Report 79-05
Stanford -- KSL

Knowledge Engineering for Dynamic Clinical Settings: Giving Advice in the Intensive Care Unit. Lawrence M. Fagan, John C. Kunz, Edward A. Feigenbaum, et al., Aug 1979

KNOWLEDGE ENGINEERING FOR DYNAMIC CLINICAL SETTINGS: GIVING ADVICE IN THE INTENSIVE CARE UNIT

Lawrence M. Fagan, John C. Kunz, Edward A. Feigenbaum
Stanford University
Stanford, California

John J. Osborn
Pacific Medical Center
San Francisco, California

ABSTRACT

This paper reports work in progress on a program to provide diagnostic and therapeutic suggestions about patients in the Intensive Care Unit (ICU). The Ventilator Manager program (VM) dynamically interprets the clinical significance of quantitative data from the ICU. This data is used to manage patients receiving ventilatory assistance. An extension of a physiological monitoring system, VM (1) provides a summary of the patient's physiological status appropriate for the clinician; (2) recognizes untoward events in the patient/machine system and provides suggestions for corrective action; (3) suggests adjustments to ventilatory therapy based on a long-term assessment of the patient status and therapeutic goals; (4) detects possible measurement errors; and, (5) maintains a set of patient-specific expectations and goals for future evaluation. The program produces interpretations of the physiological measurements over time, using a model of the therapeutic procedures in the ICU and clinical knowledge about the diagnostic implications of the data. These therapeutic guidelines are represented by a knowledge base of rules created by clinicians with extensive ICU experience.

This research is supported by the NIH under Grant GM-24669, and utilizes the computing resources of the SUMEX-AIM project, under NIH Grant RR-00785.

Keywords: knowledge based systems, knowledge representation, knowledge engineering, expert systems, dynamic clinical settings, medical applications.

34. Winograd, Terry. (1977). A Framework for Understanding Discourse. Stanford University, AIM-297.

35. Winograd, Terry. (1973). A Procedural Model of Language Understanding. In Computer Models of Thought and Language (R.C. Schank and K.M. Colby, eds.), W.H. Freeman & Co.. San Francisco.

The physician behavior modeled in most AI diagnosis systems--a single assessment of patient status and selection of the most appropriate therapy--fails to capture the dynamic changes inherent in most phases of patient care. In such dynamic situations, the clinician receives additional information from tests and observations over time and must reevaluate hypotheses about the nature of the diagnosis and redetermine the status and prognosis of the patient. The patient situation is affected by the progression of the disease process and the response to prior therapeutic interventions. Some of these aspects have been captured in current computer medicine work, particularly the digitalis therapy advisor [Gorry 78], which manipulates one major conclusion over time: the size and timing of the next dose of digitalis. The IRIS system [Trigoboff 77], deals with some aspects of representing dated information, with the resolution of the time dimension based on the interval between patient visits to the clinic.

One attempt to explore these issues is the Ventilator Manager program for providing diagnostic and therapeutic advice in the Intensive Care Unit [Fagan 78]. The input to VM is the values of 30 physiological measurements provided on a 2- or 10- minute bases by a automatic monitoring system [Kunz 74],[Osborn 69]. The output is in the form of suggestions to clinicians and periodic summaries (see example case below).

Example Case

The following case demonstrates the current state of development of the system. The data used in this example were obtained from a post-cardiac surgery patient from the ICU at Pacific Medical Center. The terms VOLUME, ASSIST, CONTROLLED MANDATORY VENTILATION (CMV), and T-PIECE refer to specific types of ventilatory assistance. The output format is:(a) ..time of day.., (b) generated comments for clinicians, starting with "**", and (c) commentary in {}.

```
 ..1350.. ..1351..
 ** SYSTEM ASSUMES PATIENT STARTING VOLUME VENTILATION.
                                        {monitoring started}
 ** HYPERVENTILATION                    {diagnostic conclusions
 ** TACHYCARDIA                          based on monitored data}
 ** PATIENT HYPERVENTILATING.           {suggested therapy based on
 ** SUGGEST REDUCING MINUTE VOLUME       diagnosis}
 ..1400..
. . .
 ..1450..
** HYPERVENTILATION
** TACHYCARDIA
** PATIENT HYPERVENTILATING.
** SUGGEST REDUCING MINUTE VOLUME
 ..1500..
** HYPERVENTILATION
** PATIENT HYPERVENTILATING.
** SUGGEST REDUCING MINUTE VOLUME


Current conclusions:               {summary information}
HYPOTENSION PRESENT for 41 MINUTES
HYPERVENTILATION PRESENT for 33 MINUTES
SYSTOLIC B.P. LOW for 46 MINUTES
{etc.}

Conclusions:       {time of day}   |.....|.....|.....|.
                                   13    14    15    16
HEMODYNAMICS -- STABLE                        ====
HYPERVENTILATION -- PRESENT            =     == == ====
HYPOTENSION -- PRESENT                   ====  ========
TACHYCARDIA -- PRESENT                 ==== ==

patient is on ASSIST                          =====   ==
patient is on CMV                        ====     ===
patient is on VOLUME                   ==
patient is on NOT-MONITORED        ====

Goal is CMV                            ================
Goal is VOLUME                     ====
                                   |.....|.....|.....|.
                                   13    14    15    16
```

The availability of new measurements requires updated interpretations based on the changing values and trends. As the patient setting changes--e.g., as a patient starts to breathe on his own during removal (weaning) from the ventilator--the same measurement values lead to different interpretations. In order to properly interpret data collected during changing therapeutic contexts, the knowledge base includes a model of the stages that a patient follows from admission to the unit through the end of the critical monitoring phase. Recognition of the appropriate patient context is an essential step in determining the meaning of most physiological measurements.

The program maintains a description of the current and optimal ventilatory therapies for any given time. The list of states and possible state transitions are represented in Figure 1.

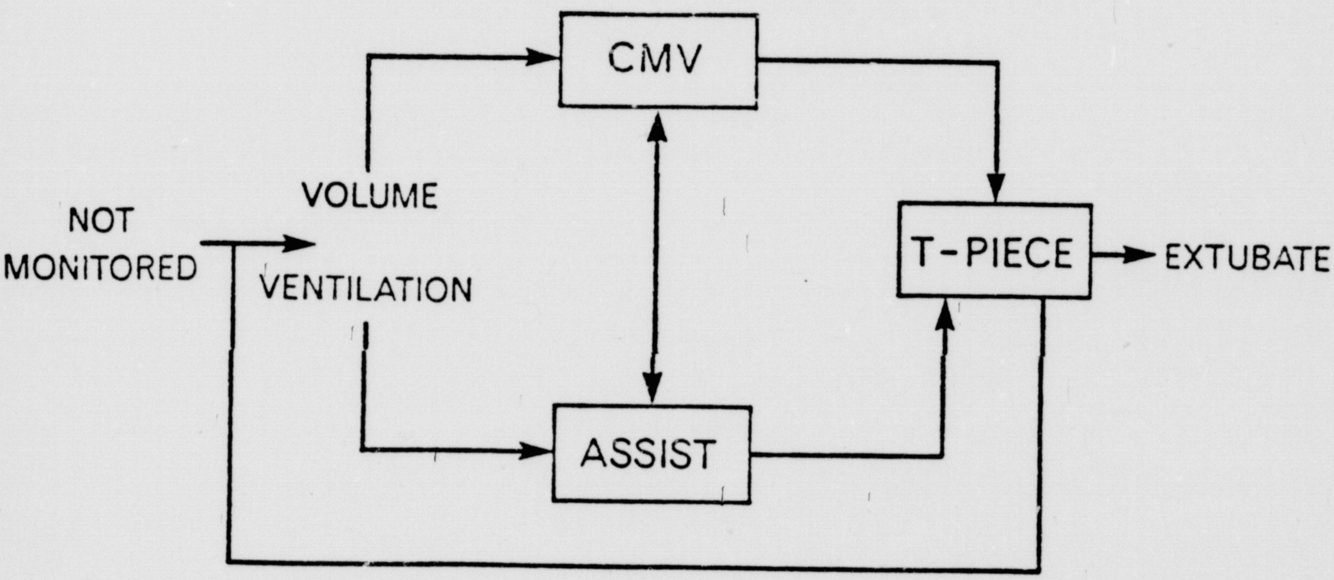

Figure 1. Representation of ventilatory therapies: The model of the typical set (and order) of therapeutic decisions made for control of mechanical ventilators. CMV stands for controlled mandatory ventilation.

The majority of the knowledge of the VM program is concerned with the relations between the various concepts known by the program. These concepts include: measurement values, typical therapeutic decisions, diagnostic labels, and physiological states. The connections between concepts are represented by a form of production rules [Davis 76], [Shortliffe 76], using the structure "IF premise THEN action."

The rules in VM are of the form:

IF facts about measurements or previous conclusions are true

THEN

1) Make a conclusion based on these facts;

2) Make appropriate suggestions to clinicians; and

3) Create new expectations about future acceptable ranges for measured variables.

Additional information associated with each rule includes the main concept of the rule and all of the therapeutic states in which it makes sense. Figure 2 shows a sample rule for determining hemodynamic stability.

```
STATUS RULE: STABLE-HEMODYNAMICS
DEFINITION: Defines stable hemodynamics for most settings
APPLIES to patients on VOLUME, CMV, ASSIST, T-PIECE
COMMENT: Look at mean arterial pressure for changes in
    blood pressure and systolic blood pressure for maximum
    pressures.
IF
  HEART RATE is ACCEPTABLE
  PULSE RATE does NOT CHANGE by 20 beats/minute in 15 minutes
  MEAN ARTERIAL PRESSURE is ACCEPTABLE
  MEAN ARTERIAL PRESSURE does NOT CHANGE by 15 torr in 15 minutes
  SYSTOLIC BLOOD PRESSURE is ACCEPTABLE
THEN
  The HEMODYNAMICS are STABLE
```

Figure 2. Sample VM Interpretation Rule. The meaning of 'ACCEPTABLE' varies with the clinical context--i.e., whether the patient is receiving VOLUME or CMV ventilation, etc. This rule makes a conclusion for internal system use. Similar rules also make suggestions to the user.

Most of the rules represent the measurement values symbolically, using the terms "acceptable" or "ideal" to characterize the appropriate ranges. The actual meaning of "acceptable" changes as the patient moves from state to state, but the statement of the relation between the physiological measurements remains constant. The use of symbolic statements (e.g., "heart rate is acceptable") allows for a simple representation of common clinical practice and the exposition of common principles of physiological interpretation in different contexts. In addition, it minimizes the number of rules needed to describe the complexity of the diagnostic situation.

The meaning of the symbolic range is determined by rules that establish the context-dependent expectations about the value of measured data. For example, when a patient is taken off the ventilator, the upper limit of acceptability for the expired pCO2 measurement (ECO2) is raised. The actual numeric calculation of "ECO2 high" in the premise of a rule will change when the context switch happens (removal from the ventilatory support), but the syntax of the rule remains the same. An example rule that creates these expectations is shown in Figure 3.

```
INITIALIZING RULE: INITIALIZE-CMV
DEFINITION: Initialize expectations for patients on CMV
APPLIES to all patients on CMV
IF ONE OF
     PATIENT TRANSITIONED FROM VOLUME TO CMV
     PATIENT TRANSITIONED FROM ASSIST TO CMV
THEN EXPECT THE FOLLOWING
                           [---- Acceptable range----]
                        very       [- ideal -]          very
                        low  low    min   max    high   high
                        ---- ----   ----  ----   ----   ----
MEAN ART. PRESSURE  + 60  + 75  + 80  + 95   + 110  + 120
HEART RATE          +     + 60  +     +      + 110  +
END TIDAL CO2       + 22  + 28  + 30  + 35   + 42   +  50
 . . .
```

Figure 3. Portion of an Initializing Rule. This rule establishes initial expectations of acceptable and ideal ranges of variables.

The VM knowledge base includes the following levels of reasoning: (1) characterizes measured data as reasonable or spurious, (2) determines therapeutic state of the patient (currently the mode of ventilation), (3) establishes expectations of future values of measured variables,(4) checks physiological status, including: cardiac rate, hemodynamics, ventilation, oxygenation, and (5) checks compliance with long-term therapeutic goals. This represents the "goal rule" of the system, and is applied every time new measurements are available to provide an interpretation of the new situation.

Each level of reasoning is associated with a collection of rules, sorted by the type of conclusions made in the action portion of the rule--e.g., all rules that determine the validity of the data. The current method of rule selection is to examine each rule at the particular level of abstraction to determine if it applies to the current context (applicable contexts are stored along with the premise and action of the rule.) Each applicable rule in a group is "executed" to determine whether the rule premises are true in the current situation, and the appropriate conclusions are recorded by the program. The history of these conclusions forms a basis for comparing how the patient status is changing over time. If a rule refers to a parameter that has not yet been defined in the current time frame, the system backchains within the current rule group to determine the appropriate conclusions. More sophisticated rule invocation schemes are being explored.

The system records the interval defined by the beginning and ending (contiguous) times when a conclusion was made. Determining the truth of the rule clause "Patient hyperventilating for 30 minutes" would require a check to see (1) that the most recent time that hyperventilation was concluded was the current time, and (2) that similar conclusions were made during every sampling period during the last half hour. This is accomplished by examining the endpoints and duration of the interval associated with a conclusion. The actual data values used for determining hyperventilation for previous time periods are not reexamined. The internal representation for conclusions across time is the analog of the graph presented at the end of the sample case.

VM currently has 60 production rules in its knowledge base. About 50 measurements and physiological states are known to the program. Currently, during a typical 24-hour patient stay, 100-200 significant conclusions are made from about 6,000 examinations of rules.

VM demonstrates the use of production rules, state diagrams, and expectations to represent knowledge about dynamic clinical settings. The ability to interpret a situation changing over time is an important goal for medical expert systems. This project has concentrated on the development of a syntax for representing time-varying situations and the extensions needed to production rules to support continual reevaluation of a rule set.

FILMED FROM BEST AVAILABLE COPY