[redacted]

```
(TYPICALLY (*STREP-SYMPTOMS FINDING
                            AGN
                            (AND (STATUS PHARYNGITIS PRESENT)
                                 (STATUS FEVER PRESENT)
                                 (STATUS MALAISE PRESENT))))

(USUALLY (TIME-OF *STREP-SYMPTOMS
                  (AFTER (ONSET STREPTOCOCCAL-INFECTION)
                         (INTERVAL (DAYS 1.) (DAYS 5.)))))

(ALMOST-ALWAYS (*AGN-SYMPTOMS FINDING
                              AGN
                              (AND (NOT *STREP-SYMPTOMS)
                                   (STATUS WEAKNESS PRESENT)
                                   (STATUS ANOREXIA PRESENT))))

(TIME-OF *AGN-SYMPTOMS
         (AFTER (ONSET STREPTOCOCCAL-INFECTION)
                (INTERVAL (WEEKS 1.) (WEEKS 2.))))
```

FIGURE 8. FRAGMENT OF THE AGN CONTEXT

NOTE:
For convenience, GOBBLE permits
expressions to be labelled for later reference. Expressions beginning
with starred words are labelled. The starred word is discarded,
but it is remembered as standing for the rest of the expression.
Later mentions of the name are replaced by the full expression.
We have used this convention in this Figure.

and it would have the tentative hypotheses of stone, renal tumor, etc.

We have begun to integrate GOBBLE into our various projects. For example, we are planning to convert the present illness program to this system., and we are experimenting with the conversion of the formal representation of clinical knowledge to this format. Also the digitalis/digoxin advisor project is using GOBBLE in its preliminary programming. Some further examples of the use of GOBBLE will be presented in the next section when we discuss the time specialist.

<u>Building "Specialists"</u>

Any expert system needs specialists in common sense knowledge. A doctor in addition to needing medical knowledge must know rather everyday things about time , location or quantities. During the process of diagnosis the doctor must be able to understand that if a patient is 25 years old and he was told that when the patient was about 22 years old he had a heart murmur, that it occured three years ago or during 1970-1971.

The GOBBLE system also needs specialists. When asked if there is a mention of edema of the face, the system must respond positively if there is periorbital edema mentioned. This requires that the system know that periorbital edema is located around the eyes and the eyes are part of the face. Many such <u>elementary</u> deductions are required for accessing a large knowledge. The question is how best to provide such a facility.

One solution is to distribute the requirement for such deductions through the system. Another solution, which seems much more promising is to concentrate as much special knowledge about such matters as time, location, etc. in isolated <u>specialists</u>, programs which are expert in the rather shallow deductions needed. Our belief is that most of the questions about time can be answered by a <u>time specialist</u>. The same holds true for location, status, amount, etc. Undoubtedly there will be special questions, in certain contexts, which may be beyond the competence of the specialists, but we think that such questions will be rare.

With these considerations in mind, a time specialist for was developed as part of the GOBBLE framework. First a representation of time expressions was developed. Two different time representations were chosen to be as close to everyday usage as possible . One is absolute time where the time is given as a date and a <u>fuzz</u> factor to describe the uncertainty of the time of the event's occurrence. The format is:

```
(TIME-OF <event> (DATE (19NN NN NN)
                  (FUZZ <days,weeks,months,years> NN)))
```

Where event is either an event such as "(STATUS EDEMA PRESENT)" or an event preceded by either "beginning-of" or "end-of". Beginning-of and end-of are used to specify that an event occured over a period of time longer than a day. If only the beginning-of an event is specified it is assumed to be currently true as in "(BEGINNING-OF LIFE)" . The fuzz is simply the length of time from the date given, that one considers it possible that the event occured and is used in the routines that search the data base.

The other representation for the time of an event is more common in everyday speech, that is the time is given relative to some other event whose time is presumably known. Thus "25 years old" translates to "(AFTER (BEGINNING-OF LIFE) (BY-AMOUNT (YEARS 25.) (FUZZ MONTHS 6.)))". "Exactly three weeks ago" becomes "(BEFORE TODAY (BY-AMOUNT (WEEKS 3.) NIL))". To express the fact that edema occured two weeks after a strep infection one would GOBBLE:

```
(TIME-OF (STATUS EDEMA PRESENT)
         (AFTER (STATUS STREP-INFECTION PRESENT)
                (BY-AMOUNT (WEEKS 2.) (FUZZ DAYS 3.))))
```

What the Time Specialist Does

When a fact is GOBBLE'd in the relative time format the corresponding absolute time is computed and GOBBLE'd, leaving the original alone. In addition when an absolute time is GOBBLE'd the event is put on a "time line" which orders the events on a number line as either points or segments. This time line is used by a function called "SEARCH" which takes one or two dates in the form "(19NN NN NN)" and finds all events that were true during that period regardless of whether they began or ended between those dates.

The other main interrogator of the data base is the function "TIME-OF" which when applied to an event, a time specification identical to that of the time specification for general non-fact rules, i.e. interval instead of amount, and a context, returns the internal identifier of the first fact it finds that meets the time specification which in the case of non-fact contexts is found in that context and is matched in the facts context. For example,

```
(TIME-OF '(STATUS EDEMA PRESENT)
         '(AFTER STREP-INFECTION A-FEW-WEEKS)
         'FACTS)
```

would return "nil" if edema was not a few weeks after the strep infection otherwise the identity of the expression whose TIME-OF edema matched. If the context were say, edema, then the time expression would be searched for in the edema context and matched in facts. (See Figure 9.)

```
========================================================================

The following is a sample conversation with the time specialist.
Lower case letters are typed by the user and upper case by the
the computer.  Comments are preceeded by "**** ".

when he was 21 years old he had a heart attack.

IF YOU THINK THE FOLLOWING IS  RIGHT THEN RESPOND  YES
AND IT WILL BE GOBBLED INTO FACTS.
(TIME-OF HEART-ATTACK (AFTER (BEGINNING-OF LIFE)
                             (BY-AMOUNT (YEARS 21.) (FUZZ MONTHS 9.))))
                    **** This is the Gobble form translated from
                    **** the English.  After the present testing
                    **** stage this will automatically be Gobbled.

THE TIME OF HEART-ATTACK IS WHEN THE PATIENT WAS 21. YEARS
GIVE OR TAKE 9. MONTHS  OLD
                    **** This is the English paraphrasing of the
                    **** Gobble form.

yes                 **** The fact in now in the data base.

(cp 'facts)         **** This displays the "FACTS" context.

THE TIME OF HEART-ATTACK IS ABOUT JANUARY 25. , 1973.
GIVE OR TAKE 9. MONTHS
                    **** The date was calculated and Gobbled by
                    **** the time specialist.
THE TIME OF HEART-ATTACK IS WHEN THE PATIENT WAS 21. YEARS
GIVE OR TAKE 9. MONTHS
THE TIME OF THE BEGINNING OF LIFE IS EXACTLY JANUARY 25. ,
1952.

three years ago he had edema.
                    **** The system can presently accept a wide
                    **** variety of ways of expressing when
                    **** something happened.

IF YOU THINK THE FOLLOWING IS  RIGHT THEN RESPOND  YES
AND IT WILL BE GOBBLED INTO FACTS.
(TIME-OF EDEMA (BEFORE TODAY
                       (BY-AMOUNT (YEARS 3.) (FUZZ MONTHS 9.))))
THE TIME OF EDEMA IS 3. YEARS GIVE OR TAKE 9. MONTHS AGO

yes
========================================================================
```

FIGURE 9. Session With The TIME SPECIALIST

```
************************************************************************

(time-of 'heart-attack
                  '(before today (interval (years 2.)
                                           (months 4.))) 'facts)
                          **** Here the computer is asked if
                          **** the heart attack occured between
                          **** two years and four months ago.

YES, THE TIME OF HEART-ATTACK IS ABOUT JANUARY 25. , 1973.
GIVE OR TAKE 9. MONTHS

(*why)                    **** Here the system is asked why it
                          **** answered as it did.

I WAS ASKED IF THE TIME OF HEART-ATTACK WAS BETWEEN 2. YEARS
AND 4. MONTHS AGO
SO FIRST I TRIED TO FIGURE OUT WHAT YOU MEANT BY BETWEEN 2.
YEARS  AND 4. MONTHS AGO
THE EARLIEST POSSIBLE TIME TODAY COULD HAVE BEEN IS 1974. 2.
27.  AND THE LATEST POSSIBLE TIME IT COULD HAVE BEEN IS 1974.
2. 27.
I THEN FIGURED OUT THE DATES WHICH WERE BETWEEN 2. YEARS
AND  4. MONTHS BEFORE 1974. 2. 27.  AND 1974. 2. 27.
WHICH WERE 1972. 2. 27.  AND  1973. 10. 27.
THEN I CHECKED TO SEE IF THE TIME OF HEART-ATTACK FELL INTO
THE RANGE BETWEEN 1972. 2. 27.  AND  1973. 10. 27.
THE EARLIEST TIME HEART-ATTACK COULD HAVE HAPPENED IS 1972. 4.
25. AND THE LATEST IT COULD HAVE HAPPENED IS 1973. 10. 25.
SO I DECIDED THAT
THE TIME OF HEART-ATTACK PROBABLY WAS BETWEEN 2. YEARS  AND 4.
MONTHS AGO

(setq time-of-talk-sw t)    **** This tells the system to
                            **** "think outloud".

(time-of 'edema
           '(after (beginning-of life) (interval (years 20)
                                                 (years 18))) 'facts)

I WAS ASKED IF THE TIME OF EDEMA WAS WHEN THE PATIENT WAS
BETWEEN 20.  AND 18. YEARS OLD
SO FIRST I TRIED TO FIGURE OUT WHAT YOU MEANT BY
WHEN THE PATIENT WAS BETWEEN 20.  AND 18. YEARS OLD
THE EARLIEST POSSIBLE TIME THE BEGINNING OF LIFE COULD HAVE
BEEN IS 1952. 1. 25.  AND THE LATEST POSSIBLE TIME IT COULD
HAVE BEEN IS 1952. 1. 25.
I THEN FIGURED OUT THE DATES WHICH WERE BETWEEN 20. YEARS
AND  18. YEARS AFTER 1952. 1. 25.  AND 1952. 1. 25.   WHICH
WERE 1970. 1. 25.  AND  1972. 1. 25.
THEN I CHECKED TO SEE IF THE TIME OF EDEMA FELL INTO THE RANGE
BETWEEN 1970. 1. 25.  AND  1972. 1. 25.
THE EARLIEST TIME EDEMA COULD HAVE HAPPENED IS 1970. 5. 27.
AND THE LATEST IT COULD HAVE HAPPENED IS 1971. 11. 27. SO I
DECIDED THAT
THE TIME OF EDEMA PROBABLY WAS WHEN THE PATIENT WAS BETWEEN
20.  AND 18. YEARS OLD

************************************************************************
```

FIGURE 9. Continued

Note: Patient is known to have been born on
January 25, 1952, and the discussion is being held
on February 27, 1974.

Research on the Time Specialist and Other Specialists

Although the time specialist deals well with rudimentary questions about time, some additional work is needed to expand its capabilities. One of the most important problems is to incorporate into it some understanding of rates. For example, it should understand such statements as

> The onset of the disease is abrupt.
> Usually the disease develops insidiously.
> The hypertension subsides slowly after the diuresis.
> etc.

Now it is clear that in certain circumstances, even doctors would have difficulty saying exactly what these statements mean. So we are not proposing to equip the time specialist with more than human expertise. On the other hand, we can get very good agreement on what these statements do not mean. For example, if the symptoms of the disease mentioned in the first statement appear over a two week interval, then we would not call the onset abrupt. Similarly, we would not call the development of a disease within a few weeks insidious. The time specialist should be aware of these distinctions, too.

It is very important to realize that even rough definitions of these concepts will allow the time specialist to answer a great many questions. People have developed these concepts and have used them successfully because in most instances, their exact definitions do not matter. If someone tells you that an event will occur "within a few days", you may find that acceptable, never ascertaining whether two days, three days, or more is meant. The language of medicine is rich in terms which are understood, but never precisely defined. In certain instances, this lack of precise definition can be troublesome, but for the most part, a rough idea, commonly shared, of the meaning of the concept is sufficient.

We propose to pursue our research on the time specialist and other specialist with such a bias. The goal will be to equip each specialist with just enough knowledge to permit a reasonable discussion with a clinician. The program should answer the questions of the clinician directly even when they contain vague phrases of the type mentioned above. The goal is to have the specialist have trouble only when most people would have trouble in interpretting a question.

In addition to the problems associated with rates, we want to look at another important problem for the time specialist. This is the concept of episodes. In a sense, this problem belongs in the domain of representation work as well as here in the province of the time specialist. In any event, the representation and understanding of episodic disease is very important, and will require considerable research before a good solution can be developed. Basically we need a mechanism to describe the "prototypical" episode and the time intervals between occurrences of episodes. For certain instances, this is quite straightforward, but for other situations, this is quite difficult. Because we have just begun to work on this problem, we cannot discuss it further here, other than to note that it will receive careful attention in the near future.

Inquiry and Explanation

The development of markedly improved facilities for inquiry and explanation is one of the central computer science research projects of the proposed Laboratory. The importance of such facilities should be recognized, because without them, it is doubtful whether a large, knowledge-based program can be built for a complex clinical problem. The construction of such a program will require three things:

1) understanding of the processes of clinical cognition
2) mechanization of a very large amount of knowledge
3) development of new programming concepts and technology

The achievement of the first two goals will require the close collaboration of clinicians and computer scientists. The former must be able to actively work with the computer realizations of the cognitive theories, and they must also be able to explore the knowledge base of the programs in use. Hence, the clinicians will need <u>direct</u> interaction with the developing system. Further as the system grows, computer scientists as well will need such access. As the system grows in complexity, it must be able to answer questions about its knowledge and performance.

Further, if we look to the day in which such systems are introduced into the health care system, we see the additional need for such facilities. It is unreasonable to expect that clinicians will accept advice from such a system about a serious problem without any access to the knowledge or reasoning upon which the advice is based. In addition, this explanation of the reasoning of the system must be in terms which the clinician can understand.

So for our own immediate needs, and for the long run needs of the field, we will actively pursue research in both inquiry and explanation. Of the two, explanation will receive the most attention. The reason for this is that other researchers at M.I.T. are vigorously pursuing natural language research. This research has already led to significantly improved parsers. We plan to adopt one of these parsers when it has reached a satisfactory state of development. We plan to invest only enough time and resources to assure that the special needs of an interface designed for clinicians can be accomodated by the parser we select.

As an example of this policy, consider the English language facility used in the dialogue with the time specialist. The parser used there is called LINGOL (19) and it was developed by Professor Vaughn Pratt of M.I.T. We found that we could easily adapt it to our needs, and that it provides us with a reasonable interface. Certainly, there are problems which it doesn't handle, but we will leave most all of these problems to the language researchers. For the small effort involved in adapting it to our needs, LINGOL has returned considerable benefit. Other language research at M.I.T. may yield even better facilities. If so, we will be able to further improve our interface with the clinicians, and thereby improve our ability to achieve our research objectives.

The matter of explanation, however, is one to which we will put more effort. Because of its importance, and because it appears to be a problem in which we are more interested than other computer science researchers, we feel that we must take more of a lead in research. To this end, we have undertaken the development of an explanation facility to incorporated into GOBBLE.

Now the first issue to be considered is what constitutes an adequate explanation. In certain instances, simply retrieving a fact may suffice. In other cases, the explanation may require the use of a model (e.g. of physiology). In still other cases, a dialogue may be required to accomplish the task.

As a first step, we have developed a rudimentary "explainer" for GOBBLE. It gives simple explanations of relationships in a knowledge base. An example of an interaction with this explanation program is shown in Figure 10a. The program is following back through a causal chain to produce an explanation of the findings of nephrotic syndrome. Although it is not apparent from this particular interaction, this program differs from one which has a "canned" response in that it can enter this chain at any point as requested by the user. A more interesting example of this capability is shown in Figure 10b.

[redacted]

```
AT ANY TIME YOU MAY ENTER THE QUESTION MODULE BY TYPING A ?
  FOLLOWED BY A SPACE. A  RETURNS TO PROGRAM.
I HAVE FOUND 2. POSSIBLE CONTEXTS
1. NEPHROTIC SYNDROME
2. GENERAL
WHICH DO YOU WANT TO REFERENCE ?

>>> 1

EDEMA CAN OFTEN BE OBSERVED IN NEPHROTIC SYNDROME
THE BASIC CAUSE OF EDEMA IN NEPHROTIC SYNDROME IS MASSIVE PROTEINURIA
WOULD YOU LIKE TO KNOW MORE ?

>>> Y

EDEMA IS DIRECTLY CAUSED BY INCREASED INTERSTITIAL FLUID
WOULD YOU LIKE TO KNOW MORE ?

>>> Y
INCREASED INTERSTITIAL FLUID IS DIRECTLY CAUSED BY RENAL SALT AND
WATER RETENTION
WOULD YOU LIKE TO KNOW MORE ?

>>> Y

I THINK THAT THERE ARE 2. POSSIBLE CAUSES OF RENAL SALT AND WATER
  RETENTION
1. DECREASED GLOMERULAR FILTRATION RATE
2. INCREASED MINERALOCORTICOID SECRETION
WHICH WOULD YOU LIKE TO KNOW MORE ABOUT ?

>>> 2

INCREASED MINERALOCORTICOID SECRETION IS DIRECTLY CAUSED BY
DECREASED PLASMA VOLUME AND DECREASED CARDIAC OUTPUT
BY THE WAY DECREASED PLASMA VOLUME AND DECREASED CARDIAC OUTPUT
ALSO CAUSES DECREASED RENAL BLOOD FLOW
WOULD YOU LIKE TO KNOW MORE ?

>>> Y

IN NEPHROTIC SYNDROME
DECREASED PLASMA VOLUME AND DECREASED CARDIAC OUTPUT IS DIRECTLY
CAUSED BY DIFFUSION OF WATER AND SOLUTES TO INTERSTITIAL FLUID
```

FIGURE 10a. An explanation from the knowledge base

```
*********************************************************************
 WOULD YOU LIKE TO KNOW MORE ?

>>> Y

 DIFFUSION OF WATER AND SOLUTES TO INTERSTITIAL FLUID IS DIRECTLY
 CAUSED BY DECREASED ONCOTIC PRESSURE
 WOULD YOU LIKE TO KNOW MORE ?

>>> Y

 DECREASED ONCOTIC PRESSURE IS DIRECTLY CAUSED BY HYPOPROTEINEMIA
 WOULD YOU LIKE TO KNOW MORE ?

>>> Y

 HYPOPROTEINEMIA IS DIRECTLY CAUSED BY MASSIVE PROTEINURIA
 BY THE WAY MASSIVE PROTEINURIA IS ASSOCIATED WITH
 HYPERCHOLESTEROLEMIA AND LIPIDURIA
 WOULD YOU LIKE TO KNOW MORE ?

>>> Y

 I DO NOT KNOW ANY MORE
*********************************************************************
```

FIGURE 10a. Continued

```
=======================================================================

 YOU HAVE JUST ENTERED THE QUESTION MODULE. TYPE ANY QUESTION THAT
  YOU LIKE TERMINATED BY A "?" FOLLOWED BY A SPACE.
  PLEASE CONTINUE

>>> what causes decreased renal blood flow ?

  THE MOST IMMEDIATE CAUSE OF DECREASED RENAL BLOOD FLOW IS DECREASED
  PLASMA VOLUME AND DECREASED CARDIAC OUTPUT
  PLEASE CONTINUE

>>> what is the usual result of decreased oncotic pressure ?

  THE RESULT OF DECREASED ONCOTIC PRESSURE IS DIFFUSION OF WATER AND
  SOLUTES TO INTERSTITIAL FLUID
  PLEASE CONTINUE

>>> what could cause decreased renal blood flow ?

  THE MOST IMMEDIATE CAUSE OF DECREASED RENAL BLOOD FLOW IS DECREASED
  PLASMA VOLUME AND DECREASED CARDIAC OUTPUT
  PLEASE CONTINUE

>>> what could cause a decreased glomerular filtration rate ?

  THE MOST IMMEDIATE CAUSE OF DECREASED GLOMERULAR FILTRATION RATE IS
  DECREASED RENAL BLOOD FLOW OR DAMAGE TO GLOMERULI

>>> what is the possiple cause of hypoproteinemia ?

  THE MOST IMMEDIATE CAUSE OF HYPOPROTEINEMIA IS MASSIVE PROTEINURIA
=======================================================================
```

FIGURE 10b. Explanations in inquiry mode

Methods of Procedure

Introduction

Much of the work reviewed above is already underway. Some activities are more advanced than others, but all the projects discussed are receiving the attention of at least one member of our group. In most cases, most of the members of the group are involved in at least some aspect of each project. We expect that this mode of operation will be common in the Laboratory, and as a result, it is not a simple matter to give a detailed timetable for each project. The researchers in our group will naturally tend to shift their attentions somewhat to those problems which loom most prominantly at any point in time. We believe that this flexibility will prove tremendously beneficial to the Laboratory, but it, coupled with our present uncertainty about the degree of difficulty each project will manifest, makes our current projections only informed guesses.

Nonetheless, we offer here our best guesses as to the course the research of the Laboratory will take. As our work proceeds, we will undoubtedly modify these plans in the light of new problems and developments.

Present Illness Project

Because of its complexity, it is most difficult to chart the course of the present illness project. The broad outlines are clear, but the details are hard to discern at this point in time.

For the next six months or so, we will continue our detailed analysis of the problem-solving behavior of a few renal experts. The procedure we will use will include protocol analysis and close man-machine interaction involving a computer simulation of cognitive process. This approach has been quite successful so far, and we expect it will become one of the major methodological tools of the Laboratory.

The work on the simulation program for the present illness will remain focused on the presenting problem of edema during the next six months. We believe that a very detailed study of the way in which one or two experts deal with this one problem will prove extremely useful and interesting.

Within a year, we will have a simulation of this behavior which is rather complete, in that the program can take a a present illness for edema which will deal with all the major issues outlined in the above discussion (e.g., pattern-matching of signs and symptoms, finding a specific context for the problem, "backing up" in the face of failure, etc.) in at least a preliminary way.

We cannot expect that the program will take a present illness of edema which is fully comparable to that which would be taken by an expert.

The major problem, as we see things now, is not so much a matter of <u>strategy</u> (although some knotty problems are apparent), but rather the <u>amount</u> of real world knowledge which the expert uses. Thus the program might do quite well on one problem, but on a second problem, it might "fail" because it didn't know that "waitresses who stand up all day often get swollen ankles at night".

At this time (approximately July, 1975), we expect to produce a paper aimed a a medical audience which discusses the cognitive theory we have developed, and the implications of this theory with respect to such issues as the assessment of problem solving skill, medical education, etc. This paper will draw on the study of cognitive style which at this point should have produced some new and interesting results. (Of course, this may be best presented in a separate paper.) The second major paper will be focused on the use of computer science methodology in cognitive theory formulation.

At this point, we expect that our experiences of the first six to eight months will prompt us to undertake a re-design of the simulation program, and will help us structure the "knowledge acquisition" problem so that several teams can be set to work on it. During the year 1975-1976, the emphasis should be on the broadening and deepening of the knowledge base for the program. If large areas of knowledge can be dealt with by separate groups, our work should proceed much more rapidly.

Here we expect that the work on the formalization of clinical knowledge will begin to yield great benefits. By this time, a scheme for codifying knowledge should be available, and a "compiler" for knowledge expressed in this scheme will have been developed. This will greatly facilitate the expansion of the knowledge base of the simulation program.

It should also aid in the exploration of another medical area. During this year (1975-1976), we expect to begin a similar project in a different medical speciality (perhaps cardiology). We would be interested in assessing the usefulness of our theories and concepts in a different area. Although we expect that some modifications will be required, we believe the bulk of the theory will apply.

By July, 1976, we expect to have built sufficient knowledge about the present problems of edema, hematuria, etc. into the present illness program that its performance can be meaningfully compared with that of clinicians of various skill levels. Such comparisons will involve detailed studies of the protocols of the clinicians and the trace of the program on the same cases.

Undoubtedly, this study will also point out deficiencies in theory and in the program. The direction of this research beyond this point will be determined in large part by the outcome of tests such as this. At this point in time, we can say little other than that the basic effort will be directed at expanding the theory and developing the program.

As we proceed, however, we will make a concerted effort to publicize successes of the Laboratory and to find ways to make these successes available to researchers in other centers. One way in which we will do this is through publications; another way may be through the ARPA network. A third way is through conferences and research meetings. The point is that our proposed work touches on so many central issues that it will be to our advantage and to the benefit of others for us to maintain close contacts with the existing research community in computer science and medicine.

<u>Digitalis Advisor</u>

It is anticipated that the central mathematical algorithm will be implemented and packaged in simple routines for limited physician use within six months' time. Programming of criteria for speed of administration, interpretation of therapeutic and toxic effects and searches for factors influencing sensitivity should take an additional two to three months, with allowance for an additional two months to create a crude set of programs to facilitate more extensive physician interaction with the model. Thus, by April, 1975, we would hope to have a crude program available for testing by physicians both in our Laboratory and possibly in limited areas of the hospital. We would envision this initial testing phase to encompass about three months time, and then another three months for further program development before a second stage program is available for testing. At that stage, we would hope to be able to begin testing effectiveness among non-expert physicians. We would plan that this trial include some of our surgical colleagues, who deal with patients requiring this drug.

This test of effectiveness will require careful study of the decision-making of clinicians and surgeons both before and after their introduction to the program. This raises the question of how one should measure the effectiveness of clinical decision-making, and we will have to give this question careful thought. The particular problem we have chosen, however, may make this problem somewhat less troublesome, because over a sufficient number of trials, the toxic/therapeutic response of the patient can be taken as the prime indicator of effectiveness of decision-making.

Papers recounting the development of the program and the experience with it in the clinical setting will be prepared at this time. Further, steps will be taken to provide the program to other researchers for their use and evaluation.

If this project is successful, we plan to initiate another "model-based" effort such as the administration of antibiotic therapy or the like to gain more experience, and to test our ability to transfer the technology and understanding we have gained to other problems.

GOBBLE Development

By introducing GOBBLE into the various projects which are underway, we expect to learn a great deal about its limitations. Some are already known to us, because we have made a conscious decision to defer the development of certain features of the system until we have more experience with medical problems. Others will arise in the course of the research in the various projects. Thus at present, we can only give a rough time-table for the development of the system.

The basic development of GOBBLE should be complete within the next six months. That is, by December 1, 1974, we should have the first version in sufficiently de-bugged and polished state that it can be "frozen" and it can be a major tool in the program development activities of the Laboratory. The features of this first version of the system will be:

1) An improved facility for stringing <u>sub-contexts</u> together
2) Semantics for specifying retrieval searches through various contexts and subcontexts
3) Facilities for specifying "a-kind-of" relationships (e.g. pedal edema is a kind of edema) such that the subclasses <u>automatically</u> take on the properties of the main class unless otherwise indicated
4) A rudimentary capability for responding to questions about the knowledge base
5) An improved <u>dictionary</u> facility to automatically check new additions to the knowledge base for obvious errors (misspellings, etc.) and obvious contradicitons

At this time, a small manual will be written on the use of the system, and it will be formally introduced into each of the projects. For a period of three months, we will record problems and failings in the system. After this trial period, several decisions will be made.

First, we will decide whether GOBBLE is a viable and useful concept. At present, we believe that it almost certainly will prove to be one. It may prove more useful for some projects than for others, however, and at this point, we will decide which projects should continue to use the system.

From the recorded problems with the system and from our general understanding of its limitations, we will identify the most important additions to and revisions of the system which are required, and undertake a new design. Into this design, we will incorporate the results of the three projects described below, the specialists project, the explanation and inquiry project, and the interface project. This new implementation should be completed within a month or so, and then GOBBLE will be a basic part of the work of the Laboratory, with revisions being made as necessary by members of the staff.

A detailed description of the system with examples of its applications in the medical project will be issued by the Laboratory about six months after the second implementation of the system.

In addition to further work on the time specialist, the development of other specialists will be undertaken. The current choice for the next project is the location specialist. This program will manage the common sense knowledge about the parts of the body and their locations relative to one another. This specialist will know the difference between the inside and the outside of the body as well. In large, the location specialist will be like the time specialist. Instead of a time-line for organizing facts, the location specialist will maintain a model of the body, and it will organize statements about locations around this model.

We expect that a first version of the location specialist can be developed with eight months, and so by December, 1974, this specialist, and the improved time specialist should be available in the second version of GOBBLE. Although other specialists will be developed, we cannot say at this time how many there will be, or in what order they will be built.

Further developments of GOBBLE or its descendants will flow from the use of this technology in the medical projects. Their needs will determine the efforts in this area.

Significance of the Research

The impediments to the use of computer science and technology to favorably influence the quality and the quantity of health care available to the community are large and complex. These impediments will not fall to simple extensions of past work, rather new, more powerful combinations of resources and people will be required. The most immediate significance of the proposed laboratory is that it can focus the attentions of first rate medical scientists and computer scientists on one of the most important of these problems, the lack of a well-articulated theory of clinical cognition. Further the efforts of these researchers can be built on the base of the most advanced technology and methodology of its kind in existence.

The development of such a theory and the successful application of the technology which will be developed in concert with the theory will radically alter the way in which expert physicians can interact with programs, and the kind of expertise these programs can have. Further the technology which results will allow an attack on many clinical areas by other workers. Thus we see the techniques and facilities which will result from our research as being the vital first step on the road to creating distributable expertise in the form of specialist consultant programs.

In this way the physician dealing with even the most complex problems in a site remote from consultants could be assured of guidance that would allow him to enormously upgrade his performance. The expectation is not that the local physician can perform at a level equal to the best consultant but simply at a level approaching that of the expert, a level far above that generally achieved today.

Beyond the use of programs such as these, and perhaps even more significant in the long run, lies the prospect of analogous programs being prepared for the support of allied health personnel in the delivery of primary medical care. Such support is vital, because even if the current shortage of physicians can be overcome, it is unlikely that the problem of maldistribution of physicians will be resolved. Few physicians wish to practice in the rural areas (consisting of nearly 40 million people without adequate access to physicians) nor in the inner city where tens of millions more face a similar problem. For this reason it seems to be highly likely that new classes of allied health personnel must be trained to fulfill the primary care functions. Such personnel must, if they are to be accepted by the patient, be able to provide care of good quality. Current programs for use of allied health Personnel, such as the MEDEX effort, promise quantity but cannot provide quality and it is here that the computer can make its contribution.

Once the basic problems related to computer-support of the physician have been worked out, as described in the present proposal, it should be possible through utilization of this knowledge and experience to develop programs geared to the needs of the allied health professional in his triage function-making as certain as possible that he does not overlook serious disease and restraining him from taking on complex problems beyond his capability. These programs could also provide him with the assistance necessary for dealing with crises under circumstances in which a transfer of the patient is not feasible.

We realize, that most patients coming to most primary care physicians (or or new kinds of allied health personnel envisioned as delivering primary care) do not have serious diseases and that a wide range of relatively simple algorithms will be necessary to assist in the care of the patient. Nevertheless, these procedures must be organized within the context of a knowledgable system in order to insure their correct application. Our studies and those being pursued at the Massachusetts General and Beth Israel Hospitals and elsewhere should complement each other . Thus in the long term we believe that our work can assist in solving our manpower and quality problem by contributing to an understanding of the use of the computer in serious management problems by both physicians and non-physicians.

A second major benefit of this research is its potential impact on medical education. The development of clearly understood theories of expert knowledge and its application is a major goal of our effort. Although it is undoubtedly true that effective decision-making is one of the central factors in clinical practice, little, if any, attention is directed to this subject in current medical education. Most medical students are forced to infer from their observation and experience the general principles of diagnostic and therapeutic decision-making. At present there exist no well-articulated theories of medical decision-making, and it is very difficult for the average medical student to become a good problem-solver.

We believe that our work will result in extensive new knowledge of the way in which clinical experts solve problems, and further it will suggest many new ways in which students can be introduced to the processes upon which expertise is built. Rather than simply being a collection of facts about the medical problem in question, programs will provide procedures for solving the problem, and students can study and interact with these programs. Such procedures, supported by additional reference material, organized in more associative ways, will allow the student to enlarge his understanding of a given area.

A further benefit which will result from the activities of the Laboratory will be the training of computer science graduate students to work with clinicians on important research questions, and in turn the Laboratory will offer clinicians the opportunity to learn about the methodology of computer science. We believe that the Laboratory will be the basis for a whole new area of collaborative research and education, an area which can greatly benefit society.

<u>The Management of the Laboratory</u>

As Principal Investigator and Director of the Laboratory, Professor Gorry ultimately will be responsible for all activities of the Laboratory, both scientific and administrative. Because of the interdisciplinary nature of the activities of the Laboratory, Professor Gorry will draw on the advice and assistance of key senior people in both medicine and computer science. Dr. Schwartz has accepted the responsibility for overseeing the medical aspects aspects of the research, and he will be the Deputy Director of the Laboratory. His judgments concerning the medical importance and relevance of projects will be a key factor in determining the directions in which our efforts go.

Professors Fredkin and Minsky will help with the development and maintenance of close relations between the Laboratory and Project MAC and the Artificial Intelligence Laboratory.

One of the goals of the Laboratory will be to promote a real community devoted to research on computer science and clinical decision-making. The facilities and research programs of the Laboratory represent on nucleus about which such a community could be centered. Through a concerted effort to publicize these facilities and resources, we will establish relationships with individuals and groups who are already active in this area or who could be fruitfully encouraged to become active. A variety of relationships between the Laboratory and these individuals and groups will be explored. We expect that some relationships will be very close, while others will be quite loose.

We believe that it will be to the advantage of the research programs of the Laboratory to develop such contacts, and in certain cases, to grant the use of some of its resources to researchers who are technically outside it. We would like to accept certain proposals from research outside the Laboratory to use resources of the Laboratory, particularly the computer. If such a proposal were in keeping with the broad aims of the Laboratory, and if the required resources were available, it would be accepted.

As an extension of the above idea, we would consider inviting certain researchers to come to the Laboratory for a period of time ranging from a few days to a few months. These guests would be chosen for the potential of the contribution they could make to the programs of the Laboratory. Such contributions might be lectures or consultations with staff and students. These visitors would also provide a good source of criticism of our activities, either from a medical or from a computer science point of view.

Because we believe that informed criticism is very valuable, we plan to form a small visiting committee composed of three or four respected computer scientists and physicians from other institutions. They would come to the Laboratory for a day or two every six months to review and criticize our activities. We feel that careful consideration of our work by this committee will be extremely valuable.

If it is possible, we would like to hold some form of conference once each year on computer science and clinical decision-making at the Laboratory. Currently, we envision this as a working research conference attended by people who are active in the field. We also will encourage Laboratory staff to prepare papers for conferences and publication as appropriate to help transfer the ideas and technology of the Laboratory to others in the field.

Facilities

The Laboratory computer will be directly linked to 4 large time-sharing computer systems at M.I.T.: the MULTICS system which is owned by M.I.T. and operated by the Information Processing Center, and 3 compatible PDP-10 systems, 2 at Project MAC and one at the Artificial Intelligence Laboratory. Through this connection, we will have direct access to an impressive array of software including an advanced operating system and programming languages such as LISP. These languages will operate on all these systems.

All these machines are linked to the ARPA network, and thus are accessible to researchers and general users at 25 other locations. We plan to connect our machine to this network as well to facilitate use of our technology by selected researchers at other institutions.

In addition to these computers <u>per se</u>, we can draw on a large reservoir of computer talent. The Laboratory will be located in the same building with Project MAC and the Artificial Intelligence Laboratory, and many members of these two research efforts have an active interest in our work. Further, we expect to attract some very good graduate students in computer science by virtue of our close proximity to these laboratories and the inherent appeal of our research program.

Further, the Laboratory will have access to a library of computer science publications, a printing and reproduction section, an electronics shop, and a machine shop, all housed in the same building with the Laboratory.

The primary offices of the clinical members of the effort will be located at the New England Medical Center Hospital. The Hospital is a general hospital consisting of about 400 beds. This private, non-profit university hospital has 11,000 admissions per year and 140,000 out-patient visits per year. Approximately 30% of these out-patient visits are handled by the Department of Medicine. The in-patient Medical Service is divided into units of 15 beds each, each of which has a professional staff consisting of an attending physician, an assistant resident, an intern, and two medical students. One or more of these units will serve as a test environment for programs developed in the

Laboratory.

As Physician-in-Chief, Dr. Schwartz has control of the beds in the hospital. In addtion, Dr. Kassirer is the Director of the House Staff Training Program. Both these facts should greatly facilitate the interaction of the research program of the Laboratory with the clinical environment.

Principal Investigator Assurance

The undersigned agrees to accept responsibility for the scientific and technical conduct of the research project and for provision of required progress reports if a grant is awarded as the result of this application.

G. Anthony Gorry 3/22/1974

Principal Investigator

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