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THE COMBAT EMERGENCY MEDICINE EXPERT SYSTEM (CEMES) PROJECT
PHASE I REPORT

by
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BIOMEDICAL APPLICATIONS RESEARCH DIVISION

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20. ABSTRACT:

The exploratory development of an expert system (designated CEMES: Combat Emergency Medicine Expert System) designed to diagnose and treat hemorrhagic shock under battlefield conditions is being conducted. This report outlines the project's rationale and documents the major design concepts underlying the exploratory development of CEMES. The project is being conducted in two phases. The first phase has been completed, consisting of the design of a basic CEMES that can diagnose hemorrhagic shock and simulate fluid infusion treatments. This report summarizes the interim progress of this project at Phase I.

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I would like to thank MAJ Glenn Mitchell and MAJ Braxton DeGarmo for their advice and assistance in determining the medical requirements and operation of CEMES. I would also like to thank COL J.D. LaMothe, LTC Bruce Leibrecht, and Dr. Mike Sanders for their guidance and assistance during the initial development efforts of CEMES. Many of the original ideas and concepts for artificial intelligence-based military medical systems, some of which lead to the initial feasibility studies underlying CEMES, were developed during conversations and "brainstorming" sessions with Mr. Ed Rash, MAJ Braxton DeGarmo, Dr. Kent Kimball, and COL J.D. LaMothe.

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Introduction

Overview

This is an interim progress report concerning the exploratory development of a combat emergency medicine expert system (CEMES). The work presented in this report documents the Phase I exploratory development of CEMES conducted from November 1985 to August 1986. The CEMES project is the core effort within the artificial intelligence research program being conducted at the U.S. Army Aeromedical Research Laboratory.[1]

The theoretical background and feasibility analysis for the CEMES project was completed in September 1985 under the In-House Laboratory Independent Research (ILIR) program and documented in Landon (1986). The feasibility study outlined the concept development underlying the CEMES project in addition to providing a general review of artificial intelligence and existing medical expert systems.

CEMES' Phase I is documented in two separate reports. This report outlines the rationale, general operation, and specific design concepts underlying the CEMES project. A second report (Landon, 1987) documents the CEMES programs and program code. The second report exists primarily for archival purposes and is not required for reference when reading this report.

Military relevance

Army 21 operational doctrine anticipates a complex, fluid, and chemical, biological, and/or radiological (CBR) contaminated battlefield expected to produce mass casualties. The expertise of physicians and other medical personnel will be needed at all battlefield levels to reduce medical complications and prevent avoidable deaths. However, the nature of the battlefield and anticipated lack of numerical superiority in both land and air forces may prevent quick and efficient casualty evacuation. Rapid and expert care will be necessary for casualty survival and potential return to duty. Lack of personnel will make it unfeasible to assign the required numbers of physicians at all battlefield levels as necessary to provide the appropriate medical care. In

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[1] DD Form 1498, Artificial Intelligence and Robotics: Biomedical Applications, Project Number 3E16277A879, Work Unit Number 167. Protocol titled "Investigation and Exploratory Development of Medical Expert Systems for Military Applications" dated 22 March 1985 and approved 19 July 1985.

addition, casualties among medical personnel would aggravate the effects of mass casualty situations.

The Medical Systems Program Review (Robertson and Glazier, 1985) outlined a new battlefield medical care strategy. This strategy included a continuum of care from the forward line to the continental United States. A casualty would "flow" through the continuum only so far as his injury(s) dictated and then he would be returned to duty as soon as possible. Combined with the continuum of care was the idea of far forward care, where first aid and trauma care would be administered as far forward in the continuum of care as possible. Technological advances in emergency medicine would enhance the implementation and effectiveness of the continuum and far forward care concepts.

Artificial intelligence has been designated as one of the Army's major research and development thrust areas,[2] with artificial intelligence-based medical systems a major subarea.[3] Although medical expert systems have been developed and used for academic research, there have been few attempts at developing this technology for military medical applications. The likelihood of successful attainment of the medical and health care mission could be enhanced through artificial intelligence systems that both diagnose and treat casualties. In addition, a properly designed and implemented medical expert system could bring to the battlefield health care capabilities currently available only from specialists in rear echelon facilities. Such systems also could serve as aids to physicians during peacetime.

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[2] The Militarily Critical Technologies List, Office of the Under Secretary of Defense, Research, and Engineering, Washington, D.C., October 1985, paragraph 1.3.3.

[3] Combat Service Support Mission Area Analysis - Level II, Vol 1: Executive Summary, January 1983, pages 14a-14b, paragraph 15. Also see the study on artificial intelligence by the National Research Council (1983).

System concept

Background

Artificial intelligence (AI) is a term, first coined in 1956 by John McCarthy, used to refer to the subarea of the cognitive sciences devoted to the attempt to program computers to perform tasks usually thought of as requiring some measure of intelligence (indicated by a human's unique ability to accomplish the same task). General research in AI has resulted in the technological capability for producing limited domain, but sophisticated, problem solving programs. These programs are known collectively as expert systems because they attempt to duplicate or emulate human expert abilities within some well-defined domain.

The specific design and implementation of any particular expert system is unique to that system. The technical aspects of general expert system design were reviewed in the CEMES feasibility study (Landon, 1986). The specific design aspects of CEMES are covered in this report.

CEMES medical domain of operation

CEMES task domain is emergency medicine diagnosis and treatment of casualties with respect to hemorrhagic shock and related cardiovascular problems prior to receiving definitive care. The importance and critical nature of hemorrhage and shock with respect to the morbidity rate of casualties was pointed out by Bellamy (1984) in an analysis of the causes of death in conventional land warfare:

> "First and foremost, there is a need to improve the field management of hemorrhage. The combination of simple first aid measures plus infusion of an oxygen-carrying solution and/or use of pharmacologic interventions designed to optimize cardiac output (antishock drugs) might be lifesaving in a surprisingly large number of casualties." (pg. 61)

The primary objectives in emergency medicine are resuscitation and stabilization pending a complete diagnosis and determination of disposition later. Initial resuscitative measures and battlefield first aid must be accomplished by the platoon medic, medic extender, or a physician. The extensive hands-on requirements for first aid measures preclude the use of an automated system (*i.e.*, although great advances have occurred in robotics, a robotic hand with the sensitivities and dexterity of the human hand has yet to be devised). However, once a casualty is attached, an automated system could provide limited aid to a physician or medic in any future resuscitative measures that might be required.

CEMES is designed to provide the casualty care management required to reduce morbidity rates due to hemorrhage and shock. Specifically, CEMES manages IV fluid infusion and periodic or continuous drug treatments based on casualty condition. The system monitors vital and other signs and establishes trends based on those measures both to guard against and warn of catastrophic or gradual deterioration in condition. CEMES also maintains a medical history record for later examination to aid in a complete diagnosis and determination of disposition at a definitive care facility.

CEMES military operational requirements

The prevalent operational environment for CEMES is dictated by military requirements. Following military doctrine (Department of the Army, FM 100-5, FM 8-10; Cook, 1984; Robertson and Glazier, 1985), several operational and environmental assumptions that have governed the design of CEMES are:

1. The system should be capable of operating within a CBR contaminated battlefield, requiring diagnosis and treatment of CBR contaminated casualties.

2. Expendable supplies (e.g., IV fluid) may be extremely limited, placing a high value on economy of supply use and efficient treatment strategies.

3. Qualified maintenance personnel may not be present, requiring the system to be self-diagnosing to compensate for damaged or inoperative subassemblies (i.e., degraded mode operation).

4. Immediate casualty evacuation will not necessarily be available, requiring long-term casualty care up to 48 hours.

Although the above four operational assumptions are not exhaustive, they cover the major aspects of design that are somewhat unique to the military. The implications of these requirements for CEMES' design were examined in the feasibility study (Landon, 1986).

It is anticipated that CEMES could be deployed as far forward as the battalion aid station. A CEMES unit could function in a multicasualty mode, where a single CEMES system monitors several casualties, or in a single casualty mode, where each casualty has a unique CEMES unit. The latter case is more likely. That is, a single casualty, battery-operated

CEMES unit could be incorporated into a stretcher or other suitable transport device and be evacuated with the casualty until definitive care is reached. Add-on modules could provide increasingly sophisticated medical capabilities as the casualty moves through the evacuation system, possibly to the point of providing the casualty with his own personalized mobile critical care unit.

Outline of CEMES operation

One of the central design concerns for CEMES is closed-loop operation. Closed-loop expert systems are defined as systems that require little or no human intervention to accomplish their objectives. For an emergency medicine expert system, this means diagnosis and treatment (or at least the suggestion of a comprehensive treatment regimen) of emergency medical conditions is accomplished primarily by the expert system. Literally interpreted, closed-loop operation requires the system operate either in the absence of, or in lieu of, an attending physician, possibly with a human assistant serving to aid the system by attaching biomedical sensor/monitoring equipment and replacing expendable supplies. However, CEMES is being designed for the more conservative and realistic purpose of serving as a sophisticated assistant. CEMES is designed to decrease physician or medic workload by having some elements of autonomy and not requiring continuous human interaction.

The closed-loop aspect of CEMES operation is implemented in a process control loop (which will be explained more completely in the section "The CEMES expert system"). To provide a preliminary overview, the major processing events in the CEMES' closed-loop cycle are:

1. CEMES first obtains whatever data is available either automatically through noninvasive biomedical sensors attached to the casualty or through querying an attending medic or physician. CEMES will query an attending medic or physician only when required due to an inability to obtain a unique diagnosis using the biomedical sensor data. This design consideration aids in workload reduction by not requiring attending personnel to continually monitor the system. However, the medic or physician, when desired, can query the system.

2. Following data collection, CEMES determines a diagnosis with respect to shock or related cardiovascular problems and develops a treatment recommendation based on the diagnosis. CEMES treatments currently are limited to IV fluid infusion and a small set of drugs that can be administered intravenously through the IV line (e.g., antishock agents or atropine). The final IV infusion rates and drug treatments are

determined later in the cycle based on trend and logistical analyses in addition to the current diagnosis.

3. Following the diagnosis, CEMES examines the casualty's vital sign history for trends. The trend analysis can have three directions (improving, deteriorating, or unchanging) and two magnitudes (catastrophic and gradual) for a total of five trend outcomes.[4] Trends are established both by examining directionality of vital signs over time and by relationships between consecutive diagnoses over time. For example, class three hemorrhagic shock obviously is worse than class one hemorrhagic shock, and so a casualty that jumps to class three shock directly from class one shock is deteriorating rapidly. CEMES recognizes these relationships and takes appropriate actions based on them.

4. The logistical analysis involves determination of IV fluid and line status, amount of fluid remaining, and anticipated need based on current infusion rate. For example, the treatment recommended by the current diagnosis may require IV fluid infusion when no IV line has been established. The logistical analysis traps this potential problem, provides the necessary messages to the medic or physician to establish an IV line, and inhibits other CEMES systems from assuming that an appropriate treatment is being administered until an IV line has in fact been established. The logistical analysis also watches for low fluid conditions in IV bags, inoperative sensors, and other logistically based conditions.

5. CEMES concludes an operation cycle by establishing a treatment (i.e., IV fluid infusion rate), updating the casualty history, and providing the appropriate signals to the biomedical hardware to effect the actions CEMES has determined are necessary. CEMES then recycles after a 1 minute real-time interval.

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[4] The unchanging trend direction has no magnitude.

Phase I development status

The major Phase I objective was to develop CEMES sufficiently to perform diagnoses and treatment suggestions for cardiovascular conditions based on blood pressure and heart rate assuming ideal conditions (i.e., no degraded modes) and no CBR contamination. That is, to provide a system that works with respect to its major design objectives.

CEMES has been developed to the extent of demonstrating the concept of closed-loop diagnosis and treatment. The system uses blood pressure, heart rate, and respiration rate that are manually entered through a menu-driven front-end. CEMES currently is able to complete full operational cycles indefinitely, so long as the vital sign data are entered when required. CEMES diagnoses hemorrhagic shock and related cardiovascular problems, displays appropriate IV infusion treatments and rates for conditions of shock, maintains a casualty medical history, and manages IV logistics. A color graphics display is used to present the state of the casualty and system as determined by CEMES.

At this interim stage, CEMES is designed to operate in a pure closed-loop fashion. That is, the operator is totally passive, entering the values of the signs at the appropriate times and thereby simulating the collection of data assumed to be available through automatic biomedical sensors. Human operator query and response are not yet available. It is fully realized that diagnosis, particularly of hemorrhagic shock, is often dependent on qualitative signs such as capillary fill, mental state, skin color, the presence of obvious serious wounds, etc., that may require an operator's interactive input. Those type of inputs will be addressed in Phase II. The primary Phase I goal was to demonstrate the core closed-loop concept of CEMES as an initial effort.

CEMES general design

Conceptual organization

The conceptual organization of CEMES is shown in Figure 1. This conceptual organization partially was developed in the feasibility study, but reflects some changes required during the exploratory development of CEMES. CEMES is organized around a blackboard (Erman and Lessor, 1975; Hayes-Roth, 1985) which is a shared data structure accessible to all of the CEMES subsystems. The core of CEMES consists of the diagnostics, trend, and management subsystems. These three subsystems comprise the main expert system responsible for governing CEMES' operation. The core expert system completes the diagnosis, constructs the IV-based treatment regimen, watches for trends, and manages the general operation of the entire system. The diagnostics, trend, and management subsystems are directly analogous to the knowledge sources used in a standard blackboard-based system, obtaining input from and recording output on the blackboard. These three subsystems and their operations as an expert system will be explained in depth in the section "The CEMES expert system."

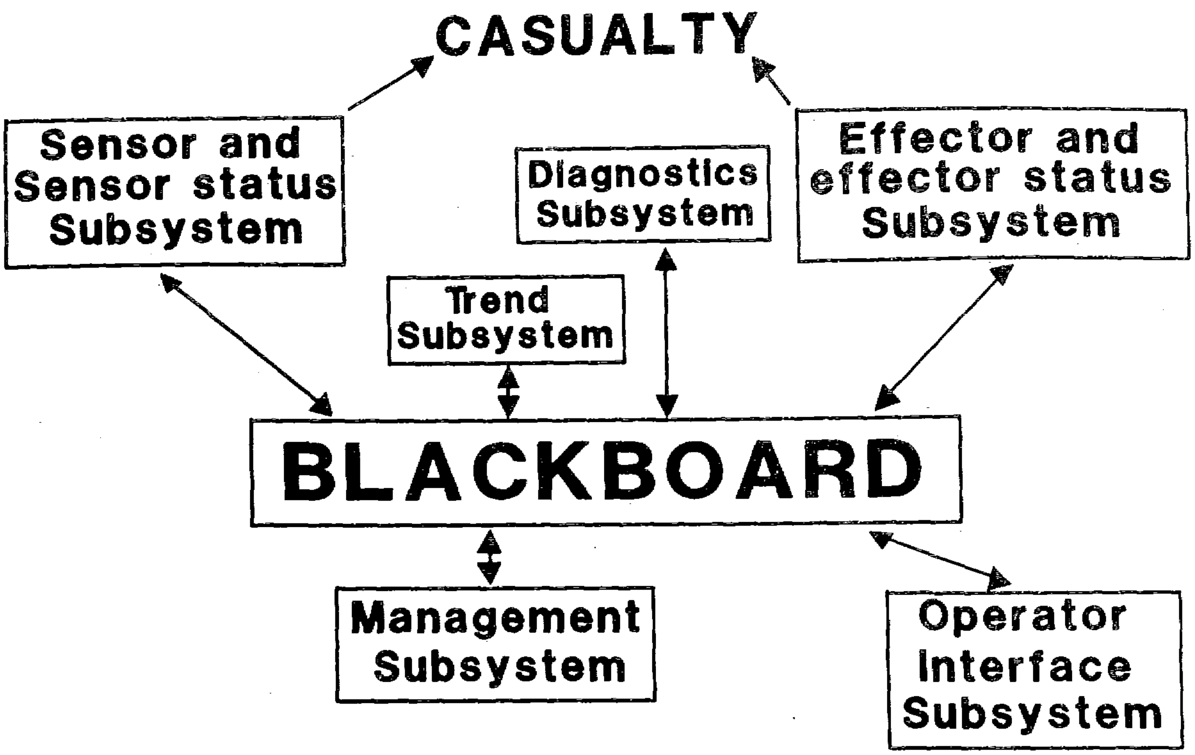

FIGURE 1. CEMES conceptual organization.

Figure 1 also diagrams two subsystems that have not been designed and programmed for Phase I, but require brief explanations. These are the sensor and effector subsystems. The sensor and sensor status subsystem includes the necessary hardware and software for sensing and translating biomedical signals along with providing information concerning the integrity of the front-end sensor ensemble. Some of this technology now is available in off-the-shelf medical equipment.[5] The available equipment usually includes the necessary algorithms for translating the raw signals into some standard or useful form along with being able to sense improper transducer attachment and simple malfunctions.

The effector and effector status subsystem consists of the appropriate hardware and software to govern electronically controlled IV fluid flow administrators. Its primary function is as a delivery mechanism for IV-based treatment regimens. This type of equipment is available and includes capabilities for sensing blockages and other malfunctions in IV fluid delivery.

Laboratory equipment

The exploratory development of CEMES is being conducted using a Hewlett-Packard (HP) 9000, Model 520, general purpose minicomputer (see Appendix A) with the HP BASIC operating system, and a Symbolics 3640 standalone LISP machine (see Appendix A) with the Symbolics LISP operating system. Figure 2 provides a diagram showing the relationship between these computers, various other CEMES equipment, and the CEMES subsystems shown in Figure 1.

The core expert system portion of CEMES is programmed in LISP on the Symbolics 3640 LISP machine. The LISP language was selected due to its close connection with artificial intelligence development and the object-oriented programming style. However, the LISP machine and the LISP language do not provide good mechanisms for real-time input/output. LISP was designed as and is best used as a very high level programming language. Since it also is a highly interactive language, real-time oriented mechanisms certainly exist in the language. However, it was felt real-time signal analysis and other front-end functions were best left to equipment and languages better designed for those functions. Therefore, the core expert

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5 This off-the-shelf equipment probably will need to be modified and hardened to meet military specifications for a fieldable CEMES system. There are other equipment requirements that are not available off-the-shelf which will be documented in the CEMES final report.

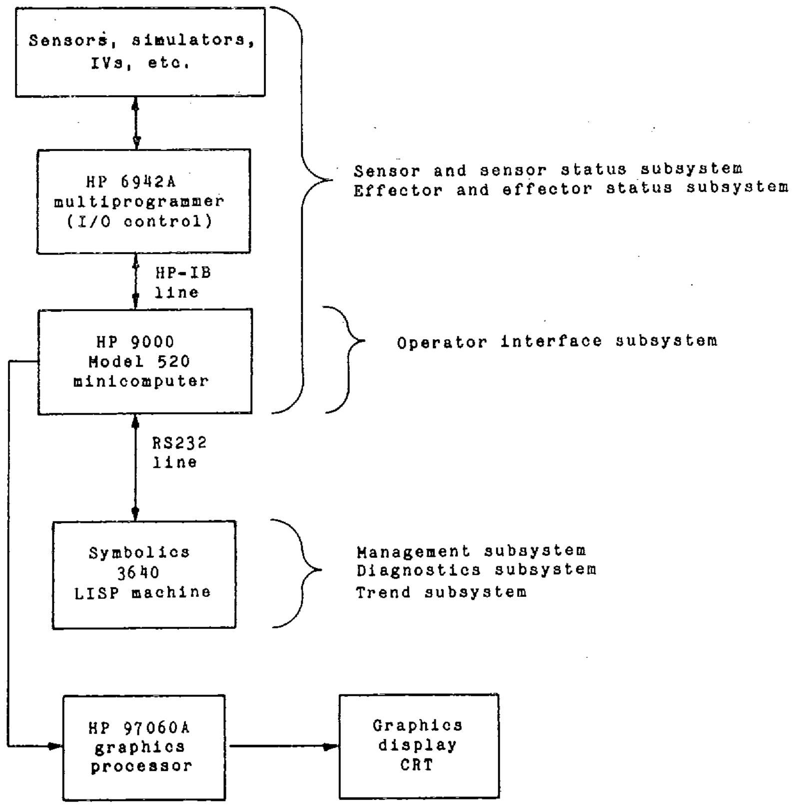

FIGURE 2. Laboratory equipment and CEMES subsystem relationships.

system uses a front-end programmed in basic on the HP 9000 minicomputer to facilitate real-time input/output operations. In addition, the HP 9000 provides the operator interface functions and the necessary communications capabilities for the CEMES' graphic display and sensor/treatment operations. The HP 6942A multiprogrammer (see Appendix A) provides the required analog-to-digital, digital-to-analog, and other hardware and software functions for interfacing off-the-shelf biomedical sensors, simulators, IV units, etc., to the CEMES computers.

Detailed design chart and design methodology

A detailed organizational master chart of CEMES is provided in Figures 3a and 3b. The charts in Figures 3a and 3b break down CEMES' organization in terms of equipment, subsystem, subsystem communications and information flow, and central aspects of the programming design of each subsystem. The actual flow charts and code for each subsystem are documented in a separate report. The charts in Figures 3a and 3b diagram relationships and design details to aid in the explanation of CEMES' design and operation in the following

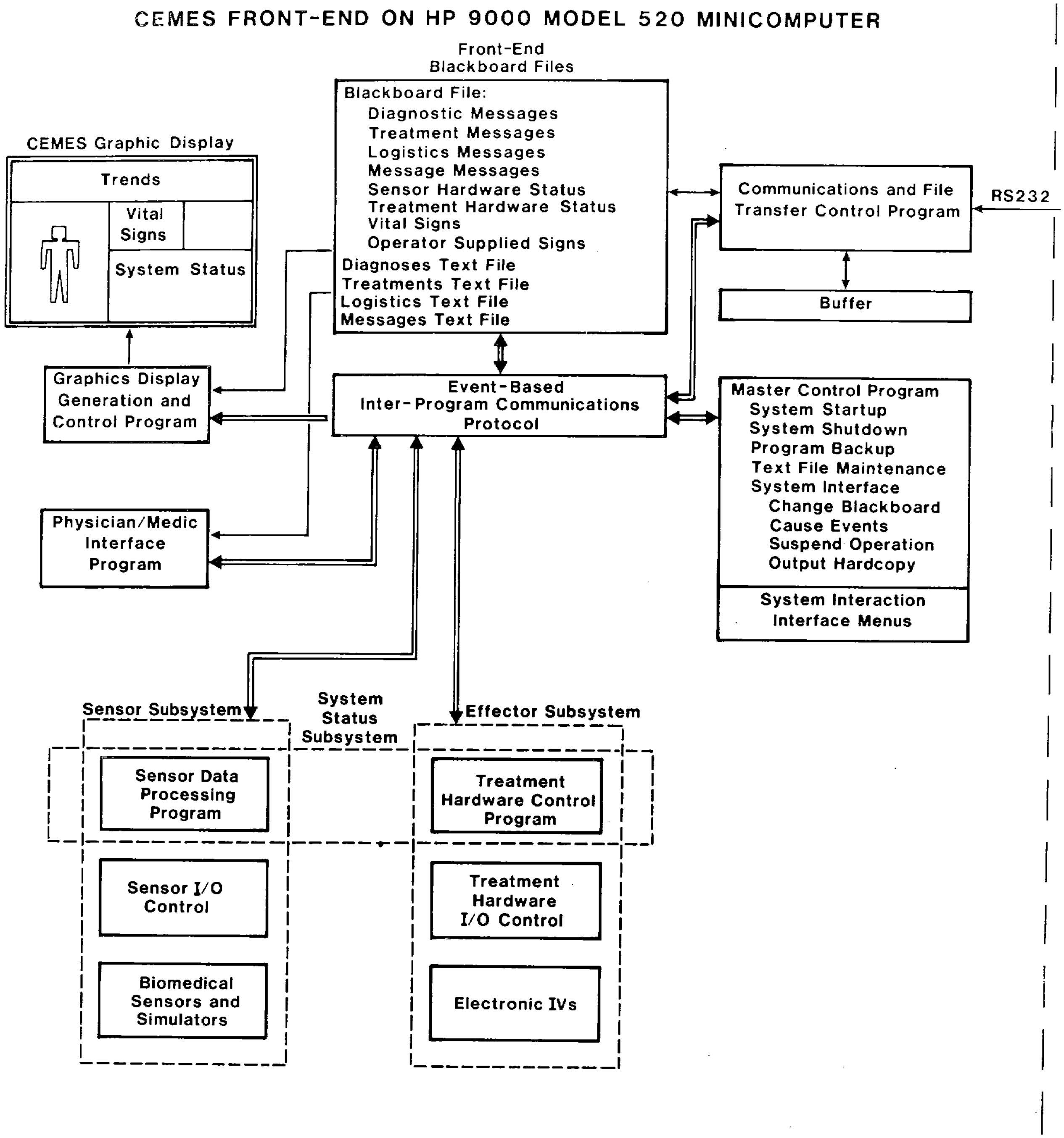

FIGURE 3a. CEMES front-end detailed organizational chart.

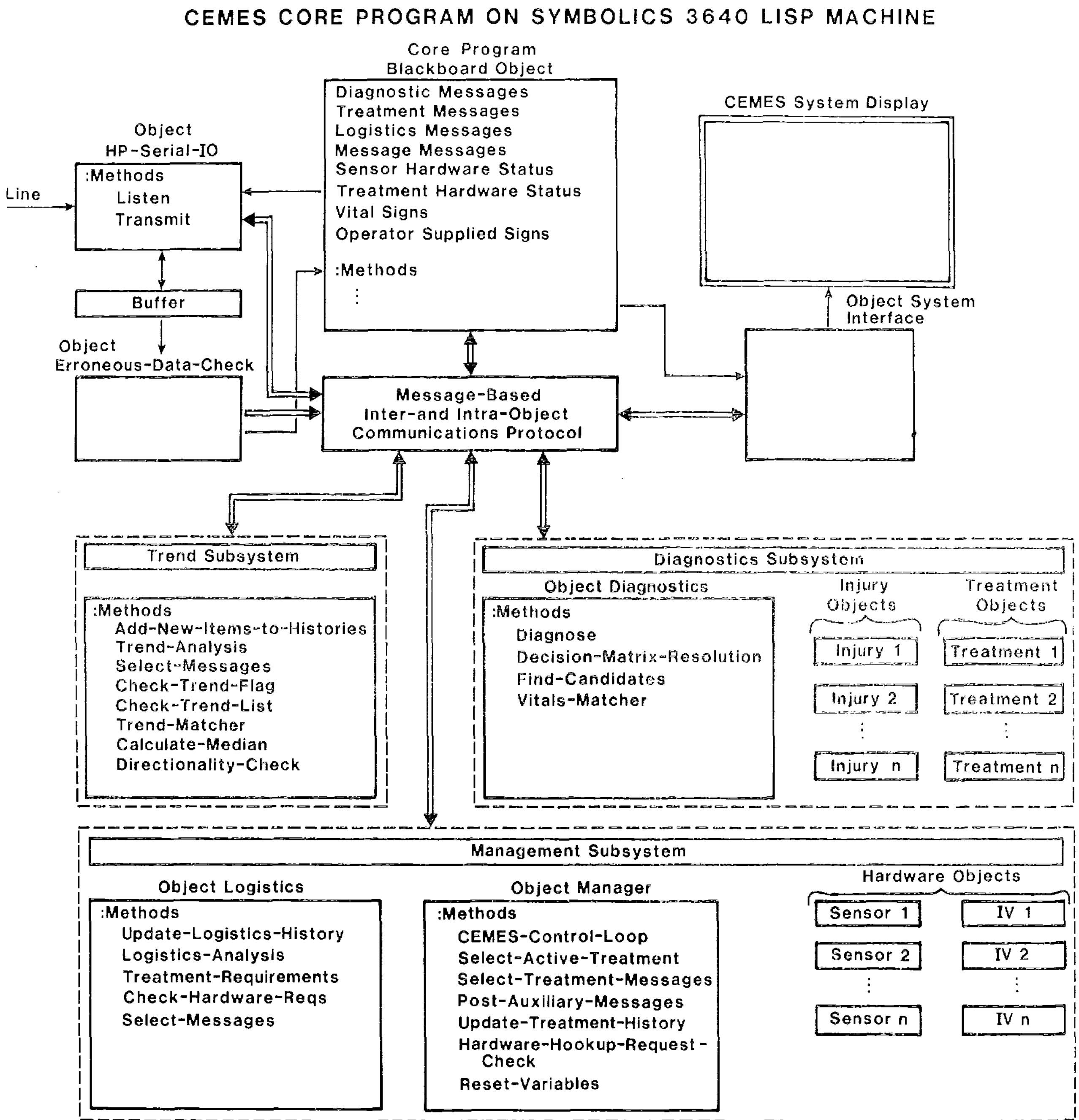

FIGURE 3b. CEMES expert system detailed organizational chart.

sections. Figures 3a and 3b also have served as master plans for integrating the various subsystems.

The double lines and arrows in Figures 3a and 3b represent communications capabilities and directions between subsystems within each computer. The single lines and arrows represent communications and data flow between the two computers and the operator. Note that the connection between the two computers is via a RS232 line, a portion of which appears in each figure. This separation is necessary because the double lines represent communications implemented differently than the communications represented by single lines. Communications represented by double lines are not accessible to the operator during normal operation of the CEMES system.

The double-lined communications also represent the style of programming used for CEMES. CEMES was developed using an object-oriented programming style. This style involves programming in terms of independent chunks, or objects, that directly correlate with the major aspects and divisions of the programming problem.[6] This division is straightforward with CEMES, each subsystem being programmed as its own object or collection of objects.

The LISP language implementation on the Symbolics 3640 provides direct object-oriented programming constructs. The communication protocol used between objects is referred to as message passing. Therefore, the subsystem objects programmed on the Symbolics 3640 use a message-based inter- and intra-object communications protocol. However, the BASIC language implementation on the HP 9000 does not provide for a direct object-oriented programming style. It is a multitasking language which was used to simulate the features of object-oriented programming. This was accomplished by coding an object as a complete program (i.e., task) and using the event semaphores provided by the HP BASIC language for message passing.[7]

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[6] An in-depth explanation of object-oriented programming, message passing, and its importance as a general programming style is outside the scope of this report. The reader is referred to Stefik and Bobrow (1986) for a discussion and additional references concerning object-oriented programming.

[7] Event semaphores generally are used to signal control or availability of shared devices in multitasking environments. For example, two programs running concurrently may need to use a single device such as a printer. Both programs cannot access the device concurrently. Semaphores are used as signals between the programs to indicate the availability of shared devices.

It is important to note there are two blackboards diagrammed in Figures 3a and 3b. The core program blackboard object appearing in the Symbolics 3640 portion of CEMES (i.e., Figure 3b, the actual expert system portion) represents the blackboard shown in the general design in Figure 1. The blackboard shown for the HP 9000 programs (Figure 3a) is a duplicate with some additional support data files. This type of design was selected to facilitate the speed and efficiency of communications between the subsystems on the two computers and avoid a potential bottleneck that might degrade real-time operation. The communications programs for each computer maintain congruency between the two blackboards by transmitting only those data required or changed. The scheduling of the communications is controlled by the expert system portion of CEMES on the Symbolics machine.

<u>The process control loop and subsystem taskings</u>

The primary operational portion of CEMES is the expert system that resides on the Symbolics 3640 LISP machine. As noted in the previous section, the CEMES expert system is composed of the diagnostics, trend, and management subsystems (Figures 1 and 3b) that act as independent knowledge sources with the blackboard serving as a shared data repository. However, CEMES does not use a strict blackboard control strategy. In a prototypical blackboard-based expert system (such as Hearsay), each knowledge source operates independently and simultaneously based on the information on the blackboard. Knowledge sources attempt to complete their tasks automatically when the appropriate information is entered on the blackboard. Their sole means of communication are through information posted on the blackboard. Knowledge sources compete for processing time with conflicts being arbitrated through a central scheduling mechanism.

CEMES, however, has a strict process control loop that activates each knowledge source (<u>i.e.</u>, subsystem) at the appropriate time when its task <u>must</u> be completed. The flow of information (<u>i.e.</u>, data) only is mediated through the blackboard. In addition, the CEMES blackboard is unidimensional in that it contains "raw" data (vital signs), intermediate results (system status data), and final results (diagnoses and display messages). There is no time or other second dimension as is the usual case for systems based on a blackboard control architecture.

The process control loop is relatively straightforward and largely based on the requirements for medical diagnosis and treatment (from Landon, 1986). The process control loop is diagrammed in Figure 4. It should be noted easily that the subsystem organization in terms of objects and collections of objects (Figure 3b) directly corresponds with the principal steps of the process control loop (Figure 4). This reflects the object-oriented programming style and maintains a direct and visible relationship between program function and code structure. Each step in the process control loop will be explained along with the tasking assignments of the various subsystems for each step in the loop.

CEMES first obtains the necessary biomedical data through the front-end sensor subsystem. At this Phase I interim stage, the collection of vital sign data is simulated through a menu-driven system interaction program that is part of the front-end master control program on the HP 9000. The data are entered manually and recorded on the front-end blackboard for transfer

Request data
Determine diagnosis
Determine trend
Logistical analysis
Treatment selection
Update medical history
Perform required actions
Recycle

FIGURE 4. CEMES expert system process control loop.

to the expert system when requested. These vital sign data currently are limited to blood pressure, heart rate, and respiration rate (*i.e.*, the key vital signs for hemorrhagic shock).

Following data collection, the first step for the expert system is to determine a diagnosis with respect to shock or any related cardiovascular problems (or to indicate if the casualty is stable, should that be the case). The diagnostics subsystem is tasked with completing this step. Although the diagnostic procedures currently are limited to using blood pressure, heart rate, and respiration rate, at later phases this step will have to be accomplished with *whatever* data the front-end can provide (*i.e.*, degraded mode functioning). The diagnostics subsystem also retains all knowledge representations of the various possible diagnoses and their treatment models. The form of these representations will be covered in a later section. However, it must be noted that treatment models are "attached" to each diagnosis, so that once a diagnosis is made, the appropriate treatment model is known.

The next step is to determine a diagnostic trend within the trend subsystem. This is accomplished both by examining relationships between successive diagnoses and analyzing the vital sign history of the casualty. The trend analysis can have three directions (improving, deteriorating, or unchanging) and two magnitudes (catastrophic or gradual) for a combined total of five trend outcomes (*i.e.*, the unchanging direction has no magnitude). The trend subsystem also maintains a medical history of vital sign data, diagnostic results, and trend results.

After determination of the trend, a logistical analysis is completed by the logistics object within the management subsystem. The logistical analysis currently involves signaling the hookup of IV infusion units when required, tracking the administration and depletion of IV fluid, and providing indications for IV bag replacement as necessary. For example, the treatment model attached to the current diagnosis may require IV fluid infusion when no IV lines have been established. The logistical analysis senses this problem, provides the necessary messages to signal the medic or physician that an IV line is required, and inhibits other subsystems from assuming that an appropriate treatment is being administered until the logistical conditions necessary for the treatment are met. The logistics object uses system hardware representations attached to the management subsystem to accomplish its task. At present, there is only one representation which is used to model IV fluid infusion units. During later phases, representations will be added for sensor units to aid in degraded mode determinations using a prediagnostic logistical analysis in the erroneous-data-check object shown on Figure 3b.

The last principal step in the process control loop is the selection of a treatment regimen by the manager object in the management subsystem. The appropriate treatment model was determined previously during the diagnosis step. The treatment selection step actually involves selection of the appropriate treatment parameters, which currently is limited to adjustment of IV fluid infusion rate. The guidelines for parameter selection are represented by the treatment models. That is, the rate of fluid administration is dependent upon the diagnosis (from diagnostics and the knowledge representation), the rate of deterioration or improvement (from the trend analysis), and whether the appropriate logistical conditions have been met (from logistics).

The process control loop is concluded by updating all medical history accounts in the various subsystems maintaining such accounts and providing the proper signals to effect the treatments or update the graphics display as required. The process control loop then recycles after a 1-minute interval.

The process control loop itself is mediated through inter- and intrasubsystem object-oriented message passing. The method (i.e., code) containing the control loop currently resides as part of the manager object in the management subsystem. This loop also serves as point of entry and exit for external control of CEMES on the Symbolics LISP machine. At this interim phase, once the loop is entered, it can only be exited through a machine-dependent interrupt. A more appropriate interface to the system (the system interface object in Figure 3b) will be included at a later phase.

Knowledge representation

The principal representational technique used in CEMES expert system is the frame. Each diagnosis, treatment, and system component model is represented using a frame-based form. Each treatment model frame is attached to a complementary diagnosis model frame, which are related via a network. The system component models are independent frames.

The general relationships between the various diagnostic outcomes are expressed in terms of a general network which represents a diagnostic decision matrix for values of blood pressure and pulse. This diagnostic matrix/network is shown in Figure 5. The nodes of the network in Figure 5 represent the nine outcomes from combining systolic blood pressure and pulse vital sign values in terms of their relations to normal. That is, whether systolic blood pressure and pulse are within the normal range, higher than normal, or lower than normal.[8] The

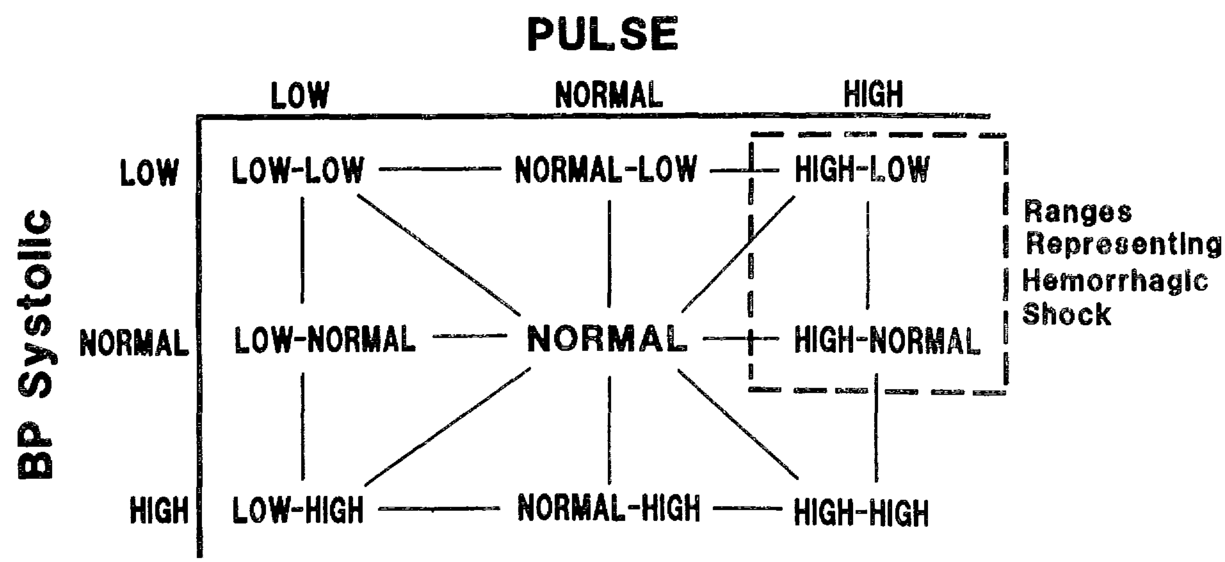

FIGURE 5. Knowledge representation decision matrix network.

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[8] Normal ranges have been defined in terms of a well-conditioned male approximately 19 years old. Blood pressure would normally be 120/80 with a systolic range of 90-160. Pulse would normally be 75 with a range of 70-100.

specific nodes of this network that define shock have been outlined. The nine nodes in this network serve as a basis for the detailed representation of the diagnostic outcomes in terms of frames. Each node in the network is in turn represented by one or more diagnostic model frames that contain the details for each diagnostic outcome.

Since the principal tasking of CEMES is the diagnosis and treatment of hemorrhagic shock, the various levels of hemorrhagic shock have been separated into a more detailed network as shown in Figure 6. Note that there are two basic types of relationships between the hemorrhagic shock and normal nodes, better/worse and much-better/much-worse. These relationships aid in determining trends as a casualty's condition changes from one shock class to another. Each class of shock has its own diagnostic model frame.

While the networks serve as a type of meta-representation, the actual technique of knowledge representation in CEMES is the frame. The form of each diagnostic model frame is shown in Figure 7. The features of each diagnostic frame include a group of slots for diagnostic analysis, a group of slots for trend analysis, a single slot that identifies the treatment model attached to that particular diagnosis, an active flag slot to indicate whether or not that diagnosis frame has been

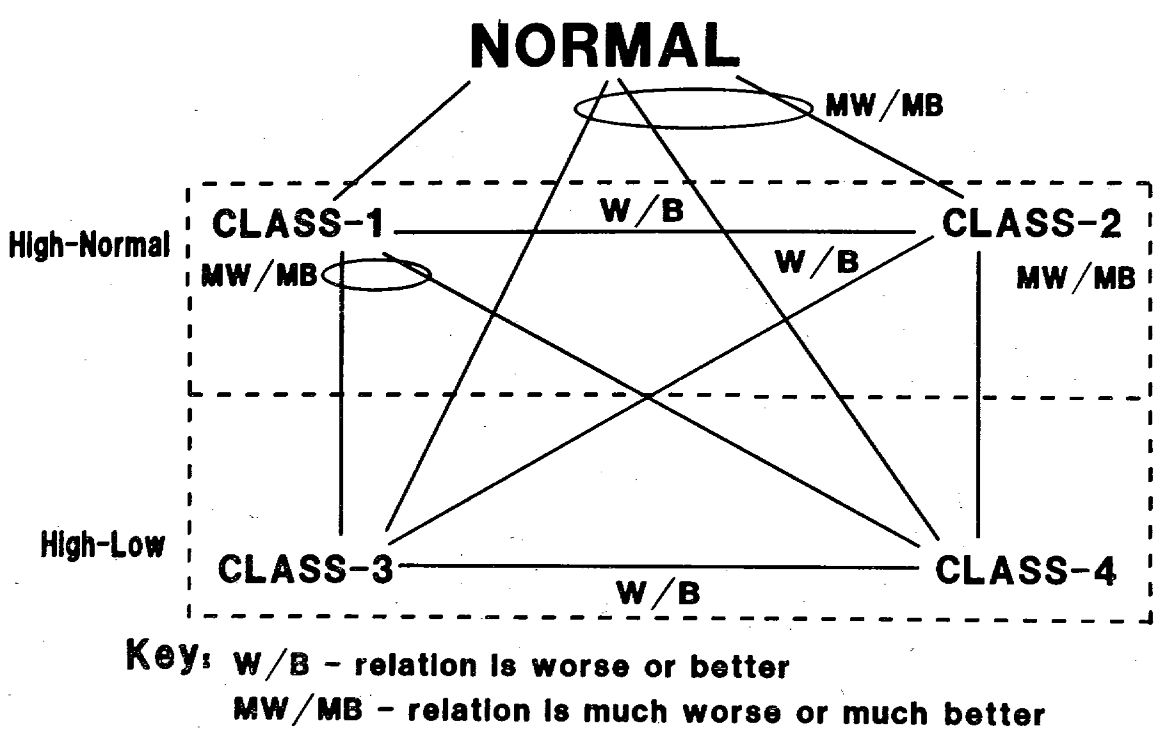

FIGURE 6. Knowledge representation network for shock.

```
Injury-name: <name-of-injury>
     Diagnostics:
          Essential-properties:  (<property,range>,...)
          Auxiliary-properties:  (<property,range>,...)
     Trends:
          Properties:
               Getting-worse:   (<property,direction>,...)
               Getting-better:  (<property,direction>,...)
          Relations:
               Worse-than:         <name-of-injury>
               Much-worse-than:    <name-of-injury>
               Better-than:        <name-of-injury>
               Much-better-than:   <name-of-injury>
          Current-direction:
               Range:   (worse,much-worse,better,much-better,
                         unchanged)
               Default:  unchanged
     Treatment-procedure:  <procedure-name>
     Is-active:
          Range:    (yes,no)
          Default:  no
     Severity-index:
          Range:  (1-10)
```

FIGURE 7. Diagnostic model frame organization.

```
Injury-name:  Class-3-hemorrhagic-shock
     Diagnostics:
          Essential-properties:  (bp-sys 80-89,pulse 121-180,
               capillary-blanch positive,mental-status
               confused-lethargic)
          Auxiliary-properties:  (resp 29-33,urine 5-19)
     Trends:
          Properties:
               Getting-worse:   (bp-sys <,pulse >)
               Getting-better:  (bp-sys >,pulse <)
          Relations:
               Worse-than:         Class-2-hemorrhagic-shock
               Much-worse-than:    Class-1-hemorrhagic-shock
               Better-than:        Class-4-hemorrhagic-shock
               Much-better-than:  None
          Current-direction:  unchanged
     Treatment-procedure:  Class-3-shock-treatment
     Is-active:  yes
     Severity-index:  8
```

FIGURE 8. Class 3 hemorrhagic shock diagnostic frame.

activated, and a severity index slot to indicate the relative severity of that diagnosis on a scale of 1 to 10. An actual diagnostic frame for class 3 hemorrhagic shock is provided in Figure 8 to show the types of information that are entered into the various frame slots.

The diagnostics slots provide information related to the activation of the frame as the current diagnosis. The various vital signs and other properties and the appropriate ranges necessary for the frame's activation are listed. In the case of a vital sign where numerical values are available, a numerical range is given. In other cases, a qualitative word or phrase appropriate to the sign is provided. The inference procedure then uses this information when determining if the frame should be activated.

The trends slots provide both property lists for trend directions and pointers that represent the network relations shown in Figures 5 and 6. The trend properties provide directional indicators for various vital sign data with respect to a general improving or deteriorating trend. The trend inference procedures use this information to determine trend direction and magnitude. The trend relations slots provide names of other diagnostic frames as appropriate for their relationship according to the networks.

The treatment procedure slot contains the name of the appropriate treatment model frame for the diagnosis. The treatment models also are represented by frames in the general form shown in Figure 9. All treatment procedures currently simulated by CEMES are based on IV fluid administration. Therefore, all current treatment frames are of the type "IV-based" and have the particular frame organization as shown in Figure 9. The treatment model frame includes a group of slots representing the particular properties of the IV treatment, a trend adjustments group of slots, and an active flag slot to indicate whether or not the treatment frame currently is activated. An example treatment frame for class 3 hemorrhagic shock is shown in Figure 10.

The properties slots in the treatment frame contain general information of relevance to IV-based treatments. The number of IV units required is stated explicitly. The IV-rate-range provides practical lower and upper bounds in cc/hr for the administration of fluid for the particular diagnosis. Absolute lower and upper bounds currently are limited by equipment considerations (0 and 6000, respectively). IV-additives currently are not implemented at this interim phase, but will include lists of drugs and dosages appropriate for the treatment. IV-blood is a simple indicator of whether or not a transfusion is required. CEMES currently does not manage blood

```
Treatment-name:  <name-of-treatment>
     Type:  IV-based
     Properties:
          IV-units-required:
               Range:    (0,1,2)
               Default:  1
          IV-rate-range:  <min,max>
               Range:     (100-6000)
          IV-additives:  (<additive,dosage>,...)
          IV-blood:
               Range:  (indicated,not-indicated)
     Trend-adjustments:
          Unchanged:    <direction,amount>
          Worse:        <direction,amount>
          Much-worse:   <direction,amount>
          Better:       <direction,amount>
          Much-better:  <direction,amount>
     Is-active:
          Range:    (yes,no)
          Default:  no
```

FIGURE 9. Hemorrhagic shock treatment procedure frame organization.

```
Treatment-name:  Class-3-shock-treatment
     Type:  IV-based
     Properties:
          IV-units-required:  2
          IV-rate-range:      (3000,6000)
          IV-additives:       <not yet determined>
          IV-blood:           indicated
     Trend-adjustments:
          Unchanged:    (+ 1000)
          Worse:        (+ 1000)
          Much-worse:   (+ 1500)
          Better:       (- 1000)
          Much-better:  (- 1000)
     Is-active:  yes
```

FIGURE 10. Class 3 hemorrhagic shock treatment frame.

transfusion. The IV-blood indicator is based on the average amount of volume loss necessary to produce the various classes of hemorrhagic shock.

The treatment frame's trend-adjustments slots provide modifiers for IV rates based on the trend direction and magnitude. The management of fluid administration not only depends on the diagnosis, but also on trends. These modifiers aid in the adjustment of the actual cycle by cycle fluid flow rates. A "+" sign indicates fluid flow should be increased by the stated amount, while a "-" sign indicates a decrease.

The various hardware system components in CEMES also are represented by frames. Unlike the frames for diagnoses, the hardware frames generally are independent and not related through networks or other means. Presently, only automated IV fluid administration units are represented in CEMES.[9] These units have the frame organization shown in Figure 11. The Is-attached slot is an indicator for attachment to the casualty. The Is-functioning slot has been included for degraded mode operation. It will change depending upon whether the IV unit is functioning properly, not functioning (e.g., not attached or out of fluid), or if there is a problem (e.g., actual fluid

```
Type:  IV-fluid-unit
     Is-attached:
          Range:    (yes,no)
          Default:  no
     Is-functioning:
          Range:    (yes,no,problem)
          Default:  no
     Location:
          Range:    (arm,neck,leg,other)
     Relative-start-time:
          Range:    (0-1440)
     Absolute-start-time:
          Range:    (0-1440)
     Renewals:
          Range:    (0-50)
     Fluid-remaining:
          Range:    (0-1000)
     Administration-rate:
          Range:    (0-3000)
     Additives:
```

FIGURE 11. IV treatment unit frame organization.

---

9 An IV administration unit is assumed to consist of an IV bag containing appropriate solution (usually Ringer's lactate), tubing and needle for fluid delivery, and an automated pump that generates fluid flow at the rate determined by CEMES.

flow does not match signalled fluid flow, indicating a possible blockage). The absolute start time slot provides the cycle number when the IV unit successfully was attached to the casualty, while the relative start time slot indicates the cycle when the current IV bag was started on this IV unit. Renewals indicate the number of IV bags that have been delivered on the IV unit exclusive of the current bag. Fluid-remaining and administration-rate are self-explanatory and are given in cc and cc/hr measurements.

Inference procedures

The inference procedures used by the CEMES' expert system are different in both technique and use from the process control loop. Whereas the process control loop governs the order of task completions in CEMES, the inference procedures govern the matching of the vital sign data to the diagnostic frames in order to determine an appropriate diagnosis at each cycle.

The basic inference model used in CEMES is a simple forward chaining using a matching procedure for the various diagnostics properties in the diagnostic model frames. The procedure first attempts to match the blood pressure and pulse vital signs against the constraints specified in the meta-representation network shown in Figure 5. Since all nodes in this network can be uniquely identified, a successful match at this step often will identify a particular diagnostic frame for activation. However, in some cases, particularly those nodes identifying hemorrhagic shock, there are multiple diagnostic frames, only one of which can be activated. Any frames that cannot be viable candidates after this step are eliminated from further consideration. Those that remain are entered on a temporary candidate list for further analysis.

When the general network analysis is insufficient for a unique frame identification, the inference procedure attempts to match all available data against the diagnostic constraints in the essential properties list of each diagnostic frame. If two or more frames still can be activated after this matching, the auxiliary property lists are checked. If a unique frame still cannot be identified, the severity indices are checked and the most severe diagnostic frame then is activated.

The inference procedure of selecting a unique frame does not exhaustively examine each frame's properties in turn (*i.e.*, a depth search). The various vital signs (and other symptoms to be considered at later stages) have been ordered in terms of their medical importance with respect to hemorrhage and shock.[10] The current value of the most important vital sign is first checked across the diagnostic constraints for the remaining frames in the candidate list (*i.e.*, a breadth search). Those frames that fail the match are eliminated from further consideration. The next most important sign then is checked across the remaining frames, etc., until a single frame remains, which then is activated. If multiple frames remain after all signs and symptoms have been checked, then the frame with the highest severity index is activated. If the severity indices match, a frame is selected at random.

The check and eliminate scheme of inference is shown in flow-chart form in Figure 12.[11] This particular form of inference was selected due to its anticipated capability for completing a diagnosis during degraded mode operation. That is, any prototypical forward chaining inference procedure would collapse as less and less information was available in the database (*i.e.*, matches would be impossible to obtain or the knowledge base would have to be expanded to include frames accounting for all possible available combinations of the various signs and symptoms). The elimination technique has both an advantage of speed and a robustness when various vital sign data are unavailable. That is, the matching procedure for unavailable data results in no eliminations from the current candidate list. If the most important vital sign data are available, elimination down to a single candidate will be fairly quick and avoid all sorts of confirmatory procedures and mechanisms.

In addition to diagnostic inference, CEMES also incorporates trend inference mechanisms to determine the current diagnostic trend. Recall there are three directions (improving, deteriorating, and unchanging) and two magnitudes (catastrophic and gradual) for a trend outcome. The conditions

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10 The current ordering is blood pressure, pulse, and respiration rate. Additional signs and symptoms will be entered in the list as required in later stages. Note this ordering is established only for diagnosis. Some signs (*e.g.*, urine output) are not essential for diagnosis, but do have significant meaning for treatments or other aspects of CEMES operation.

11 This elimination scheme was described by Tversky (1972) in a study of human choice processes. He referred to it as the "elimination by aspects" choice process. A complete theoretical treatment of various choice and selection processes can be found in Landon (1983).

for trend direction are provided by the activated diagnostic frame in terms of properties and relations.

The trend inference generally is straightforward. The previous cycle's diagnosis (kept by the trend object) is checked to see if it is the same as the current active diagnosis. If it is, then the vital signs are checked by the elimination method described above against the trend property lists to determine direction. It is generally the case that each vital sign has opposite indications for an improving or deteriorating direction, and so the general direction can be determined quickly. However, medical requirements sometimes dictate that more than one sign (usually at least systolic blood pressure and pulse) satisfy the trend constraints before a direction is confirmed. In such cases, the elimination inference procedure continues until the required number of constraints are failed by either the improving or deteriorating direction. If both the improving and deteriorating directions fail, then the trend direction defaults to unchanging.

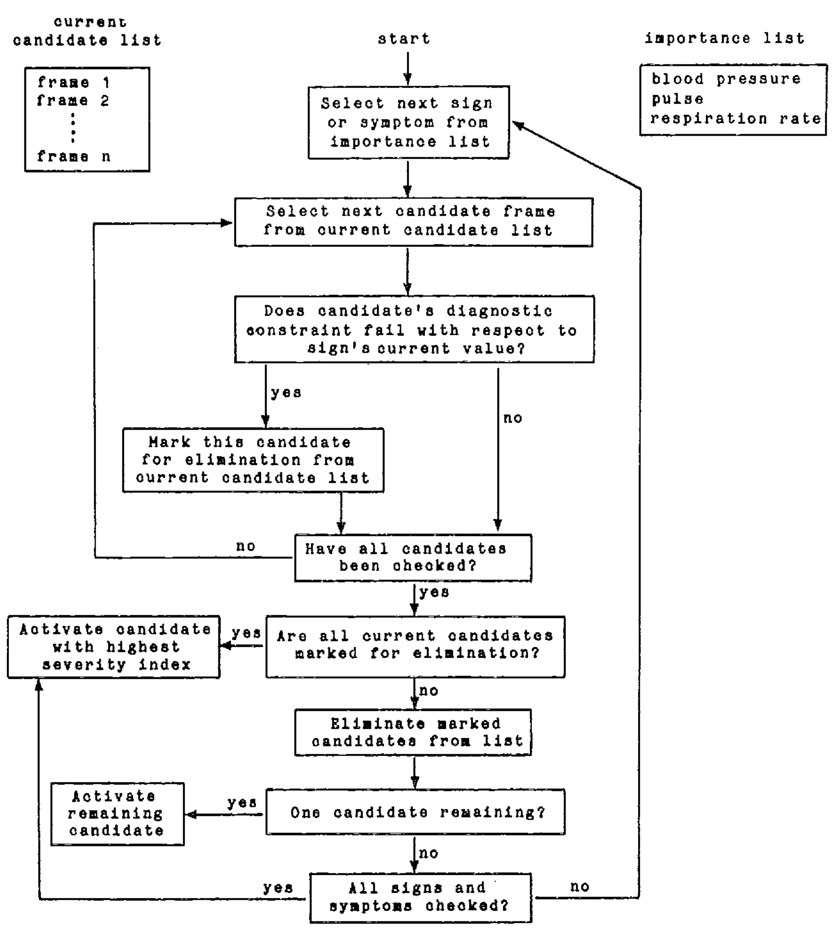

FIGURE 12. Check and eliminate inference procedure.

Trend magnitude is determined through straightforward algorithmic techniques accomplished concurrently with directionality checking. Catastrophic magnitude is indicated if the current vital sign value deviates from the previous vital sign value or the median of the previous five values by 10 or more. Gradual magnitude is indicated by a strict increasing or decreasing ordering of the vital sign values over the last five cycles if such an ordering does not meet the catastrophic magnitude constraints. If the direction indicated is unchanged, then magnitude is irrelevant. Conversely, if neither catastrophic nor gradual magnitude is found (as indicated by failure to meet the algorithmic requirements), then the direction is unchanged.

In the cases where the previous (i.e., last cycle's) activated diagnostic frame is not the same as the current active frame, the previous diagnostic frame is checked against the network relations of the current active diagnosis. If a match is found, then the trend is established by which category of match was obtained (i.e., worse-than indicates a gradual deterioration, much-worse-than indicates a catastrophic deterioration, etc. See Figure 7). If a match is not found, then the trend defaults to unchanged. That is, if the current active diagnostic frame has no relation with the previous active diagnostic frame, then there is no trend. A trend cannot be established in a single cycle.

The final type of inference made by CEMES is the selection of a treatment. Currently, this consists of selection of an appropriate IV fluid infusion rate if an IV is indicated by the active treatment model frame. The selection of an infusion rate has three principle steps. First, the active treatment model frame is checked to see if an IV is required. If so, the IV infusion frames are checked to see if the required units are attached and functioning (which was determined by the logistics analysis). If they are not attached, a message is printed on the graphics display informing the medic or physician the casualty requires an IV line be established for treatment. Attached but malfunctioning units will be handled by the logistics analysis when degraded mode operation is included in CEMES. Next, assuming attached and functioning IV infusion units, the IV-rate-range slot of the active treatment frame is examined. If the current administration rate is less than the minimum specified by the range, the rate is increased to the minimum, otherwise the rate is not changed. Last, the trend outcome is examined and the appropriate adjustment to the rate is made. If the adjustment causes the rate to go outside of the rate bounds, the rate is changed to the minimum or maximum as required.

The CEMES front-end

<u>The process control loop and subsystem tasking</u>

The front-end portion of the CEMES system resides on the HP 9000 minicomputer. The front-end is responsible for controlling or simulating all data input/output for the expert system portion on the Symbolics LISP machine. As noted in the previous section "CEMES general design," the front-end primarily is composed of the sensor and effector subsystems. However, these subsystems have not been completed at this interim stage. Instead, their functions are simulated within the Master Control Program shown on Figure 3a. Presently, those portions of the front-end that are operational include the Master Control Program, the Graphics Display Generation and Control Program, and the Communications and File Transfer Control Program. As in the expert system portion of CEMES, the front-end is governed by a process control loop that coordinates the various programs that comprise the front end.

Despite the use of a process control loop, the front-end systems are nearly totally independent of each other and are much truer to a pure blackboard type of expert system architecture. The only form of interprogram communications is signals indicating when the various types of information on the blackboard have changed. This provides a more orderly approach to blackboard file access by each program. The reason for this is to maintain control over access to a single device (<u>i.e.</u>, the blackboard file) by multiple programs running concurrently in a multitasking environment.

The CEMES front-end process control loop, diagrammed in Figure 13, is implemented within the Communications and File Transfer Program on the HP 9000. This program cycles in response to signals received from the CEMES expert system. The signals function as either data requests or information updates. Data request signals identify data the expert system wants transmitted this cycle. For example, vital signs are requested every cycle. Information updates can contain graphics display updates and/or effector control information. Data request signals <u>always</u> precede information updates (<u>i.e.</u>, the expert system requests new data, processes it, and returns its solutions to the front-end for implementation).

Upon receiving a data request signal from the expert system, the Communications and File Transfer Control program obtains the requested data from the blackboard through a simple file access. Note that in an operational CEMES unit, the sensor and effector subsystems continuously will be updating the front-end blackboard. At present, blackboard data updates are being simulated through a menu-driven manual data entry

Wait for data request from expert system

↓

Obtain vital sign or other requested data from biomedical sensors, effectors, etc.

↓

Transmit new data to expert system

↓

Wait for display updates and other control information to be sent by expert system

↓

Update graphic display

↓

Generate appropriate control signals for treatment effectors

↓

Recycle

FIGURE 13. CEMES front-end process control loop.

system that is part of the Master Control Program. The operation of the menu-driven system will be explained in the subsection "The master control program."

The Communications and File Transfer Control Program then sends the requested data to the expert system through the HP-serial-io object, which controls communications for the expert system. The communications and data transfer between the front-end and the expert system consists of a simple ASCII file transfer using a RS232 line between the HP 9000 and Symbolics 3640. At present, no special communications protocols (e.g., Kermit, Xmodem) or networking (e.g., Ethernet) other than X-on and X-off are used to accomplish file transfers. In addition, the communication is synchronous with the HP-serial-io object on the Symbolics 3640 acting as the controller. Asynchronous communications capabilities and the required processing interrupt mechanisms will be included for Phase II to implement operator interaction.

After sending the requested data, the Communications and File Transfer Control Program enters a wait state until updated information is received from the expert system. The updated information consists of changes to the graphics display and other control signals describing the treatment regimen during the next cycle. When the updated information is received, the Communications and File Transfer Control Program enters the new information on the blackboard and sends the appropriate messages informing the other front-end programs that certain information on the blackboard has changed. Currently, the front-end simply updates the graphics display as all effector actions are being simulated on the display. At later stages, the effector subsystem will generate the necessary control signals to change IV fluid infusion rates or drug administration rates as necessary.

After processing the updated information, the Communications and File Transfer Program enters another waiting state until the expert system restarts the process control loop through a request for data. Of course, when implemented, the sensor and effector subsystems will continue to sample vital signs and effect treatments while "waiting" for the next cycle. Although not currently planned, at advanced stages of CEMES' development, a mechanism may be included in the front-end so it can interrupt the expert system when a particularly serious condition occurs (such as ventricular fibrillation).

The graphic display

The graphic display is generated and controlled by the Graphics Display Generation and Control Program. The graphic display provides a means for visually displaying the status of CEMES and its various operations from cycle to cycle. The task of the Graphics Display Generation and Control Program is to maintain congruency between the information in the blackboard and the information on the graphic display. An example of the graphic display is provided in Figure 14. It should be noted a display of this complexity may or may not be included in a field operational CEMES system. This particular graphic display design was implemented to provide all the necessary information to aid in CEMES' design and testing. There are five major areas of the display, each set off from the other and suitably labeled.

The vital signs display area contains the most recent vital sign data (i.e., it may not be the current vital signs data, which is defined as the data last sent to the expert system). Recall that the sensor subsystem will obtain vital signs continuously and independently. Therefore, there will always be some lag between the most recent data and the current data. However, since the normal cycle time is quite short in relation to meaningful physiological changes, the effect on accurate diagnosis will be nonexistent or very minimal. Note that provisions have been made on the display for some vital signs that aren't yet being used by the expert system.

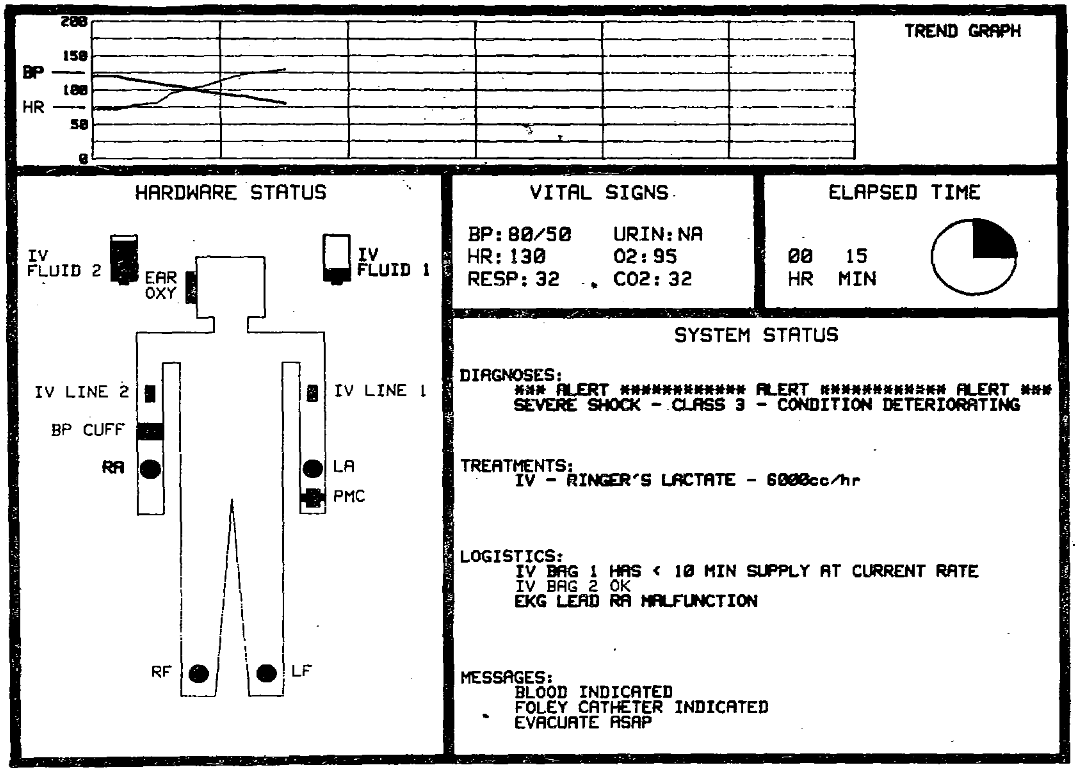

FIGURE 14. CEMES graphic display example.

The elapsed time display area provides an indication of the time the casualty has been attached to the system. This time is displayed digitally in hours and minutes. A "golden hour" also has been provided that ticks off minutes in an analog fashion by filling in portions of the circle with solid wedges. The golden hour has been included primarily for demonstration purposes since the first hour of emergency treatment often is the most critical. At later stages, the elapsed time area will include the absolute start time, the current real time, and the amount of time attached to the system (i.e., the difference between the absolute start time and the current real time).

The system status display area is where the expert system displays various messages having to do with the casualty's diagnosis, the preferred treatment regimen, logistical indicators, and any additional messages deemed necessary. These four classes of messages are separated and displayed under appropriate labels that define display subareas within the system status area. The various messages are color coded white, green, yellow, or red depending upon the type of message. The default display color is white, with system OK messages in green, cautionary or advisory messages in yellow, and severe or warning messages in red. Advisory and warning messages also are accompanied by additional visual cues in the form of a header (as in the "ALERT" header shown in the Figure 14 example) and auditory cues with differing frequencies and temporal characteristics.

The hardware status display area provides a pictorial display of the location and status of the various sensor and effector units that have been attached to the casualty. The icons and labels for each hardware item are color coded to provide visual cues as to their status. Green indicates the hardware is OK and functioning properly. Yellow indicates a problem or a malfunction. Red indicates the hardware item is not functioning (for whatever reason).

The hardware status display area in the example (Figure 14) shows various devices that serve as examples for what could be included in an operational-front end.[12] There are four EKG limb leads appropriately labeled RA, LA, RF, and LF. Note that lead RA is malfunctioning with a message to that effect appearing in the logistics subarea of the system status area. An automated BP cuff is attached to provide blood pressure measurements. The PMC label represents a personal monitor and communicator which provides heart rate and respiration rate.[13] An ear oximeter also has been attached in this example. This particular casualty has had two IV units attached, one of which is getting low on fluid.

The last display area is the trend graph at the top of the display. This graph provides a chart upon which the various vital sign data can be plotted for a visual indication of how those signs have changed across time. The example in Figure 14 shows systolic blood pressure and heart rate. The values plotted are absolute values, with the scale shown at the left of the graph. The intermittent vertical lines represent 10 minute intervals in real-time. At this interim stage, the Graphics Display Generation and Control Program only can display systolic blood pressure and heart rate on the trend graph. The capability for displaying all the various vital signs in various combinations will be added at a later time.

---

12 The example in Figure 14 is <u>not</u> meant to indicate that all of the equipment shown is either necessary or will be assumed to part of an operational CEMES front-end. There are both scientific and practical questions that must be addressed with regard to how to noninvasively monitor certain physiological signs.

13 This wristwatch type device is being developed under contract and currently exists in brassboard.

Note the trend graph has room to display 1 hour's worth of data. This shows the graph's particular configuration for the first hour of operation. After the first hour, the horizontal scale on the graph condenses to represent 2 hours' worth of data (*i.e.*, the number of vertical lines doubles). The *last* hour's data is redrawn on the new scale with new data being graphed on the end of the previous hour. That is, there is always as much data as is available, or at least 1 hour's worth of data with the new data being tacked on as received.

The master control program

The principal program for the CEMES front-end at present is the Master Control Program shown on Figure 3a. This program provides all the various menu-driven capabilities for simulation, control, and bookkeeping on the front-end. An organizational chart of the various menus available in the Master Control Program is provided in Figure 15. The specific menus themselves are shown in Figure 16 exactly as they appear on the console CRT and serve as labels for the softkeys provided on the HP 9000 keyboard. A push of the appropriate softkey initiates the particular action indicated by the key's label. An explanation of the Master Control Program will proceed through an explanation of what can be done within each menu.[14]

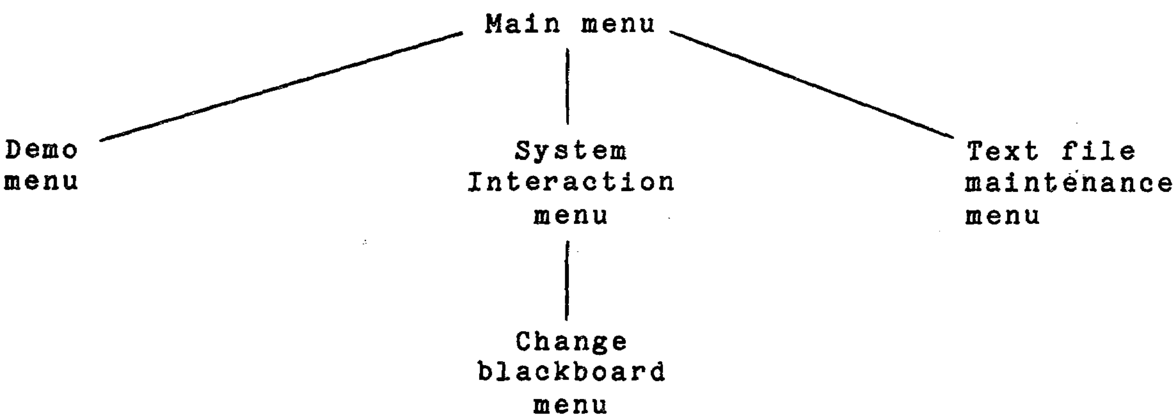

FIGURE 15. Master Control Program menu hierarchy.

[14] This subsection is not intended as a user's or instructional manual for the operation of the CEMES front-end, even though the explanation of the various menu selections of the Master Control Program will provide a basic knowledge of how to operate the front-end at this interim stage. A complete operational manual may be written for CEMES at a future date.

The main menu provides a starting point for selecting the particular activity to be accomplished. The "System Startup" selection begins execution of the front-end programs (as opposed to loading and running the Master Control Program which requires some knowledge of the HP 9000 minicomputer). Once booted and started, the front-end enters a waiting state for the initial data request from the expert system. Selecting the "System Shutdown" option performs the opposite task by stopping operation of the front-end programs and resetting the HP 9000 for normal computer operations. "File Backup" provides a means for automatically generating floppy disk backups of all the front-end programs and files that normally reside on the HP 9000's internal hard disk. A full backup requires three properly formatted 5.25-inch floppy disks, each of which is inserted into the internal floppy disk drive on cues provided by the backup program. The backup program returns to the main menu upon completion. The last three selections on the main menu provide branches to the other menus of the Master Control Program.

The main menu "Txt_file Maint" selection branches to the text file maintenance menu. This menu is used to control operations with respect to the four text files that are part of the front-end blackboard (see Figure 3a). These four text files contain the various text messages that appear in the system status portion of the graphic display. The expert system signals the display of the various messages in the four subareas of the system status display area through appropriate codes that are transmitted to the front-end on each cycle. The Graphics Display Generation and Control Program interprets the various codes, retrieves the proper messages from the text files, and generates the appropriate graphics for the display.[15]

Text file maintenance operations proceed by first selecting a file to work on (the "Select File" choice on the menu), and then completing whatever actions are desired. The "Add Text" selection branches to a routine for adding new text messages to the file. The "Output Hardcopy" selection produces a listing of all text messages currently in the file on the internal thermal printer of the HP 9000. The "Change Text" selection branches to a routine allowing changes to be made to existing text messages.

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[15] The text message codes are the actual information stored in the blackboard file after being parsed from the updated information file by the Communications and File Transfer Control Program. That is, the <u>only</u> place where the text messages appear in readable form is on the graphic display or in a hardcopy dump of the text file.

MAIN MENU:

System Startup	System Shutdown	File Backup	Txt_file Maint	System Interact	Not Used	Not Used	Cemes Demo

TEXT FILE MAINTENANCE MENU:

Select File	Add Text	Output Hardcopy	Change Text	Not Used	Not Used	Not Used	Main Menu

DEMONSTRATION MENU:

Demo Setup	Demo Shutdown	Create Demo	Change Demo	Hardcopy Demo	Not Used	Start Demo	Main Menu

SYSTEM INTERACTION MENU:

Change Blckbrd	Cause Events	Suspend Opertn	Output Hardcopy	Not Used	Not Used	Not Used.	Main Menu

CHANGE BLACKBOARD MENU:

Diagnose Treat	Logist Mess	Treat Hardware	Sensor Hardware	Not Used	Vital Signs	DO IT	Interact Menu

FIGURE 16. Master Control Program menus.

As can be inferred from the names of the four text files, each corresponds to messages that are displayed in the four subareas of the system status display area. Each text file can contain up to 400 different messages with no more than 52 characters per message (including spaces and punctuation). The operation of the expert system determines the types of messages entered into each file.

The "Cemes Demo" selection on the main menu branches to the demonstration menu. The demonstration menu is used when generating, changing, and conducting demonstrations of the CEMES system. A demonstration consists of normal CEMES cycles with a recycle rate of 20 seconds rather than 1 minute. This is to allow reasonable casualty scenarios to be presented in shorter times. The demonstration mode of operation also requires modified versions of the Communications and File Transfer Control Program and the Graphics Display Generation and Control Program. In addition, the demonstration operates by automatically retrieving new blackboard data (*i.e.*, vital signs, etc.) from a file rather than using manual input.

To initiate a demonstration of CEMES, the "Demo Setup" selection is first made (the expert system portion having been started independently in demonstration mode on the Symbolics machine). This prepares the front-end programs for operation and establishes a wait state. After opening or other remarks, the "Start Demo" selection can be made and the demonstration will run until data in the demonstration file is exhausted, when the demonstration will be shut down automatically. If the demonstration needs to be stopped prematurely for some reason, the "Demo Shutdown" selection can be made.

The other selections on the demonstration menu are used to operate on the demonstration data file. The "Create Demo" selection branches to a routine for the generation of a new demonstration data file. Various prompts are provided as required to aid in the entering of the data. The "Change Demo" selection branches to a routine for changing a specific cycle's data in an existing demonstration data file. The "Hardcopy Demo" selection provides a printed output of the current demonstration data file on the internal thermal printer of the HP 9000. It should be noted at present only one demonstration data file can exist at any time. Future provisions may be made for multiple demonstration data files so different casualty scenarios can be demonstrated without going through an involved "Create Demo" process.

The "System Interact" selection on the main menu branches to the system interaction menu. The system interaction menu is used when simulating the sensor and effector subsystems during a normal test run of the CEMES system. The "Output Hardcopy" selection provides either a 'snapshot' printed output on the internal thermal printer of the data currently in the front-end blackboard, or a color graphics plot of the current graphic display screen on an HP 7475A six-pen plotter (see Appendix A) that's attached to the HP 9000. The "Cause Events" and "Suspend Opertn" selections on the system interaction menu currently are not programmed. They are included for more advanced mechanisms to test CEMES operation at later stages.

The "Change Blckbrd" selection of the system interaction menu branches to the change blackboard menu which provides selections for simulating the collection of new data on the front-end. This is where manual entering of vital signs and other data is accomplished during a test run of the CEMES system. The basic procedure for using this menu is to first select the category of change to be made. The selection enters a prompted procedure for entering the types of changes allowable in that category. After all changes have been made in the various categories, the "Do it" selection is made. This starts a routine that makes the changes permanent in the front-end blackboard file. That is, changes that are entered do not take effect until the "Do it" selection is made. Once "Do it" is started, the changes in the blackboard will show up on the graphic display.

The "Vital Signs" selection of the change blackboard menu branches to a routine that prompts for new vital sign data to be entered. Any or all of the currently programmed vital signs can be changed. The "Treat Hardware" selection branches to a routine that allows changes to be made to the available treatment hardware ensemble. This includes signaling that an IV unit is attached and indicating whether the hardware is functional or not (even though the expert system cannot yet deal with attached, but malfunctioning hardware). The "Sensor Hardware" selection is used to make similar changes for the available sensor hardware ensemble. These three selections are the principal types of changes that are made during operation and testing of CEMES.

The "Diagnose,""Treat,""Logist," and "Mess" selections are for changing message entries that are displayed in the system status area of the graphic display. These selections were included to test the operation of text message display, and should not be selected during an operational test of CEMES. To do so could create a mismatch between the messages the expert system thinks are being displayed and the messages actually being displayed, giving a false impression that the expert system has malfunctioned. These selections will be deleted at a later stage.

Phase II objectives

The Phase II exploratory development of CEMES has four major objectives: design the necessary operator interfacing for CEMES' query/response operation, expand CEMES diagnostics to include operation under CBR contamination, expand CEMES for operation under degraded modes, and design and construct a more realistic front-end using biomedical simulators and automated IV units.

Following Phase II, it is anticipated a proof of concept operational CEMES will be available for full demonstrations of medical expert system operation in the domain of emergency medicine for shock. Data input will be accomplished automatically when possible or through query when necessary. Full casualty simulation of biomedical signals will be available through appropriate patient simulators or other instrumentation. IV infusion treatment will be demonstrated through automated IV infusion units.

Summary

This report has described interim progress concerning the exploratory development of a combat emergency medicine expert system (CEMES). The principal aspects of the design and operation of CEMES have been documented. CEMES can diagnose and simulate IV treatment for all classes of hemorrhagic shock. Additional mechanisms for drug treatments, diagnosis under contamination, and degraded mode operation have been included, but are not fully operational at this stage.

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APPENDIX A

Manufacturers list

Hewlett-Packard Company
Building 5
4700 Bayou Blvd.
Pensacola, FL 32503

Symbolics, Inc.
Department 803
555 Virginia Road
Concord, MA 01742