

NATURAL LANGUAGE INPUT TO A COMPUTER-BASED
GLAUCOMA CONSULTATION SYSTEM

Victor B. Ciesielski, Department of Computer Science,
Rutgers University, New Brunswick, N. J.

Abstract: A "Front End" for a Computer-Based Glaucoma Consultation System is described. The system views a case as a description of a particular instance of a class of concepts called "structured objects" and builds up a representation of the instance from the sentences in the case. The information required by the consultation system is then extracted and passed on to the consultation system in the appropriately coded form. A core of syntactic, semantic and contextual rules which are applicable to all structured objects is being developed together with a representation of the structured object GLAUCOMA-PATIENT. There is also a facility for adding domain dependent syntax, abbreviations and defaults.

During the past decade a number of Medical Consultation systems have been developed, for example INTERNIST [Pople, Myers and Miller 1973], CASNET/GLAUCOMA [Weiss et. al. 1978], MYCIN [Shortliffe 1976]. Currently still others are being developed. Some of these programs are reaching a stage where they are being used in hospitals and clinics. Such use brings with it the need for fast and natural communication with these programs for the reporting of the "clinical state" of the patient. This includes laboratory findings, symptoms, medications and certain history data. Ideally the reporting would be done by speech but this is currently beyond the state of the art in speech understanding. A more reasonable goal is to try to capture the physicians' written "Natural Language" for describing patients and to write programs to convert these descriptions to the appropriate coded input to the consultation systems.

The original motivation for this research came from the desire to have natural language input of cases to CASNET/GLAUCOMA a computer-based glaucoma consultation system developed at Rutgers University. A case is several paragraphs of sentences, written by a physician, which describe a patient who has glaucoma or who is suspected of having glaucoma. It was desired to have a "Natural Language Front-End" which could interpret the cases and pass the content to the consultation system. In the beginning stages it was by no means clear that it would even be possible to have a "front end" since it was expected that some sophisticated knowledge of Glaucoma would be necessary and that feedback from the consultation system would be required in understanding the input sentences. However during the course of the investigation it became clear that certain generalizations could be made from the domain of Glaucoma. The key discovery was that under some reasonable assumptions the physicians notes could be viewed as descriptions of instances of a class of concepts called structured objects and the knowledge needed to interpret the notes was mostly knowledge of the relationship between language and structured objects rather than knowledge of Glaucoma.

This observation changed the focus of the research somewhat - to the investigation of the relationship between language and structured objects with particular emphasis on the structured object GLAUCOMA-PATIENT. This change of focus has resulted in the development of a

This research was supported under Grant No. RR-643 from the National Institutes of Health to the Laboratory for Computer Science Research, Rutgers University.

system that has a core of syntax and semantics that is applicable to all structured objects and which can be extended by domain specific syntax, idioms and defaults.

Considerable work on the interpretation of hospital discharge summaries, which are very similar to case descriptions, has been done by a group at NYU [Sager 1978]. Their work has focused on the creation of formatted data bases for subsequent question answering and is syntax based. The research reported here is concerned with extracting from the case the information understandable by a consultation system and is primarily knowledge based.

1. STRUCTURED OBJECTS

A structured object is like a template [Sridharan 1978] or unit [Bobrow and Winograd 1977] or concept [Brachman 1978] in that it implicitly defines a set of instances. It is characterized by a hierarchical structure. This structure consists of other structured objects which are components (not sub-concepts!). For example the structured object PATIENT-LEFT-EYE is a component of the structured object PATIENT. Structured objects also have attributes, for example PATIENT-SEX is an attribute of PATIENT. Attributes can have numeric or non-numeric values. Each attribute has an associated "measurement concept" which defines the set of legal values, units etc.

A structured object is represented as a directed graph where nodes represent components and attributes, and arcs represent relations between the concept* and its components. The graph has a distinguished node, analogous to the root of a tree, whose label is the name of the concept. All incoming arcs to the concept enter only at this distinguished or "head" node. Figure 1 is a diagram of part of the structured object GLAUCOMA-PATIENT. There are only a limited number of relations. These are:

ATTR This denotes an attribute link.
MBY Associates an attribute with its measurement.
PART The PART relation holds between two concepts.
CONT The CONTAINS relation holds between two concepts.
ASS An ASSOCIATION link. Some relations, such as the relation between PATIENT and PATIENT-MEDICATION cannot be characterized as ATTR, PART or CONT but are more complex, as shown by the following examples:

The age of the patient	(ATTR)	(1)
The medication of the patient	(ASS)	(2)
The patient is receiving medication	(ASS)	(3)
The patient is receiving age	(?)	(4)

Although the relation between PATIENT and PATIENT-MEDICATION has some surface forms that make it look like an ATTR relation this is not really the case. A "true" structured object would not have ASS links but they must be introduced to deal with GLAUCOMA-PATIENT. The formal semantics of the ASS relation are very similar to those of the ATTR and PART relations.

* Although the class of structured objects is a subset of the class of concepts the two terms will be used interchangeably.

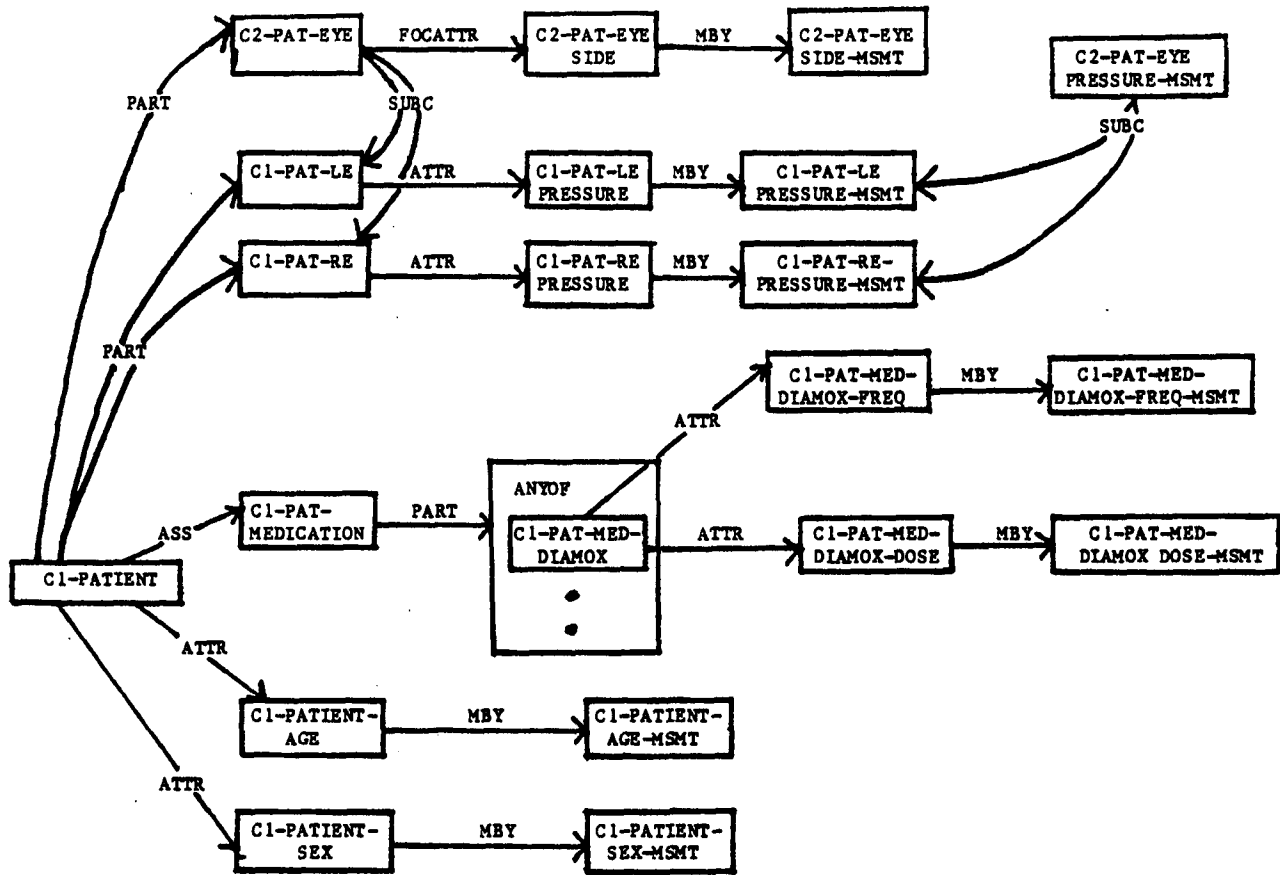


Figure 1
Part of the Structured Object GLAUCOMA-PATIENT

FOCATTR (Focussing Attribute) If there are multiple identical sub-parts then typically (but not always) the values of a particular attribute are used to distinguish between them.

SUBC One concept is a sub-concept of another.

The PART, CONT and ASS links are qualified by NUMBER and MODALITY as in [Brachman 1978]. MODALITY can have two values NECESSARY and OPTIONAL. Modality is used to represent the fact that eyes are necessary parts of patients but scotomas (blind-spots) may or may not be present in the visual field. NUMBER can be either a number (e.g. 2 EYES) or a predicate (e.g. >=0 scotomas). The target of a PART CONT or ASS relation can also be a list as in

```
C1-PATIENT-LEFT-EYE-VISUAL-FIELD
CONT (ANYOF
  C1-PATIENT-LEFT-EYE-VISUAL-FIELD-SCOTOMA,
  C1-PATIENT-LEFT-EYE-VISUAL-FIELD-ISLAND,
  .
)
```

The first member of the list is a "selection function" which describes how elements are to be selected from the list.

The numbers after the C prefix in Figure 1 denote levels of "sub-concepting". Level 1 is the lowest level, these concepts do not have any sub-concepts only instances. Note that C1-PATIENT-RIGHT-EYE is a sub-concept of C2-PATIENT-EYE, not an instance. C1-PATIENT-LEFT-EYE and C2-PATIENT-RIGHT-EYE are two different concepts, that is they have disjoint sub-structure; they are as different to the system as C-ARM and C-LEG. There is good reason for this. It is possible that a different instrument will be needed to measure the value of an attribute in the right eye than in the left eye. This means that the measurement concepts for these attributes will have to be different for the left and right eyes. Another example from the domain of glaucoma shows this more vividly. C1-PATIENT-LEFT-EYE-VISUAL-FIELD-SCOTOMA denotes a scotoma in the left eye. A particular type of scotoma is the arcuate (bow-shaped) scotoma. This must be a separate concept since it is meaningful to say "double arcuate scotoma" but not "double scotoma". This means that the concept C...-FIELD-ARCULATE-SCOTOMA has an attribute that cannot be inherited from C...-FIELD-SCOTOMA. If a measurement concept is the same for both eyes (or any other identical sub-parts) then it need only be defined once and SUBC pointers can be used to point to the definition. An example of this is the pressure measurement in figure 1.

There are many more levels of "sub-concepting" that could be represented here but it is not necessary for the interpretation of the cases. Only those mechanisms for manipulating structured objects that are necessary for the interpretation of cases are being implemented. Brachman [Brachman 1978] has examined the problems of representing concepts in considerably more detail.

1.1 MEASUREMENT CONCEPTS

Measurements are associated with those nodes of the graph that have incoming ATTR arcs. There are two kinds of measurements those with numerical values and those with non-numerical values. Numerical measurements have the following internal structure:

RANGE A pair of numbers that specify the range.
 UNITS A set of units for the measurement.
 QVALSET A set of qualitative values for the measurement.
 TIME A date or one of the values PAST, PRESENT.
 INSTR A set of possible instruments for taking the measurement.
 CF A confidence factor or measure of reliability for the measurement.

There is also some procedural knowledge associated with measurements. This relates numerical values to quantitative values, reliabilities with instruments etc. An example of a measurement concept is given in figure 2.

```

C1-PATIENT-LEFT-EYE-FLUID-PRESSURE-MSMT
  RANGE 0,120
  UNITS K-MM-HG
  QVALSET (ONEOF K-DECREASED, K-NORMAL,
           K-ELEVATED, K-SEVERELY-ELEVATED)
  TIME (ONEOF PAST, PRESENT, DATE)
  INSTR (ONEOF K-APPLANATION-TONOMETER,
         K-SCHIOTZ-TONOMETER)
  CF 0,1
  *****
  if VALUE < 5 then **ERROR**
  if 5 <= VALUE < 10 then QVAL = K-DECREASED
  if 10 <= VALUE < 21 then QVAL = K-NORMAL
  if 21 <= VALUE < 30 then QVAL = K-ELEVATED
  if 30 <= VALUE < 100 then QVAL = K-SEVERELY-ELEVATED
  if 100 <= VALUE then **ERROR**
  
```

Figure 2
The Measurement Concept for Intra-ocular Pressure

Items prefixed with a "K" in figure 2 denote constants. Constants are "terminal items" having no further definition in the representation of the structured object.

Non-numerical measurements differ from numerical measurements in that RANGE, UNIT and QVALSET are replaced by VALSET. One or more members of VALSET are to be selected in creating an instance of the measurement concept, for example:

```
C1-PATIENT-SEX-MSMT VALSET (ONEOF K-MALE K-FEMALE)
```

1.2 INSTANCES

An instance of a structured object is represented as a tree. Instances are created piece-meal as the information trickles in from the case. In some cases the

number of instances is known beforehand, for example there can only be one instance of C1-PATIENT-LEFT-EYE, while in other cases the number of instances is determined by the input, for example measurements of intra-ocular pressure at different times are different instances. Instances are created along a number of dimensions, the most common one being TIME, for example pressure today, pressure on Mar 23. When different instruments are used to take measurements this constitutes a second dimension for instances. The rules of instantiation are embedded in the core.

A partial instantiation of C1-PATIENT can be done before the first sentence is processed by tracing links marked NECESSARY. Any component or attribute instantiated at this stage will be introduced by a definite noun phrase while optional components will be introduced by indefinite noun phrases.

2. SEMANTICS

A fundamental assumption that has been made and one that is justified by examination of several sets of cases is that the sentences describe an instance of a patient with the assumption that the reader already knows the concept. None of the sentences in the notes examined had an interpretation which would require updating the concept GLAUCOMA-PATIENT. The interpretation of a case is thus considered to be the construction of the the corresponding instance of GLAUCOMA-PATIENT.

The nature of structured objects as outlined above dictates that only two fundamental kinds of assertions are expected in sentences. There will either be an assertion about the existence of an optional component as in (5) or about the value of an attribute as in (6) and (7).

There is an arcuate scotoma od.** (5)
 The pressure is 20 in the left eye. (6)
 The pressure is normal os. (7)

Very few of the sentences contain just one assertion, most contain several as in (8) and (9).

There is a nasal step and an arcuate scotoma in the left eye and a central island in the right eye (8)

The medication is 10 percent pilocarpine daily in both eyes. (9)

2.1 THE MEANING OF A SENTENCE

Even though sentences are viewed as containing assertions their meanings can be represented as sets of instances, given that there is a procedure which takes these instances and incorporates them into the growing instance of GLAUCOMA-PATIENT. This is due to the tree structure of instances since instantiation of a concept involves instantiation of all concepts between itself and the root. In fact, many sentences in the cases do not even contain a relation but merely assert the existence of an instance or of an attribute value as in (10) and (11).

Nasal step od. (10)
 a 10 year old white male. (11)

 ** Ophthalmologists frequently use the abbreviations "od" for "in the right eye", "os" for "in the left eye" and "ou" for "in both eyes"

2.2 PROVISIONAL INSTANCES

Any particular noun or adjective could refer to a number of different concepts. "Medication" for example could refer to C1-PATIENT-MEDICATION, C1-PATIENT-RIGHT-EYE-MEDICATION or C1-PATIENT-LEFT-EYE-MEDICATION. Moreover in any particular use it could be referring to one or more of its possible referents. In (12)

Medication consists of diamox
and pilocarpine drops in both eyes. (12)

"medication" refers to all of its possible referents since diamox is not given to the eye but is taken orally. In addition to this, it is generally not possible to know at the time of encountering a word whether it refers to an existing instance or to a new instance. This is due to the fact that at the time of encountering a reference to a concept all of the values of the instance dimensions might not be known. The mechanism for dealing with these problems is to assign "provisional instances" as the referents of words and phrases when they are scanned during the parse and to turn these provisional instances into "real" instances when the correct parse has been found. This involves finding the values of the instance dimensions from rest of the sentence, from knowledge of defaults or perhaps from values in previous sentences. The most common instance dimension is TIME and its value is readily obtained from the tense of the verb or from a time phrase. If the instance dimensions indicate an existing instance then the partial provisional instance from the sentence is incorporated into the existing real instance, otherwise a new instance is created.

2.3 FINDING THE MEANING OF A SENTENCE

Several mappings can be made from the representation of structured objects to syntactic classes. For example, all nodes will be referred to by nouns and noun phrases, links will be referred to by prepositions and verbs and members of a VALSET or a QVALSET will be referred to by adjectives. The links between concepts and the words that can be used to refer to them are made at system build time when the structured object is constructed. Some words such as "both" and "very" refer to procedures whose actions are the same no matter what the structured object.

The nature of structured objects and of the sentences in cases indicate that a "case" [Bruce 1975] approach to semantic analysis is a "natural". A case system has in fact been implemented with such cases as ATTRIBUTE, OBJECT, VALUE, and UNIT. One case that is particularly useful is FOCUS. It is used to record references to left eye or right eye for use in embedded or conjoined sentences such as (13).

The pressure in the left eye is 27
and there is an arcuate scotoma. (13)

For the reasons discussed in section 2.2 it is necessary to assign sets of candidate referents to some of the case values during the course of the parse. These sets are pruned as higher levels of the parse tree are built.

3. SYNTAX

It is not really possible to view the sentences comprising a case as a subset of English since many of the elementary grammatical rules are broken (e.g. frequent omission of verbs). Rather the sentences are in a medical dialect and part of the task of writing an

interpreter for cases involves an anthropological investigation of the dialect and its definition in some formal way. An analysis of a number of cases revealed the following characteristics (see also [Sangster 1978]):

- 1) Frequent omission of verbs and punctuation.
- 2) Much use of abbreviations local to the domain.
- 3) Two kinds of ellipsis are evident. In one kind the constituents left out are to be recovered from knowledge of the structured object; the other kind is the standard kind of textual ellipsis where the missing material is recovered from previous sentences.
- 4) Two different uses of adjectival and prepositional qualifiers can be distinguished. There is a referential use as in "in left eye" in (14) and also an attributive use as in "of elevated pressure" in (14)

There is a history of elevated
pressure in the left eye. (14)

An adjective can only have a referential use if it has previously been used attributively or if it refers to a focussing attribute.

- 5) Sentences containing several assertions tend to take one of two forms. In one of these the focus is on an eye and several measurements are given for that eye as in (15).

In the left eye there is a pressure
of 27, .5 cupping and an arcuate
scotoma. (15)

In the other form the focus is on an attribute and values for both eyes are given as in (16).

the pressure is 10 od and 20 os. (16)

A good deal of extra syntactic complexity is introduced by the fact that there are 2 eyes (a particular example of the general phenomenon of multiple identical sub-parts). The problem is that the qualifying phrases "in the left/right/both eyes" appear in many different places in the sentences and considerable work must be done to find the correct scope.

4. IMPLEMENTATION AND AN EXAMPLE

The system is being implemented in FUZZED a combination of the AI language FUZZY [Lefaiivre 1976], the PEDAGLOT parsing system [Fabens 1976] and RUTLISP (Rutgers UCILISP). FUZZY provides an associative network facility which is used for storing both definitions of structured objects and instances. FUZZY also provides pattern matching and pattern directed procedure invocation facilities which are very useful for implementing defaults and other inferences. PEDAGLOT is both a context free parser and a system for creating and editing grammars. PEDAGLOT "tags" correspond to Knuth synthesized attributes [Knuth 1968] and parses can be failed by testing conditions on tag values thus providing a natural way of intermixing semantics and parsing.

The implementation of the system is not yet complete but it can deal with a fairly wide range of sentences about a number of components and attributes of C1-GLAUCOMA-PATIENT. Figure 3 is some edited output from a run of the system. The interpretation of only one sentence is

shown. Space considerations prohibit the inclusion of more of the intermediate output.

```
*the patient is a 60 year old white male
*diamox 250 mg bid
  Meaning:
  (I 626 PATIENT MEDICATION DIAMOX DOSE MSMT)
                NVAL 250
                UNIT (K MG)
                TIME PRESENT
                INST PRESENT
  (I 630 PATIENT MEDICATION DIAMOX FREQUENCY MSMT)
                VAL (K BID)
                TIME PRESENT
                INST PRESENT
*epinephrine 2 percent bid od and pilocarpine 2 percent
bid os
*the pressures are 34 od and 40 os
*the cupping ratio is .5 in both eyes
*in the right eye there is 20 / 50 vision and
a central island
*in the left eye the visual acuity is finger count

***GLAUCOMA CONSULTATION PROGRAM***
  CAUSAL-ASSOCIATIONAL NETWORK
  *RESEARCH USE ONLY*

  *****
  * GLAUCOMA SUMMARY *
  *****

PERSONAL DATA:

NAME: ANONYMOUS
AGE: 60 RACE: W SEX: M
CASE NO: 50 (HYPOTHETICAL)

CLINICAL DATA SUMMARY FOR VISIT OF 3/27/79

CURRENT MEDICATIONS:
PILOCARPINE 2% BID (OS)
EPINEPHRINE 2% BID (OD)
DIAMOX/INHIBITORS 250 MG BID
BEST CORRECTED VISUAL ACUITY:
OD: 20/20 OS: FC
IOP:
OD: 34 OS: 40
VERTICAL CUP/DISC RATIO: 0.50 (OU)
VISUAL FIELDS:
CENTRAL ISLAND (OD)

*****

  Figure 3
  Some (edited) output from a run of a case
```

References

1. Bobrow D. G. and Winograd T. An Overview of KRL, a Knowledge Representation Language, Cognitive Science, Vol. 1, No. 1. Jan 1977
2. Brachman R. J. A Structural Paradigm for Representing Knowledge, Report No. 3605, Bolt Beranek and Newman, May 1978.
3. Bruce B. Case Systems for Natural Language, Artificial Intelligence, Vol. 6, No. 4, 1975.
4. Fabens W. PEDAGLOT Users Manual, Dept. of Computer Science, Rutgers University, 1976.
5. Knuth D. Semantics of Context Free Languages, Mathematical Systems Theory, Vol. 2. 1968.

6. LeFaivre R. A FUZZY Reference Manual, TR-69, Dept. of Computer Science, Rutgers University, Jun 1976.
7. Pople H., Myers J. and Miller R. DIALOG: A Model of Diagnostic Reasoning for Internal Medicine, Proc. IJCAI 4, Vol. 2, Sept 1975.
8. Sager N. Natural Language Information Formatting: The Automatic Conversion of Texts into a Structured Data-Base, In Advances in Computers, Yovits M. [Ed.], Vol. 17, 1978.
9. Sangster B. Natural Language Dialogue with Data Base Systems: Designing for the Medical Environment, Proc. 3rd Jerusalem Conference on Information Technology, North Holland, Aug 1978.
10. Shortliffe E. Computer-Based Medical Consultations: MYCIN, Elsevier, New York, 1976.
11. Sridharan N. S. AIMDS User Manual - Version 2, TR-89, Dept. of Computer Science, Rutgers University, Jun 1978.
12. Weiss S., Kulikowski C., Amarel S. and Safir A. A Model-Based Method for Computer-Aided Medical Decision-Making, Artificial Intelligence Vol. 11, No. 1-2, Aug 1978.

