Soft Computing Agents for e-Health: A Prototype for Glaucoma Monitoring

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***Abstract* - This paper proposes an e-Health framework as a medical holarchy that extends our previous telehealth implementation [1] enabling remote medical entities (physicians, medical devices, etc.) to work together to provide a needed medical service. The proposed extension opens the possibility to develop a generic e-Health expert system framework as a versatile template applicable to the improvement and easy accessibility of guidelines of care for any long term degenerative disease. Particularly we target the mining, retrieval, modification management, and synchronization of various databases used by doctors while ensuring the security requirements associated with web services in the context of e-Health applications are met. Although the proposed framework is applicable to the monitoring of any long term degenerative disease, here we resume ourselves to its application for glaucoma monitoring with particular focus on the workflow used by ophthalmologists monitoring glaucoma.**

***Keywords* - E-Health; soft computing agents; medical holarchy; glaucoma monitoring; long term degenerative disease; privacy and security of the electronic medical record.**

I. Rationale

The effectiveness of healthcare practices would significantly be improved if past experience of health care professionals could be systematically preserved and used. In response to this need we have developed [2] a neuro-fuzzy expert system (herewith referred to as *decision support system* – DSS) that is capable to learn from and consolidate expert medical opinions [3]. A prototype of this expert system [4] [5] was implemented and successfully tested for glaucoma follow-up decisions. This system (developed in cooperation with TransferTech GmbH, Germany [6]) encodes the expertise of Dr. A.C.S. Crichton, former President of the Canadian Glaucoma Society. The DSS can support doctors in the diagnostic, treatment and supervision processes of the evolution of a glaucoma patient based on the exploration of all data pertinent to the case and on the scientific data contained in various professional databases. The DSS consists of an *Education & Consultation System* to provide evidence-based guidelines of care to clinicians, and a *Consensus Analyzer* to constantly update and refine these guidelines based on patient encounters and expert opinions. Users can access the DSS *directly* via a Web-based user interface, or indirectly by using their clinical Electronic Health Record (HER) system, which integrates with the DSS.

Glaucoma is a progressive eye disease (usually associated with increased intraocular pressure [7]) that can lead to blindness if not treated properly. As a chronic eye disease which demands a lifetime treatment glaucoma is responsible for 15% of world blindness. The “follow-up time” decision is critical in the treatment of glaucoma patients. If follow-up and monitoring do not occur at the appropriate intervals, the treatment regime could cease to be effective, and may lead ultimately to blindness. For this reason assessing risk and disease progression is essential in determining treatment as well as the right time for a follow-up assessment [4]. One of the major problems facing the general ophthalmic community in North-America today [8] is that a lack of clear guidelines for follow-up timelines reflects large variances in the standard of care. Each specialist has his/her own ‘standards’ based on experience and first-hand knowledge acquired from long-term monitoring of a particular patient. This strongly suggests an immediate need to improve the target pressure guidelines to help glaucoma specialists decide when they should treat and how aggressively they should treat.

II. Consensus Metrics By Soft Competition

A first step towards defining guidelines of care in general is to investigate as much and as widely as possible expert patterns [9]. The contribution of several experts to the development of a knowledge base brings enormous value, but at the same time it presents a big challenge to the knowledge engineers. Communication between dispersedly located experts has to be supported by an adequate interface, various expert opinions have to be reconciled, eliminating contradictions and choosing the most encompassing solution in each case, privacy and security issues have to be dealt with adequately [10], etc. To cope with this we propose a methodology capable to deal with different expert opinions and consolidate the results into a rule set with each rule weighted by the *degree of consensus* reached among the experts. The methodology consists on the following steps:

A. Find the various patterns for each of the experts involved.
B. Reconcile the expert opinions. The differences are investigated using an automatic consensus analyzer capable to determine why these experts' views clash and reconcile them within a broader, more generic rule.
C. *Determine and Test the Core Rule Set.* The result of this reconciliation process will be a *core rule set* shared by all experts, running into a separate expert system accessible via the web interface.

Each time a new rule is proposed by an expert or an existing rule needs to be modified as a consequence of an expert's profile discrepancy to reconcile experts disagreement, the rule is presented to all the experts for evaluation. The expert opinions are analyzed by the Consensus Analyzer which evaluates the distance between each expert's opinion and the point of minimum consensus (the point of maximum conflict – where the expert opinions are most distant.) To evaluate this distance we use soft competitive learning [11], [12]. To define a typical value of distance to consensus we are asking the experts to indicate their preferences for each characteristic of the fuzzy rule, expressing each preference as a fuzzy value. We consider the individual preferences as fuzzy relations.

Suppose we are developing consensus in a universe X = {x_1, x_2, ...,x_n}; a fuzzy relation **R** of order n will have elements r_{ij} encoding the preferences given to x_i relative to x_j. r_{ij} = 1 implies that alternative *i* is definitely preferred to alternative *j*. At the other extreme we have maximal fuzziness, where $r_{ij} = r_{ji} = 0.5$. Two common measures of preference are defined here as average fuzziness (F) in R and average certainty (C) in R**:**

$$F(R) = \frac{tr(R^2)}{n(n-1)^{1/2}} \tag{1}$$

$$C(R) = \frac{tr(R \cdot R^T)}{n(n-1)^{1/2}} \tag{2}$$

where *tr* is the trace and T is the transposed of the matrix. The measure F(R) averages the joint preferences in **R** over all distinct pairs in the Cartesian space X x X. F(R) is proportional to the fuzziness or uncertainty about pair wise rankings. Conversely the measure C(R) averages the individual dominance of each distinct pair of rankings. The two measures are related:

$$F(R) + c(R) = 1 \tag{3}$$

Measures of preference can be useful in determining consensus. We define three type of consensus as follows:

Type I consensus: There is a clear choice, say alternative *i* (the ith column is all zeros) and the remaining (n-1) alternatives all have equal secondary preference (i.e 1/2).

Type II consensus: There is one clear choice say alternative *i* but the remaining (n-1) alternatives all have definite secondary preference (i.e 1).

Type Fuzzy consensus: Occurs when there is a unanimous decision for the most preferred choice, say alternative *i* but the remaining (n-1) alternatives have infinitely many fuzzy secondary preferences.

From the degree of preferences measures given in previous equations we can construct a distance to consensus metric defined as

$$m(R) = 1 - (2 \cdot C(R) - 1)^{1/2} \tag{4}$$

Where:

$$m(R) = 1 - (2/n)^{1/2}$$

for a Type I consensus relation (5)

$$m(R) = 0$$

for a Type II consensus relation (6)

When *n > 2*, the distance between Type I and Type II consensus increases with *n* as it becomes increasingly difficult to develop a consensus choice and simultaneously rank the remaining pairs of alternatives. The value of distance to consensus quantifies the dynamic evolution of a group as the group refines its preferences and moves closer to a Type I or Type II or Type Fuzzy consensus. The vast majority of group preference situations eventually develop into Type Fuzzy consensus, Types I and II being typically only useful as boundary conditions.

Based on the consensus metrics, the rule base is tuned to embrace all opinions as much as possible. This means that the rules obtained will be positioned in the equidistant point to all expert opinions. Once the distance to consensus predefined is reached, the rule is integrated in the knowledge base. In case of strongly divergent expert opinions the generated rule may not make sense as its generality may render it useless. However, this will not affect the system overall, as the rule will be implicitly overlooked by the fuzzy reasoning process.

III. A MEDICAL HOLARCHY SUPPORTING EXPERT INTERACTIONS

In a global e-Health Policy context [13], privacy, confidentiality, and security are central policy needs. Therefore, to enable expert interactions we propose an e-Health framework as a medical holarchy (Fig. 1) that integrates deployable rules-based medical software development with medical policy development. The medical holarchy is a system of collaborative medical entities (patients, physicians, medical devices, etc.) that work together to provide a needed medical service. Medical holarchies [1] can act as a primary response to the needs and requirements of today's healthcare system, especially to the need for unimpeded access to healthcare services and ease of workflow management throughout the medical system. In our case the medical holarchy links several experts into *consensus analyzer software* that integrates their dispersed opinions into a unified view (Fig. 2). Reconciling the various standards of care across the continents is a major issue in e-Health technology adoption. The security and privacy of electronic medical records is of major significance and has proven to be the brake that has hampered the adoption of e-Health by clinics around the world, especially in North America. Our longer term goal is to use this scenario to develop a reusable framework for secure, high-performance web-services in e-health.

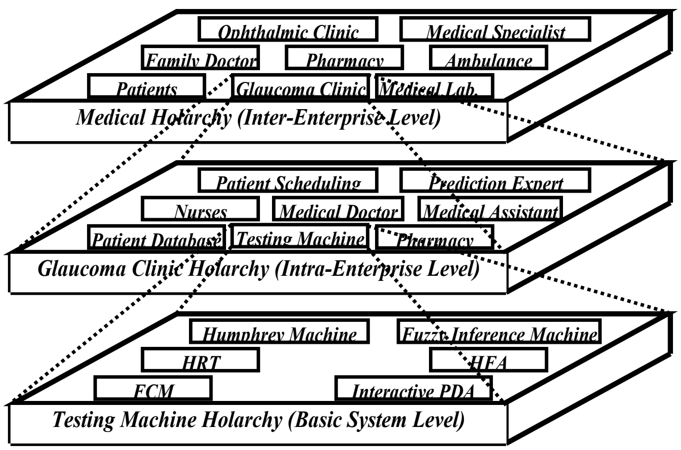

Fig. 1 Medical Holarchy

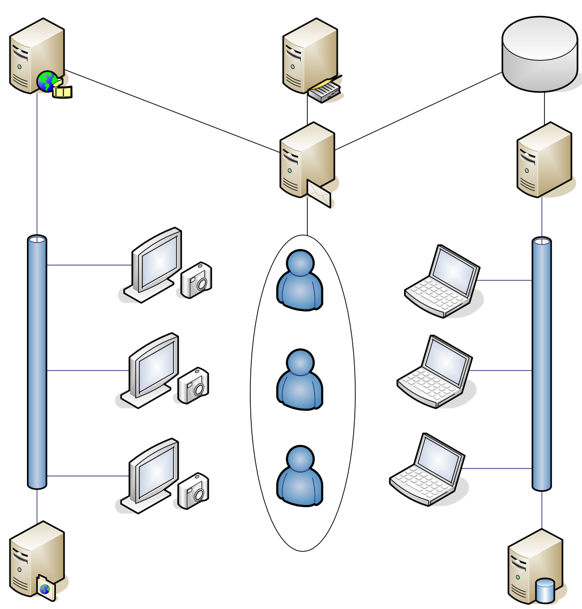

Fig. 2 Consensus domain architecture

The system, which will ensure the security layer for our e-Health infrastructure provides a high degree of protection and control of access over confidential and valuable information, even after delivery to legitimate users. Records can be expired after a fixed date, and permissions and entitlements (e.g. 'print', 'copy' functions) can be revised even after delivery and after legitimate users have taken copies.

Fig. 3 shows the system architecture composed of: Patient Provide Registry (a directory service that contains information about patients and health care providers, such as their identification number, certification, domain expertise etc.), EHR Media Knowledge System (enabling the use of multimedia and real-time collaborative web-services for pattern recognition in diagnostic images), the Decision Support System (encoding the consensus analyzer described in Section 2), Clinical EHR System (integrating several different clinical information systems), Individual Consent Manager (maintains and serves information about the consent given by individuals regarding the use of their personal health information), Authorization and Access Manager (uses the CM and the ICM to control access to information content based on personal consent, the role of the information-accessing entity, and the type of information use), Certificate Manager (distributes, controls and potentially revokes digitally signed trust certificates of providers and patients.), Audit Trail Manager (manages person-oriented audit trails for personal health information exchanged in the EHRs network).

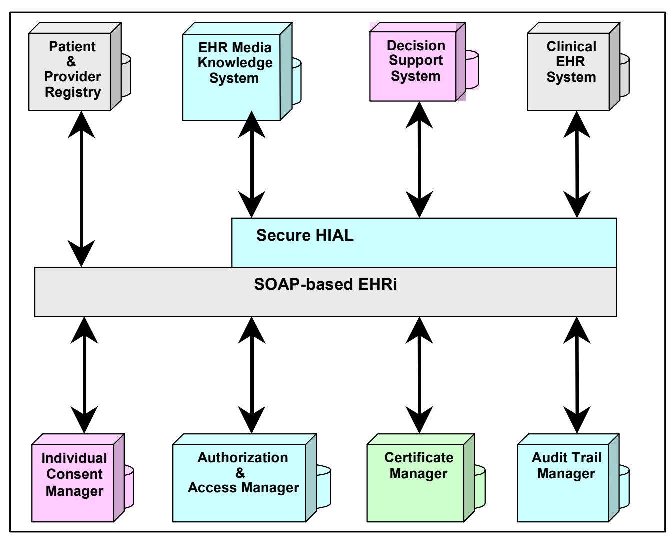

Fig. 3 Security-enabled medical holarchy

IV. SECURE HEALTH INFORMATION ACCESS LAYER (SHIAL)

Health Information Access Layer (HIAL) is a term defined in Canada Health Infoway's EHRs Blueprint Architecture [14]. The main purpose of this component (Fig. 3) is to leverage the value of existing heterogeneous medical applications and integrate them into a networked EHRs.The SHIAL has to resolve heterogeneity on two levels, namely on the technological level and on the semantic level. From a technological point of view the HIAL provides a standardized way of accessing heterogeneous systems using Web service technology (SOAP, XML, and UDDI etc.). From a semantic point of view, HIAL provides a conceptual mapping of data structures and terminologies used in the various heterogeneous medical systems to a standard ontology, based on the HL7 Reference Information Model (RIM). In terms of security, SHIAL mediates between trust credentials on the inter-organizational network level (Fig. 1) and those trust credentials used within the enterprise. From an inter-organizational view, SHIAL security is based on functionality provided by AAM. Since the semantic mapping to RIM provides SHIAL with knowledge about the semantics of information accessed by network services, SHIAL can provide AAM with meta-data important for deciding whether to grant access for a particular use case.

V. Conclusions

This work is a leading edge example of e-Health enabled guidelines of care development and accessibility. This concept can be extended into a template applicable to the development and access of other guidelines of care (Fig. 4). Table Expansion of the glaucoma focus to other diseases with a similar development path will secure the further development of integrated care models as well as the provision of new standards of care and educational opportunities beyond this project. The advantage of using an automatic tool versus face-to-face meetings to reach a consensus goes far beyond the commodity offered by the intelligent communication infrastructure in linking remotely located experts. The consensus analyzer delivers a measure of consensus that is impossible to grasp by the parties involved while negotiating their opinions, especially when they diverge.

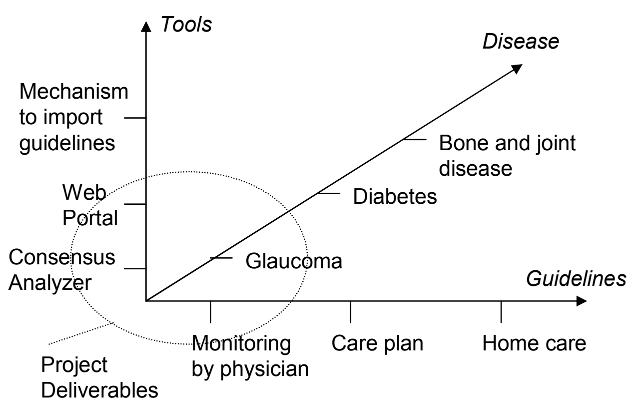

Fig. 4 System extension

Maximal objectivity is achieved through a sound mathematical approach that chooses a point equidistant to all other expert opinions, and as such the ‘winner’ point determines a rule encompassing all opinions.

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