be used in future indexing and retrieval. Some initial generalizations are more reasonable than others, however. Consider, for example, the E-MOP in Fig. 12, created by adding two trips to the Middle East to memory. All episodes indexed in this E-MOP will have the feature "destination is the Middle East," since that is the index for this sub-MOP in "diplomatic trip." Probably, these trips will continue to have the purpose of negotiating Arab-Israeli peace, at least as long as there is no peace there. We would not, however, expect that every trip to the Middle East will in-
"diplomatic trips to the Middle East"

dependencies:

destination is the Middle East

purpose is to negotiate Arab-Israeli peace

includes meeting with head of state

includes state dinner

specialization of "diplomatic trip"

differences:

destination

Israel

Egypt

Figure 12

clude a state dinner. There may also be attributes of trips to the Middle East not common to these first two trips.

As additional items are added to an E-MOP, the unreasonable generalizations must be discovered and deleted. In addition, new events must be monitored to see if additional generalized information can be extracted from them. One way to do that is to check each new event to see if its features conform to the E-MOP's generalizations. If a feature of a new event conforms to a generalization, the certainty of that norm will increase. The certainty of each norm that has a conflicting value in a new event will decrease. When the certainty of an aspect reaches a threshold, it can then be considered an actual norm for the E-MOP, or a real generalization. When a low threshold is reached, that aspect of the E-MOP's description need no longer be considered active for comparison.

In CYRUS, the certainty of a generalization is a function of the number of events indexed in an E-MOP and the number of events with features which conflict with that generalization. Until the E-MOP organizes a reasonable number of events, however (six in CYRUS), generalization certainty is not considered. This is an implementation detail which leads stability to an E-MOP until it can stabilize itself. When an E-MOP reaches a reasonable size, the certainties of the generalizations are evaluated and those which fall below a threshold are removed, while all others remain.

7.2 Additional Generalizations

After an E-MOP reaches a stable size (six in CYRUS), each time a new event is added to it, CYRUS checks each sub-MOP referred to by the incoming event to see if any index a large majority (two thirds) of the events in the E-MOP. If so, the generalizations corresponding to that set of items will also be good generalizations for the entire set of events in the E-MOP.
When this happens, CYRUS makes additional generalizations about events in the parent E-MOP by collapsing the sub-MOP and merging its generalizations with those of the parent (see Fig. 13).

Collapsing sub-MOPs

IF a sub-MOP indexes a large majority of the events in its parent E-MOP

THEN

(1) collapse the sub-MOP
(2) get rid of its index
(3) add the indexed feature plus other norms of the sub-MOP to the generalized information associated with the parent E-MOP

Figure 13

7.3 Recovery from Bad Generalizations

Recovery from bad generalizations is more complex. When new information and events contradict a previously made generalization, that generalization must be removed as one of the E-MOP’s norms.

This raises a special problem. While a feature is one of the norms of an E-MOP, events are not indexed by that feature. On the other hand, if a feature is included in the norms of an E-MOP, then many of the events already in the E-MOP have it as a feature. Because events were not indexed by that feature, however, it would be expensive to go back and find all events supporting the generalization.

Generalization removal, then, can have grave implications in retrieval. If a retrieval key specified a feature that had been removed as a generalization, but which had not yet been indexed, then the retrieval processes would not be able to find any trace in memory of an event with that feature. It would have to conclude that there had never been such an event in memory.

To correct this problem, an index to an empty sub-MOP is created each time a feature is removed from a MOP’s norms. In addition, the feature is marked as having once been “generalized.” This enables the retrieval functions to return with the message “there may be events with this description, but I can’t find particular ones,” instead of failing completely if no distinct event can be found. This message also triggers search strategies which attempt to find the sought event by some route other than the direct one. During later indexing, that sub-MOP will be treated like any other (see Fig. 14).

7.4 Maintenance of Predictive Power Judgments

The last kind of monitoring that must be done during memory update is monitoring for predictive power of features. The predictiveness of a partic-
Recovery From False Generalization

IF a norm has been disconfirmed

THEN

(1) remove it from the E-MOP
(2) create an empty sub-MOP for it indexed by that feature
(3) add other features removed from the E-MOP's norms at the same time
(4) mark the new E-MOP as "once generalized"

Figure 14

ular type of feature is inherited from the E-MOP classifications and more general E-MOPs a MOP belongs to. Particular values of some type of feature, however, might turn out not to be predictive.

In CYRUS, after a feature has occurred a reasonable number of times (6), the MOP indexed by the feature is checked for generalizations. If there are none in addition to the feature which indexes the MOP, then that feature is judged to be nonpredictive in the parent MOP, and is marked as such. After being marked as nonpredictive, a feature is no longer indexed in that MOP.

In order to constrain later indexing, similarities between events in newly created E-MOPS must be maintained. An E-MOP indexed by a feature which is nonpredictive will have no generalized information to keep track of, and it will not be able to constrain indexing and new E-MOP creation. Thus, its indices will duplicate the indices in its parent MOP without it keeping track of useful generalized information. It will waste space without contributing to the organization of generalized information.

8. HOW CYRUS'S MEMORY GROWS

To see how these processes work, we will examine growth of CYRUS's "diplomatic meetings" MOP. CYRUS's bare (initial) "diplomatic meetings" MOP has no indices, but does have generalized information about diplomatic meetings (see Fig. 15).

After adding two "diplomatic meetings" to CYRUS (one concerning SALT with Gromyko (EV2), and one concerning Arab-Israeli peace with Begin (EV1), both part of negotiations), CYRUS's "diplomatic meetings" MOP includes the structure in Fig. 16.

These two meetings are indexed by their topics, the issue underlying those topics, the sides involved, and the nationalities and occupations of the participants. Because both are part of negotiations standard to the topic they are discussing, neither are indexed by their purpose or larger episodes they are part of. Because these two meetings have nothing in common ex-
'diplomatic meetings' -- SMEET

noms:
- included in "negotiations"
- participants are foreign diplomats
- topic is an international contract
- topic involves the United States
- is political and occupational for Vance
- is a meeting

Figure 15

"diplomatic meetings" -- SMEET

differences:

participants

nationality

Arab-Israeli peace

SALT

EV1

EV2

Israel

USSR

EV1

EV2

participants

occupations

Arab-Israeli peace

SALT

arms

limits

peace

EV1

EV2

Israel

USSR

EV1

EV2

foreign minister

head of state

EV1

EV2

EV2

EV1

Figure 1A

ccept generalized information already known about meetings, they are each indexed uniquely by their differences, and "diplomatic meetings" norms do not change.

Both of these meetings were meetings that happened in August, 1978. If we continue adding meetings to CYRUS in the order in which they happened, we can illustrate how the structure of the "diplomatic meetings" MOP changes over time. The next meeting processed by CYRUS was another meeting about Arab-Israeli peace, this time with Sadat. Because this meet-
ing had features in common with Vance's meeting with Begin, reminding occurred, new E-MOPs were created, and generalized information was added to those E-MOPs. The norms of "diplomatic meetings" remained the same, since there were no additional similarities between the three meetings indexed up to that point. After adding this meeting to memory, CYRUS's "diplomatic meeting" MOP had the structure in Fig. 17.

Because this meeting, too, was with a head of state, and was about Arab-Israeli peace, new E-MOPs were created at those index points (MOP1, MOP2, MOP3, and MOP4, See Fig. 17). Those E-MOPs each contain as norms the information common to the two meetings which initiated their creation—in each of these cases, that both were about Arab-Israeli peace, involved Israel and the Arabs, and were with a head of state. Each one also is marked as a specialization of "diplomatic meetings." The newly created E-MOP "diplomatic meetings about Arab-Israeli peace" (MOP1), for example, has the structure in Fig. 18.
8.1 CYRUS Overgeneralizes

When CYRUS finds an index which indexes nearly all the events in the E-MOP, it predicts that that feature should actually be one of the E-MOP's norms, and updates those norms appropriately. As additional diplomatic meetings were added to CYRUS's memory, its "diplomatic meetings" MOP continued to grow. The next eight meetings Vance had were meetings concerning Arab-Israeli peace. Some were part of the Camp David Summit. Because so many of the diplomatic meetings CYRUS knew about were about Arab-Israeli peace, and because there was only one meeting that had been about anything else at that point, CYRUS made the generalization that "Vance's diplomatic meetings are generally about Arab-Israeli peace." Thus, after adding those eight meetings to memory, CYRUS' "diplomatic meetings" MOP had the structure depicted in Fig. 19.

As a result of this overgeneralization, CYRUS removed some of the sub-MOPS it had created previously. Thus, its E-MOPs "diplomatic meetings about Arab-Israeli peace," "diplomatic meetings about a topic involving the Arabs and Israel," and "diplomatic meetings about peace" (MOPs 1, 2, and 4 in Fig. 17) were collapsed. They were subsumed by the generalizations made about "diplomatic meetings" in general. CYRUS later recovers from this overgeneralization.

At this point, CYRUS had made a number of erroneous generalizations about diplomatic meetings. It generalized that diplomatic meetings usually involved Arab and Israeli concerns, and are normally about peace between the Arabs and Israel. We recognize that the meetings CYRUS had seen up to this point were not a good sampling of his meetings. As far as CYRUS knew, however, the meetings it had seen were typical of Vance's
"diplomatic meetings" -- $\text{MEET}$

Figure 19

meetings. To it, then, these were valid generalizations, and CYRUS used them to constrain further index and new E-MOP creation, and to guide retrieval.

8.2 Implications of CYRUS's Mistake

To see how these generalizations guide retrieval, and how erroneous generalizations can cause forgetting, consider how CYRUS would answer the following question based on the MOP above:

(Q2): What have you talked about at diplomatic meetings?
In answering this question, CYRUS would first check generalized information about topics of “diplomatic meetings” in order to direct its search. It would find that meetings are generally about Arab-Israeli peace. At that point, it would recall the most important specific Arab-Israeli topics it knew about—the Camp David Accords. It would thus attempt retrieval of “diplomatic meetings about the Camp David Accords.” Since there could have been other topics involving Arab-Israeli peace that it could not retrieve in that way, it continues its search of memory. Using this topic information, it would also infer that participants were from the Middle East (since nationalities of participants and sides of the topic under consideration generally correspond) and search the E-MOP for meetings with people from each of the Middle Eastern countries. It would thus do a good job of elaborating on and retrieving meetings about Arab-Israeli peace, but as a result of its overgeneralization, it would forget the SALT meeting entirely.

Suppose, however, that it were asked the following question:

(Q3): Who have you talked to about SALT?

Although elaboration at this point would not allow retrieval of a meeting about SALT, specification of a characteristic of such a meeting does allow its retrieval. Because an indexed feature unique to one event in the “diplomatic meetings” MOP is specified in the question, CYRUS can retrieve the appropriate meeting by simply traversing the E-MOP.

There is an important observation to be made about retrieval of events which are different from an E-MOP’s norms. Because the E-MOP’s norms will not aid in inferring their features, they may not be retrievable through elaboration. They will, however, be easily retrievable if their differentiating features are specified. This example illustrates the difference between recall and recognition found in people. Because recall may require reconstruction and elaboration, a person freely recalling a list of items is likely to forget some. On the other hand, when presented with a well-specified item forgotten during recall, he may recognize it.

8.3 Getting CYRUS Back on the Right Track

CYRUS’s memory at this point was, at best, confused. It is not always possible to know when there is a good sampling. As a result, indices and norms must constantly be monitored to keep memory’s generalized information up to date with the events it organizes.

As additional meetings were added to CYRUS’s memory, it began to notice that very few of them matched the features that it had generalized. After approximately 20 meetings had been added to CYRUS’s “diplomatic meetings” MOP, its norms became more stable. At that point, it had a good
sampling, and the meetings balanced each other in all relevant ways. It recovered and readjusted its generalizations to fit reality. It removed the bad generalizations, created E-MOP's indexed by each of those features, and used those features to index later meetings.

After CYRUS has processed approximately 60 diplomatic meetings, its "diplomatic meetings" MOP had the structure depicted in Fig. 20.

"diplomatic meetings" -- $\$\text{MEET}$

The entire structure of CYRUS's "diplomatic meetings" MOP after 60 meetings is not illustrated here. The interesting features to note, however, are that its norms had recovered from the erroneous generalizations that were made, and it again had indices and corresponding E-MOPs for the features "topic involving Arabs and Israel," "topic is peace," and "topic is
Arab-Israeli peace." Those were the E-MOPs that had been removed when CYRUS made the previous overgeneralization.

8.4 Maintaining Predictive Power Information

When CYRUS finds an index with no predictive power, it marks that index as useless and no longer uses it. When CYRUS began adding new meetings to memory, it indexed all events according to the occupations of their participants. By the time it had added 60 meetings to memory, however, it knew that the occupation "foreign minister" was not predictive of other features, and it therefore no longer used them for indices in its "diplomatic meetings" MOP. Some of the sub-MOPS to "diplomatic meetings" also have features marked as nonpredictive or useless.

As CYRUS is adding new events to an E-MOP, it monitors both its indices and norms, keeping the norms up to date and attempting to ascertain which indices are good and which are not useful. As a result of this monitoring, recovery from overgeneralization or false generalization, generalizations beyond the initial ones, and recovery from nonpredictive indices are possible.

9. FURTHER IMPLICATIONS OF MEMORY REORGANIZATION: FORGETTING

In order to evaluate the implications of memory reorganization, we must explain the internal structure of episodes in memory. An episode is composed of many events and episodes related to each other through containment, causality, and time. Every event in memory points to all of the episodes it is related to by specifying those features of each episode which can retrieve it from its MOPS. The set of features which describe an event are derived at the time the event is entered into memory. Because memory’s organization changes over time, however, a reference that was unique at input time may not be unique at retrieval time. During retrieval, if the available specification of a contextually related event is no longer unique, then elaboration must be applied to reconstruct additional details of the related event and enable its retrieval.

Consider, for example, the following event:

EV3: On his recent visit to Philadelphia, Vance was welcomed by a marching band playing "Stars and Stripes Forever."

Suppose this particular welcoming ceremony was the first that had included a band. In that case, the trip would refer to the welcoming ceremony as
"welcomed by a band." Since the welcoming ceremony itself would be stored in its own E-MOP, that specification would be a unique reference to the welcoming ceremony in its E-MOP. Suppose, however, that during later trips around the United States, Vance was again greeted by bands, sometimes high school marching bands, sometimes college bands, sometimes military bands. The specification "welcomed by a band" associated with his visit to Philadelphia, would no longer be unique. It would describe an E-MOP rather than an individual event. To retrieve the particular welcoming ceremony, the specification "welcomed by a band" would have to be elaborated, until it described a unique event that could be retrieved from the "welcoming ceremony" MOP.

Elaboration is a process of inferring plausible features. It can be faulty. In that case, the wrong event might be retrieved from memory. If a recalled event is consistent with the information that is known, its differences will not be noticed, and false reconstruction will occur. Faulty retrieval of this kind corresponds to what psychologists refer to as recall intrusion (Crowder, 1976; Owens, Bower, & Black, 1979) and recognition confusion (Bower, Black, & Turner, 1979; Gibbs & Tenny, 1980). Mistakes of this sort happen when retrieval is directed to the wrong episode, which is substituted for what actually happened.

Retrieval interferences occur because of the constantly changing memory structure. The features specified for related events depend on the memory organization at the time the event is entered into memory. They will be features which discriminate the related event in its E-MOP at that time. If memory changes before retrieval time, then what was once a unique specification of an event may no longer be unique.

10. MORE ABOUT CYRUS

CYRUS has two data bases—one each for former Secretaries of State Cyrus Vance and Edmund Muskie. CYRUS's E-MOPs include one for each type of activity a secretary of state does. They are listed in Fig. 21.

CYRUS takes conceptual representations of episodes as input. Thus, stories must be analyzed, and a representation must be built before sending them to CYRUS. CYRUS has two modes of receiving representations of stories. In one mode, the stories are analyzed and the representations encoded by the human reader are integrated into CYRUS's memory. In its second mode of operation, CYRUS is connected to FRUMP (DeJong, 1979) to form a complete fact retrieval system called CyFr (Schank, Kolodner, & DeJong, 1981). FRUMP reads stories from the UPI news wire, and sends conceptual summaries of stories about Muskie and Vance to CYRUS. CYRUS then adds the new events to its memory and answers questions about them.
Figure 21

CYRUS's Muskie memory has been built up entirely from FRUMP-processed stories. Its Vance memory is built partially of FRUMP-processed stories and partially of stories encoded by hand.

Figure 22 contains a story CyFr has processed about Vance. FRUMP produced the summary, and sent its conceptual representation to CYRUS. After adding the events to its memory, CYRUS answered the questions.

Vance went to Madrid today to talk with Spanish leaders. Vance went on a plane from the Netherlands to Madrid. Foreign Minister Marcelino Oreja Aguirre welcomed Vance in Madrid.

> WERE YOU IN EUROPE LAST YEAR?  
yes, most recently in Madrid.

> WERE YOU WELCOMED THERE?  
yes, by Foreign Minister Marcelino Oreja Aguirre.

> WHO DID YOU TALK TO THERE?  
a group of Spanish officials.

> DID YOU ALSO GO TO HOLLAND?  
yes.

Figure 22

10.1 How the Muskie and Vance Memories Differ

Although CYRUS started out with the same E-MOPs and initial memory organization for each man, because of their differing experiences, the new
categories built by the system for Muskie are somewhat different than those built for Vance. After adding events to the two data bases, their organizations differ in four ways:

1. The indices are different.
2. The types of indices are different. While the Vance E-MOP has topic indices and larger episode indices, the Muskie E-MOP has neither of those.
3. The norms associated with corresponding E-MOPs are different, (i.e., different generalizations have been made).
4. The Vance E-MOP indexes mostly sub-MOPs, and the Muskie E-MOP indexes mostly individual events.

Three factors contribute to these differences. First, the experiences the two men have had are different. This is the reason for differences between indices in corresponding E-MOPs. Second, the data entered into the Vance data base is much more detailed than that entered into the Muskie memory. This factor accounts for the differences in the types of indices in the two memories. Because the Muskie memory is not usually aware of the topics of Muskie's meetings, for example, it cannot index them by aspects of their topics.

The third factor which accounts for differences between the two memories is the degree of similarity between the events. The first ten events added to the Vance E-MOP, for example, were very similar to each other. Eight of them were meetings about the Camp David Accords. On the other hand, except for three meetings with Gromyko the meetings entered into the Muskie data base had been very different participants and locations.

This factor accounts for differences (3) and (4). The more similarities between events in an E-MOP, the more filled out the MOP's generalized information can be. In addition, the more similar events in an E-MOP are, the more sub-MOPs will be indexed in the MOP than individual events. The extent of new category creation, then, is a function of the degree of similarity between the items added to an E-MOP, and not the number of items it organizes.

10.2 CYRUS's Generalizations

There is a fifth difference between the two memories—the generalizations each has made. Each new sub-MOP that is created represents a set of generalizations. The extent of generalization in memory is dependent on the similarities between items added to memory. Figures 23 and 24 show the norms of the sub-MOPs entitled "diplomatic meetings with Russians" in the Vance and Muskie memories.
Muskie's 'meetings with Russians' E-MOP

norms:
- participants are Russian
- participant is a foreign minister
- participants include Gromyko

Vance's 'meetings with Russians' E-MOP

norms:
- participants are Russian
- participant is a foreign minister
- participants include Gromyko
- topic is SALT
- topic involves Russia
- location is Moscow

One can read off the generalizations an E-MOP organizes as "when <E-MOP descriptors> then <other norms>." Thus, the Muskie MOP organizes the following generalizations:

- Meetings with Russians are with foreign ministers.
- Meetings with Russians include Gromyko as a participant.

Reasons for the differences in generalizations parallel those used earlier to explain the differences between the MOP structures in the two memories.

The generalizations in Fig. 25 (paraphased in English) are representative of those CYRUS has made about Vance's activities.

CYRUS' generalizations

1. Meetings in the Middle East are about Arab-Israeli peace.
2. When Vance meets in the Middle East with Egyptians, he also meets with Israelis, and the topic is the Camp David Accords.
3. When Vance meets with Begin, the topic is the Camp David Accords.
4. When Vance goes to a conference concerning Egyptian concerns, the topic of the conference is the Camp David Accords.
5. When Vance negotiates with Egyptians, the topic is the Camp David Accords.
6. Trips to Russia are for the purpose of negotiating SALT.
7. When Vance attends a conference with Gromyko, the topic is SALT.
8. When Vance takes a trip to negotiate Arab-Israeli peace, the trip is to the Middle East.
Note that the first two generalizations both refer to "meetings in the Middle East," but the topics they predict are different. That is because the first generalization is a generalization about "meetings in the Middle East" in general. It is associated with that E-MOP. The second is a generalization associated with "meetings in the Middle East with Egyptians," a sub-MOP of "meetings in the Middle East" and "meetings with Egyptians." In fact, "the Camp David Accords" is a specialization of "Arab-Israeli peace," and the two do not conflict.

11. SUMMARY AND CONCLUSIONS

11.1 Maintaining Accessibility

In order to retrieve events from a category, memory's organization must provide discriminability between events. Indexing richly by differences provides such discriminability, but creates a potential problem. In a richly indexed system, indexing takes up space and can get out of hand. In CYRUS, that problem is handled by the notions of salience, predictability, and generalization. Indices are created only for salient features of a context. After a number of events with the same feature are indexed, that feature is maintained as an index only if it proves to have predictive power. As events are indexed in sub-MOPs, relevant similarities between the events in those sub-MOPs are computed and stored on each sub-MOP as generalized information about the E-MOP. Features common to events in an E-MOP are not indexed.

In order to maintain retrievability as memory grows, new memory categories must be created, and generalized knowledge must be associated with them. Because new categories are created when multiple events are indexed in the same way, the same generalization process that controls index creation also constrains the creation of new categories. Generalized knowledge is built up by extracting the salient similarities between items in a subcategory. Newly created generalized knowledge aids the retrieval process and constrains subsequent indexing within the subcategory.

11.2 Organizing Generalized Knowledge in Memory

An intelligent system needs generalized knowledge. If it is integrated into memory by associating it with the items it is generalized from, then generalized knowledge and instances will be equally accessible. Additional search outside a data base for "metalevel" information will not be necessary to retrieve the generalized information needed for further processing. In addition, associating generalized knowledge with items it is built up from allows
it to be refined and updated as new examples are entered into memory. This organization of generalized knowledge has an important processing implication:

**Associating generalized information with the items it is generalized from makes retrieval of generalized information the same as retrieval of actual items.**

In terms of the human model, this supports the theory that *there is no distinction between episodic and semantic memory* (Schank, 1975).

It also has implications in the design of computer systems. In a computer system which makes retrieval of generalized information the same process as retrieval of actual items, a user can retrieve information about the nature of the database, and not only data items themselves. Using the retrieval strategies for retrieving actual items from memory, and using the CYRUS database, answering questions such as the following would be a trivial extension to the system.

(Q4): When Vance goes on diplomatic trips, where does he usually stay?
(Q5): Do welcoming ceremonies for Vance usually include parades?
(Q6): What kinds of things does Vance discuss at diplomatic meetings?

Instead of retrieving actual events that correspond to the target event in each of these cases, E-MOPS which correspond will be retrieved, and their generalized information will be consulted.

In an information retrieval system which did not allow queries about the nature of the data, a user would have to request all or many instances of the kinds of events he was interested in and draw his own conclusions. Retrieving individual items would require elaboration by the system or a series of questions by the user. Either way, it would be less efficient.

### 11.3 Retrieval Failures and Ease of Retrieval

The theory presented makes the following psychologically relevant prediction:

**The closer a retrieval cue is to encoding at time of retrieval, the easier retrieval should be.**
An event can be retrieved only by specifying features on which it was discriminated during processing. When an event specification refers to features that have not been discriminated, retrieval can only occur if the specified features can be transformed into features that have been discriminated. Psychologists have called this phenomenon encoding specificity (Tulving, 1972). According to that theory, the ease with which an item can be recalled from memory depends on the nearness of the retrieval specification to the description initially encoded in memory for the item.

It must be taken into account, however, that memory is constantly reorganizing itself over time. Thus, it is the indices for an event at the time of retrieval, and not at time of input which determine how easy it is to retrieve it. Any time a retrieval specification refers to features of events which have not been discriminated, it will be necessary to elaborate or reconstruct aspects of the retrieval specification to correspond to features that are discriminated by the conceptual category. This often leads to recognition confusions.

Ease of retrieval depends on ease of finding unique indices: retrieval failure occurs if necessary cues are not available for construction of an appropriate retrieval context. Because reconstructive retrieval processes are knowledge-based, if the knowledge necessary to construct or elaborate a context appropriately is not available at the time of reconstruction, then retrieval will fail.

11.4 E-MOPs and Discrimination Nets

As a reorganizing memory, CYRUS resembles EPAM (Feigenbaum, 1963). Like EPAM, CYRUS indexes based on features which discriminate between items. Also like EPAM, its organization and processes explain forgetting and false retrieval. The differences between the two are more important, however. EPAM built a discrimination net in the course of its learning, and thus the structures it produced had all of the problems associated with discrimination nets (Barsalou & Bower, 1984, in press). Their arcs hold negative features rather than positive ones. As a result, there is no place to store generalized information. In fact, there is none present. In discrimination nets, search is not directed by the structure of the input, but instead is set by the order in which items were initially added to memory. Questions with no bearing on a new input will be asked of it to decide where to place it in the network. Similarly, questions will be asked of a retrieval key which have no relevance to the key itself.

The structures described differ from discrimination nets in a number of ways. First, in discrimination nets, only one discrimination is made at each level, while in E-MOPs many discriminations are made at each level of the network. As a result of this there are multiple entry points to an
E-MOPs structure. In addition, there may be multiple paths to the same item. Thus, there may be many combinations of cues which will allow its retrieval. Second, search through an E-MOP is directed by the description of the current item. Only contextually related parts of the network are ever searched. In this way, network indices serve as feature detectors rather than tests (Barsalou & Bower, 1984, in press). Also unlike discrimination nets, E-MOPs and related structures store positive rather than negative information on their arcs. This allows them to be used for storing both instances and generalized information.

11.5 Extensions and Future Work

In the model described, memory reorganization happens as new events are added to memory. A possible extension to that is reorganization because of retrieval access. If a particular kind of information is requested often, for example, memory should reorganize itself to make that information more available. Recently accessed and rehearsed information is easier for people to retrieve than unrehearsed information (Bjork & Whitten, 1974; Crowder, 1976). What this suggests is that each time memory is accessed, whether for retrieval or update, it is reorganized taking recency information into account.

The theory presented has been referred to as the basis for intelligent information retrieval. CYRUS, as an expert on Cyrus Vance, is the first step in designing an expert on current events. In order to make CYRUS into a current events expert, there are a number of additions that would have to be made. First, its domains of expertise would have to be expanded. Second, it would have to be able to access multiple data bases about numerous people. Third, its organizational structures would have to be extended to handle information about countries and political entities, in addition to handling information about people. It would also need to have a better notion of time than has been implemented in CYRUS.

11.6 On Beyond CYRUS

Although CYRUS itself is no longer being developed, it has two active descendents. The generality of CYRUS's retrieval and organizational strategies are being examined in two new areas—world affairs and medical diagnosis. They both work by drawing on past experience to make predictions about a current problem. Both add new experiences to their memories, reorganizing memory appropriately and making generalizations. In working on these programs, we are investigating more sophisticated methods for organization, creation of new categories, and learning.
REFERENCES


