On the Contributors to "System Smartness": A "Med Net Agent System"Case Study

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Abstract

This paper presents an example of how of 'intelligence' is designed into a distributed system. The exemplar is Med Net Agent system. The Med Net Agent system, developed and prototyped in response to customer requirements, may be viewed as an ontology driven, agent-based, integrated system that incorporates both patient information and disease information. The Med Net Agent system design offers diagnosis support to the human clinician via Bayesian networks and via a medical information repository. This system is designed to work within the framework of the Theater Medical Information Program. Contributors to the system 'intelligence' include the use of semantic technologies, Bayesian networks, and the design for communication and information updates.

Introduction

The theme of this AAAI RIDIS Symposium focuses on elucidation of the supporting technologies or approaches which contribute to the formation of 'intelligence' in a 'distributed intelligent system', i.e., what elements contribute to making the system 'smart'.

This paper is organized around a case study provided by the Med Net Agent System; this system has been designed in response to customer requirements and major elements have been prototyped. The overarching goal of this system is to enable medical personnel to respond quickly and correctly to medical needs of active duty military personnel. Humans are very much in the loop of any medical decision.

In keeping with the theme of the conference to elucidate how the 'intelligence' in a distributed system is realized, we focus on the issue of how information is used throughout the system. In our opinion, support for the proper use of information is a key element in supporting the 'intelligence'. As part of our discussion, we also elucidate the role of contributing technologies, including ontologies and Bayesian networks.

The paper is organized as follows. In the Introduction section, we present the high level requirements on system design. These were levied by the customer. The second section presents the information design which supports information flow and utilization within the Med Net Agent framework. The third section presents the software multi-agent design for Med Net Agent system design. The fourth section notes the features which support 'intelligence' within the Med Net Agent system. It also discusses how medical personnel may utilize the system. The Conclusion section provides summary remarks.

High Level Requirements. The high level requirements for the system were given by the customer as both necessary functionality and specific component elements that must be included in the Med Net Agent system. The customer defined mandatory components of the Med Net Agent system were given as: (1) to provide a searchable and visualize-able 'database' of medical information, (2) a software agent-based system to support medical diagnosis and (3) wearable sensors that capture physiological vital sign information. As part of the description of the ideal system components, certain desirable features for the final system were noted. For example the interface to the searchable 'database' is required to be multi-modal. The customer requirements implicitly realize that advances across several technological areas ranging from body wearable sensors to software agent systems may be utilized in concert in order to develop a functional Med Net Agent system. The Med Net Agent system is also required to interface with the established medical system, the Theater Medical Information Program (TMIP) system.

Med Net Agent System Usage. The requirements state that the primary functionality of the Med Net Agent system is to reside on a laptop that is enabled for wireless communication. Physiological sensor signs from groups of individuals may be collected onto a PDA that is also enabled for wireless communication; this PDA hosts agent functionality that can organize the information to be delivered to the Med Net Agent system component residing on the laptop. Diagnostic support functionality is hosted on the laptop; patient records may also be accessed from, cached on, or updated via the laptop's functionality. The Med Net Agent system elements that are hosted on the laptop are considered to be within the purview of the attending medical personnel. The information that is created by use of the Med Net Agent system is intended to be shared with medical applications in the Theater Medical Information Programs; this is done via a messaging channel that may be connected to the broader medical informatics infosphere through the communications support offered by the net-centric infrastructure; this includes satellite communications and offers a reach-back to the continental US.

From an intended utilization perspective, the human user (medical personnel) generally initiates the data or information flow in the Med Net Agent system. The exceptions to this are (1) an information push from a PDA that contains medical data on incoming patients or (2) an information push from software applications from TMIP. The information likely to be coming from TMIP software applications includes updates on medical issues, including updates to diagnostic Bayesian networks and informational bulletins and additional personnel medical records. (Medical supply information will also be updated, but this is not the focus of the Med Net Agent system.) As the Med Net Agent system is a conceptual research prototype and does not interface with TMIP application programs, we make the assumption that the user would review incoming information and do not discuss how it would be automatically handled in this phase.

The Med Net Agent system functionality is inherently information driven. Information that flows into / through the Med Net Agent system includes:

- Updates to current medical information,
- Updates to current patient information,
- Contextual information,
- Information organized for unambiguous use by algorithms,
- Request for retrieval of authoritative information.

Information Design

The Med Net Agent system is organized for appropriate information flow throughout the system. Software agents are developed with specific roles that facilitate the information flow. While there is a "human in the loop" via the medical personnel, the human is unaware of the agent team that supports the information flow.

We note that a model for dynamic information flow has been developed in the context of mixed –initiative teams comprised of both human and agent members by Burstein and Dillard (Burstein and Dillard 2004). They state:

> By describing communications paths in terms of roles, agents, when recruited, can often be thought of as stepping into a workflow model with understandable information pathways.

The Med Net Agent system may be viewed as an ontology driven, agent-based, integrated system that connects patient information and disease information into one system. The Med Net Agent system provides real-time support for diagnosis.

In this work, the agent team member roles are pre-defined; it is the information that is handled / manipulated by each agent member that is highly variable. The core Med Net Agent system involves knowledge management that is provided by (1) 'repositories' of information, (2) an ontological basis for all medical terms, and (3) defined schemas that support the knowledge within the Med Net Agent system repositories, data structures, and XML-encoded messages or interactions among agents.

A key design issue involved how to organize the information and data within the Med Net Agent system. We note that the biomedical area has been a driver for the development of taxonomies and ontologies. The (US) National Library of Medicine has developed the "Unified Medical Language System" (UMLS) (Tilley 2001), which involves a meta-thesaurus. UMLS has allowed for the translation across different clinical taxonomy schemes, in different countries and health care systems. Among these taxonomy schemes is that of the International Classification of Disease taxonomy (ICD). Our choice was to include the ICD code scheme (version 9) in the Med Net Agent system; this selection was motivated by its use within the Army's Telemedicine and Advanced Technology Research Center (TATRC) in clinical applications that are part of its Battlefield Medical Information System Tactical-Joint (BMIST-J) project.

All of the information/terms used in the Med Net Agent system are given a unique ID within the system. We have then connected this information to an ontology that utilizes the ICD9 codes for medical terms. Where available, a connection is also made to the Disease Ontology (DO), which is part of the Open Biomedical Ontology (OBO) project. That is, multiple 'tags' may exist for the uniquely identified information / terms within the Med Net Agent system which connect them to appropriate ontologies.

Multiple structured documents which support the functionality needed in the Med Net Agent system are developed. Each structured document is based on a defined schema. Instances of a particular document may be passed among the relevant agents.

Five schemas have been developed in order to support the medical functionality of the core Med Net Agent system, these are:

- Clinical Disease Description Schema (CDDS),
- Electronic Patient Information Schema (EPIS),
- Electronic Medical Case Schema (EMCS),
- Electronic Medical Encounter Schema (EMES), and
- Expert Knowledge Structure Schema (EKSS).

The Clinical Disease Description (CDD) schema is used to structure instances of the Clinical Disease Description Document. The Expert Knowledge Schema (EKS) structures the information that is found in the Expert Knowledge Repository (EKR). This is a document that captures the Bayes net structure and the expert knowledge cases. [In this initial prototype, we develop a small Bayes net; in a more developed system, multiple Bayes nets would be utilized.] The EMCS is the schema that governs Electronic Medical Case instances; these are stored in an Electronic Medical Case repository. Medical cases are distinguished from Electronic Medical Encounters, which are governed by the EME schema. The Electronic Patient Information schema (EPIS) governs information found in the Repository of the same name (EPIR), which contains XML-tagged patient information records. The patient information records would be initially provided via the TMIP system.

Figure 1 is a schematic of the repository types that are used in the Med Net Agent system and their relationship to the components of the Med Net Agent System. Figure 2 illustrates the possible information flows that are the focus of our conceptual prototype.

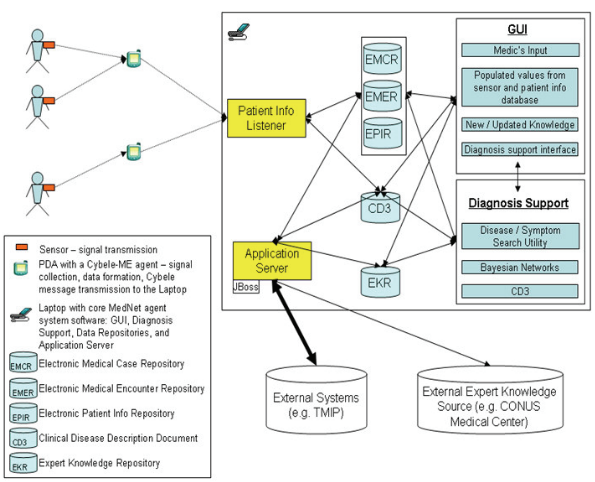

Figure 1 Repository Types within the Med Net Agent System

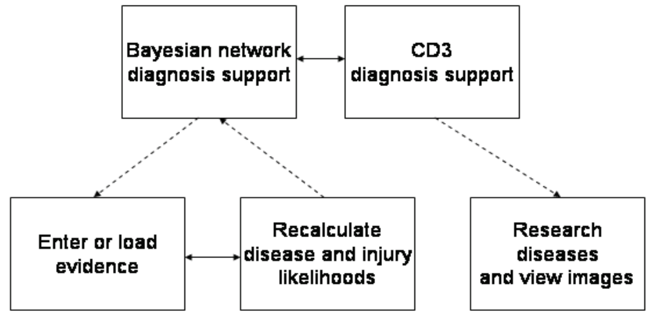

Figure 2 Schematic of Med Net Agent system Support for Diagnosis

Figure 3 shows the CDDS schema. Figure 4 shows the expanded Disease element of the CDDS. Both were designed for the Med Net Agent system. Note that:

- The CDDS defines the elements used to represent a disease in general and in sufficient detail as to be an authoritative source of information for that disease in the Med Net Agent system.
- When referring to a disease or some other medical term or expression, all parts of the Med Net Agent system exclusively use the uniquely identifying name for that term or expression that is contained in the CD3. Thus, the CD3 forms the basis for safe and informative inter-agent communication.
- The top-level element in the CDDS, CDDS, has the following seven sub-elements: *(1) Symptom, (2) Symptom_Expression, (3) Treatment_Method, (4) Treatment, (5) Risk_Factor, (6) Image, and (7) Disease.*

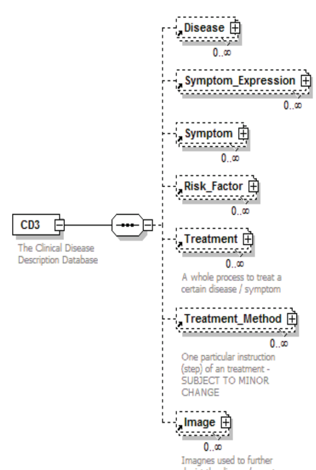

Figure 3 CDDS Schema

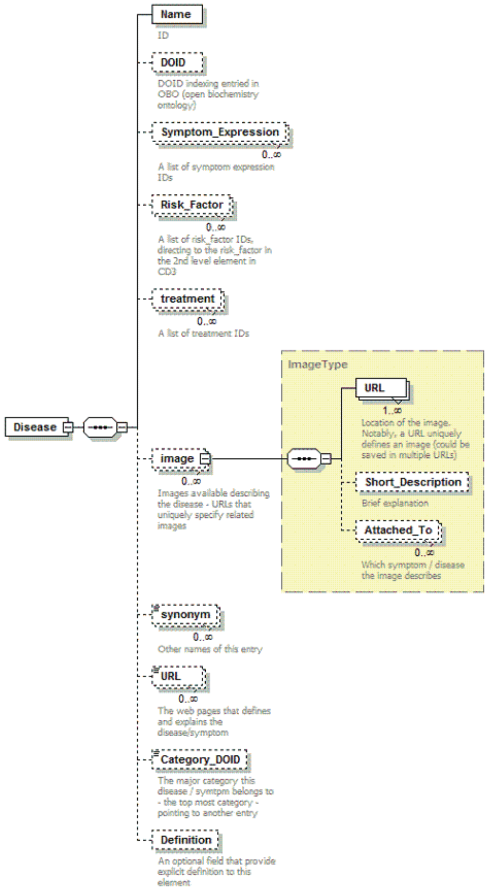

Figure 4 Expanded Disease Element

The ID is unique to the Med Net Agent system. Note that the DOID indexes an element that is referenced in the Open Biomedical Ontology (OBO). Multiple symptoms may be included; web sites and image access information is attached. Note that recent work in the medical area has involved the use of ontology languages for medical concepts. This includes the OBO effort, which is an open source 'foundry' for biomedical ontologies, from research areas to clinical areas. Specific research includes that of Hu and colleagues (Hu et al 2003), who utilized the OWL – Description Logic ontology language in order to annotate medical images. Our design choice is to allow mappings of any term within the Med Net Agent system to multiple taxonomies or ontologies, including the ICD codes, the UMLS taxonomy and the OBO ontologies. In principle, new taxonomies or ontologies, such as those developed by Hu, can be incorporated. Within our Med Net Agent system prototype, all terms have at least one mapping.

The Med Net Agent system offers the user has two complementary means of diagnosis**.** The first, Bayesian net support, allows the user to load evidence into a Bayesian network from an electronic medical case file and iteratively enter additional evidence, including "what-if scenarios," while noting changes in the resulting probability distribution over diseases and injuries. The second, termed CD3 support, allows the user access to information stored in the Clinical Disease Description Document (CD3), including links to researchable text and images.

Overview of Bayesian Network Design and Usage in the Med Net Agent System. We note that the use of artificial intelligence in medical applications is long-standing. One such early classic expert medical system, discussed by Buchanan and Shortliffe (Buchanan and Shortliffe 1984), is MYCIN. Utilization of Bayesian networks for medical diagnosis support is also well established; recent work in the literature includes that of Rose and colleagues (Rose, Smaili and Charpillet 2005) in a hemodialysis application, and work in liver diagnosis from Onisko and colleagues (Onisko Druzdzel and Wasyluk 1999). In the Med Net Agent system, we develop a simple Bayesian network (BN) that is centered on flu-like symptoms, with possible diseases including avian flu, meningitis, etc.

Bayesian Network Diagnosis Support Approach The input to Bayesian net support is a medical case file. When a user selects "Get Bayes Net Diagnosis Support" from the Med Net Agent System GUI, the XML document for the open case is parsed. An evidence set consisting of states for only those variables relevant to the diagnosis is constructed. Of great importance is the fact that all XML schemas and thus interacting systems use CD3 IDs when referring to medical terms. Therefore, there is no ambiguity involved when constructing an evidence set for the Bayesian network. Also, medical terms are linked to standard ICD9-CM codes, when possible. The qualification "when possible" in the previous sentence comes from the fact that about 20% of the medical terms found in the CD3 do not have counterparts, to the best of our knowledge, in the ICD9-CM database. Since the variables corresponding to these terms can potentially play an important role in diagnosis, we have included the terms and variables in the CD3 and Bayesian net support, respectively. In future efforts, a medical expert would determine appropriate ICD9-CM codes for such terms. Bayesian network specifications are stored in files on disk.

Our Bayesian networks each consist of three distinct sets of nodes, representing *Risk Factors*, *Diseases (or Injuries)*, and *Symptoms*, respectively. A disease node's parents are always risk factor nodes, and a symptom node's parents are always diseases. In future efforts, this constraint may be relaxed to model, for example, diseases that are complications resulting from other diseases, with directed arcs between diseases. With regard to network size, we assume that the size of a network used in a particular differential diagnosis is roughly 200 nodes and 1000 directed arcs. A schematic diagram for the generic current Bayesian net structure is shown in Figure 5.

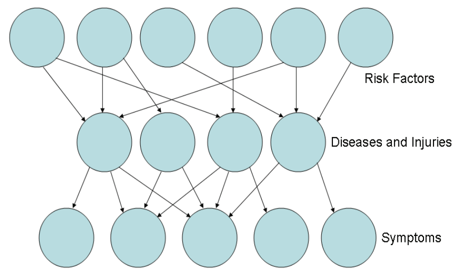

Figure 5 Structure of Bayesian Network in Med Net Agent System

Bayesian Net Representation Issues Consider the symptom Fever, which has ICD9-CM code 780.6. There are no ICD9-CM codes to indicate the particular measurements associated with a fever. So without ICD9-CM codes to guide us, how should the user enter this information into the GUI? How should it be represented as a variable in a Bayesian net? Ultimately, the answers to these two questions need not be the same. For example, the user might enter the value for Fever implicitly by entering the patient's body temperature, while the values for the node Fever in a Bayesian net belong to the set of discrete states *{none, low, medium, high}* based on appropriate definitions. (These definitions might even be represented by a "drill down network" where the state of Fever is determined by Bayesian net inference based on the values of other variables, including body temperature; drill-down networks are not implemented in the prototype.) In this example, a filter consisting of simple computations could easily convert between different representations of variables, e.g. *Fever*, given objective definitions; different definitions would be referenced to the appropriate medical ontology.

Also, with the Clinical Disease Description Document (CD3), symptom nodes in a BN refer to symptom expressions that are potentially enriched with time information. For example, one node might refer to the symptom *Fever*, which means the patient has experienced a fever during the illness, while another node might represent the expression *Fever_For_First_Two_Days*, which means the patient experienced a fever throughout the first two days of the illness.

Med Net Agent Design

Software agents in the Med Net Agent system are modularly designed for specific agent activities. The agent activities provide all the functionality that is offered by the Med Net Agent system. Of course, the Bayesian network algorithms are independent of the software agent; however, access to the algorithm for a particular evidence set is mediated by a software agent component. These agents and their activities comprise the high-level organization of the Med Net Agent software, as shown in Figure 6. Arrows indicate paths for data flow

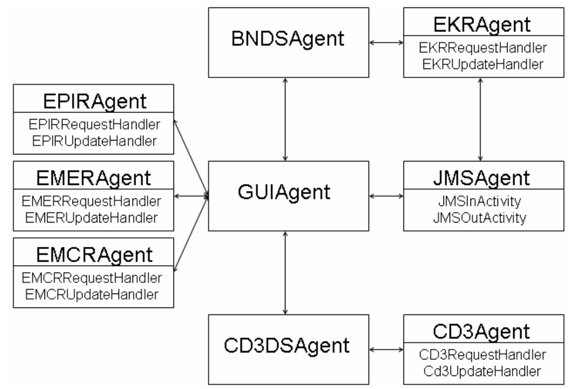

Figure 6 Software Agents in the Med Net Agent System

Note that the BNDS is the agent assigned to the Bayesian network information flow. The information flow that each agent participates in is given in Table 1.

Table 1 Agent-based Message Exchange in the Med Net Agent System

Message Sent	Agent or Agent Activity Sender	Agent or Agent Activity Receiver
EMCR File Contents	EMCR Agent. Request Handler (RH)	GUI Agent
EMCR Request	GUI Agent	EMCR Agent RH
EMCR Update	GUI Agent	EMCR Agent Update Handler
EMER File Contents	EMER Agent. RH	GUI Agent
EMER Request	GUI Agent	EMER Agent RH
EMER Update	GUI Agent	EMER Agent Update Handler (UH)
EPIR File Contents	EPIR Agent RH	GUI Agent
EPIR Request	GUI Agent	EPIR Agent RH
EPIR Update	GUI Agent	EPIR Agent (UH)
Bayesian Net Evidence	GUI Agent	BNDS Agent
Disease Probabilities	BNDS Agent	GUI Agent
JMS In	JMS Agent JMS In Activity	EKR Agent UH
JMS Out	GUI Agent	JMS Agent JMS Out Activity

In Table 1, the self-descriptive types of messages that are sent were listed. The context in sending such message types is given here:

1. EMCR File Contents: Used when the EMCR Agent reports the contents of a requested medical case file to the GUI Agent,
2. EMCR Request Message: Used when the GUI Agent requests a medical case file from the EMCR Agent,
3. EMCR Update Message: Used when the GUI Agent submits a medical case file that is to be stored in the EMCR to the EMCR Agent,
4. EMER File Contents Message: Used when the EMER Agent reports the contents of a requested medical encounter file to the GUI Agent,
5. EMER Request Message: Used when the GUI Agent requests a medical encounter file from the EMER Agent,
6. EMER Update Message: Used when the GUI Agent submits a medical encounter file that is to be stored in the EMER to the EMER Agent,
7. EPIR File Contents Message: Used when the EPIR Agent reports the contents of a requested patient information file to the GUI Agent,
8. EPIR Request Message: Used when the GUI Agent requests a patient information file from the EPIR Agent,
9. EPIR Update Message: Used when the GUI Agent submits a patient information file that is to be stored in the EPIR to the EPIR Agent,
10. Bayesian Net Evidence Message: Used when the GUI Agent submits evidence to the BNDS Agent, awaiting the results of Bayesian network diagnosis,
11. Disease Probabilities Message: Used when the JMS Agent sends updated expert knowledge to the EKR Agent,
12. JMS In Message: Used when the JMS Agent sends updated expert knowledge to the EKR Agent,
13. JMS Out Message: Used when the GUI Agent sends the results of Bayesian network diagnosis support to the JMS Agent.

Within the Med Net Agent system prototype, the JMS messages are received from or sent out via the Java Message System message bus. The JMS bus is one possible message channel that serves to connect the Med Net Agent system to TMIP.

Intelligence of the Med Net Agent System

The 'intelligence' residing in the Med Net Agent System arises from the interaction of a Knowledge Management-based design that has information organized according to well –defined schemas whose elements are grounded in medically grounded ontologies or taxonomies together with the algorithmic support offered by the Bayesian network. The Med Net Agent system incorporates:

- A Bayesian network diagnosis support subsystem,
- A clinical medical knowledge diagnosis support subsystem,
- A Repository for patient information
- A Repository for disease descriptions,
- A Repository for expert medical knowledge,
- Medically relevant XML schemas for ontology support,
- Semantic grounding of medical terms in official ICD9-CM codes,
- Access to external information to/from the larger medical system, via message channels.

The Med Net Agent system's 'intelligence' is adaptive through the incorporation of new information, which includes:

- New patient status data from its distributed PDA-based notes,
- Updates to repository information,
- Learning via the human-initiated 'what-if' disease scenarios that make use of Bayesian network capabilities,
- Updated Bayesian networks provided by expert medical personnel on a (TMIP message) channel.

The Med Net Agent system may be viewed as a smart node in a larger organism that is the Information Programs system. The Med Net Agent system node is designed to communicate via dedicated channels with the information system. Part of the 'intelligence' of the Med Net Agent system node is that it is in the flow to receive new knowledge as well as generate (and share) new knowledge. The ability to use communications to acquire new information or communicate about the environment is a hallmark of intelligence. From an agent perspective, Genesereth and Ketchpel (Genesereth and Ketchpel 1994) noted early on that communication is at the heart of 'agency'.

The trained human medical user is a key element in the Med Net Agent system, adding 'intelligence' to the overall system. From the human's point-of-view, the Med Net Agent system offers:

- An interactive GUI that guides the user through the medical encounter,
- Logically organized flow that supports the medical personnel's overall usage of the system.

Conclusions

The Med Net Agent system may be viewed as an ontology driven, agent-based, integrated system that connects patient information and disease information into one system; it may also be viewed as a smart node that can integrate into and contribute to the Theater Medical Information Programs systems.

Its diagnosis support is offered though two primary components: (1) a navigable clinical medical knowledge document that provides access to encyclopedic entries for diseases and their symptoms, risk factors, and treatment methods, and (2) an interactive Bayesian network diagnosis support that synthesizes data collected for a given medical case and outputs probabilities for various diseases and injuries.

The functionality of the Med Net Agent system is provided by a team of "Med Net Grid Agents"; they act in their respective team roles to together (1) handle the data flow, (2) handle the access to the Bayesian algorithms and (3) handle the access to the external communications. A set of medically relevant XML schemas provide the data structure that the Med Net Grid Agents utilize as they exchange information between the different logical elements of the Agent system. The XML schemas provide the Med Net Agent system with support necessary for orderly and unambiguous inter-agent communication.

Knowledge management is provided by (1) 'repositories' of information, (2) an ontological basis for all medical terms, and (3) defined schemas that support the knowledge structure within the Med Net Agent system repositories and in the XML-encoded messages or interactions among agents.

The 'intelligence' in the system is supported by a design which includes knowledge management elements, information flow and agent team infrastructure. The Bayesian network, providing the algorithmic basis for diagnosis support, also contributes to the 'intelligence' of the system. The openness and ability of the Med Net Agent system node to communicate with the larger enterprise is an additional feature supporting 'intelligence', as the node's information may be updated and the knowledge generated by the node may be shared.

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