A COOPERATIVE APPROACH TO THE DEVELOPMENT OF EXPERT KNOWLEDGE BASES APPLIED TO DEFINE STANDARD OF CARE IN GLAUCOMA

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Abstract. In this paper we introduce a methodology for knowledge base creation based on the reconciliation of multiple expert opinions using a fuzzy measure for consensus evaluation determined based on *soft competitive learning.* Real-life application of our methodology to the establishment of the standard of care in glaucoma monitoring illustrates its practical power. Based on a comparative analysis of expert patterns for glaucoma follow-up and treatment we extract a core rule set on which the experts agree. This exchange of information is supported by an advanced Cyberinfrastructure which enables fast transfer of information (highly accurate image transfer and display from the most complex and sophisticated ophthalmic machines, patient charts, etc.) to enable exchange of expert opinions.

1. INTRODUCTION

One of the major problems facing glaucoma specialists in North-America (and not only) is the lack of a standard of care clearly pointing towards follow-up timelines and treatment procedures. Each specialist has its own ‘standards’ based on their experience and first-hand knowledge acquired from long-term monitoring a particular patient. Extending experience acquired with a patient to another with similar conditions doesn’t usually work – as such each case needs as much as possible individual consideration – and this is what makes the task of the specialist so difficult. Even with decades of years of experience glaucoma specialists meet ‘new’ and ‘unknown’ cases in which they are confronted with the difficulty (or even impossibility) to make a decision.

In Canada there are absolutely no official standards regarding glaucoma follow [Cdn-Target]. The US *target pressure guidelines* are extremely weak regarding follow-up, as the physician’s flexibility ranges from 3 to 24 month, as such not pointing towards any specific responsible decision (given the fact that a patient who needs follow-up in 3 month, would go blind if requested for follow-up in 24 month!) [US-Standard].
This strongly points to an immediate need to improve the target pressure guidelines to help glaucoma specialists decide when they should treat and how aggressive they should

treat. Besides the main beneficiaries – the glaucoma experts - these improved standards would help all general ophthalmologists (although this is to date an extremely difficult endeavor given the wide range of disagreement in the ophthalmic and glaucoma communities.)

A first step towards defining standards of care in glaucoma follow up is to investigate as much and as widely as possible expert patterns in follow up decisions. For this purpose we have developed an expert system encoding follow up rules acquired with the expertise of Dr. A.C.S. Crichton [Uli02], [Vara02]. To encode complex linguistic knowledge we have chosen fuzzy technology. To date we have reached a core rule base consisting of about 30 core rules [Uli03]. To expand the current knowledge base encoding Dr. Crichton's patterns of glaucoma follow-up, we have investigated the patterns of other Canadian glaucoma experts (selected from the most reputable internationally recognized ones) joined into what we call the *Canadian Glaucoma Ring.* In the next section we present the methodology by which we have reconciled the other expert opinions into a standard of care for glaucoma follow up.

2. COLLABORATIVE METHODOLOGY FOR EMBEDDING VARIOUS EXPERT PATTERNS INTO A KNOWLEDGE BASE

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 experts located in different parts of the world has to be supported by an adequate Cyberinfrastructure, various expert opinions have to be reconciled, eliminating contradictions and choosing the most encompassing solution in each case, security issues have to be dealt with adequately, etc. To cope with this we have developed a methodology (Fig. 1) capable to deal with different expert opinions and consolidate the results in a rule set with each rule weighted by the *degree of consensus* reached among the experts. The methodology consists of the following steps:

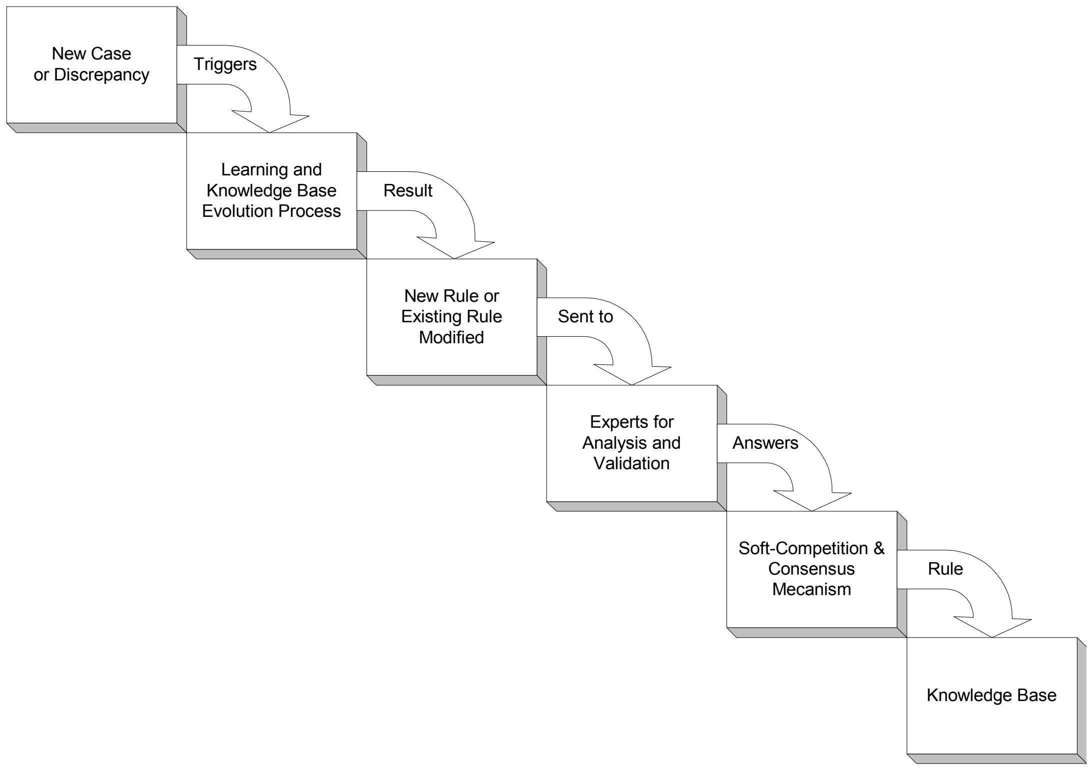

Fig. 1: Embedding various expert views into a knowledge base

- **Find the various patterns for each of the experts involved**. Each expert analyzes the existing rules encoding Dr. Crichton's expertise and expresses either agreement or disagreement (arguing wherever possible why they disagree) as well as adding new rules in case the existing ones do not encompass their whole expertise. This will define the respective expert's *profile*.
- **Investigate the differences and attempt to reconcile them**. Once each expert has defined their profile (that is their own rule base) – we will investigate the differences and attempt to reconcile them as much as possible based on a deeper understanding of each expertise, argumentation, and trying to identify the particularity of each case that led to a different rule/experience/pattern for different experts. To enable this difficult task we have developed a methodology involving a 'consensus analyzer', Fig. 2, to be presented next.
- **Determination of the Core Rule Set (Canadian Standard of Care)**. The result of this reconciliation process will be a *core rule set* shared by all the experts in the Canadian Glaucoma Ring. However each expert will be able to keep their own variations of the rule set due the particularities of their patients and geographic area. This enables each expert to consult others about how they would treat specific cases and compare the results. This "simulation" characteristic gives to the system a tremendous power when dealing with complex cases.

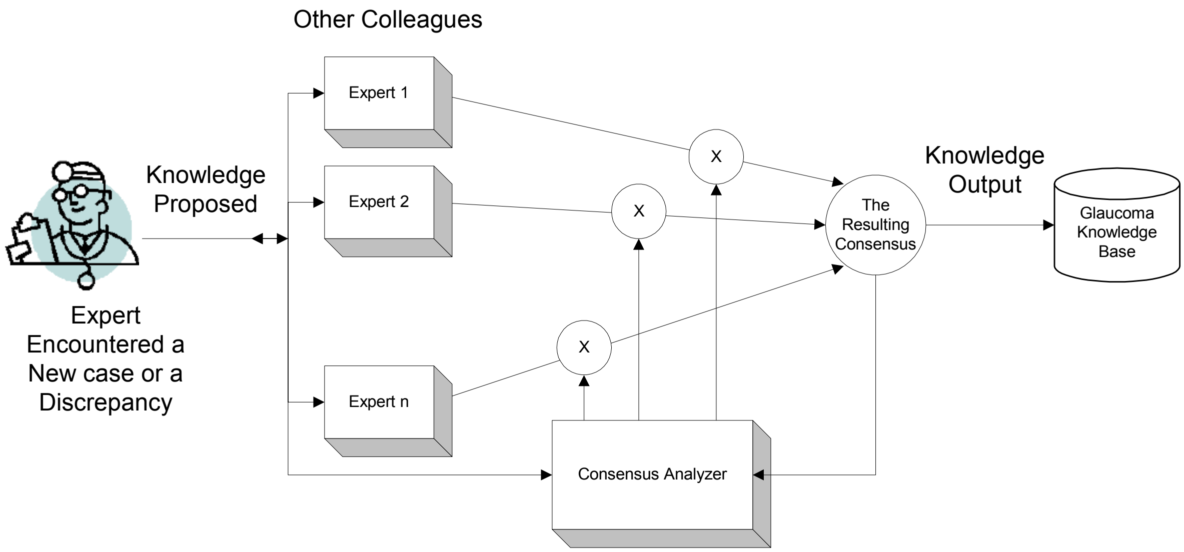

Fig. 2: Expert opinion reconciliation

3. ILLUSTRATIVE SCENARIO.

To illustrate how the consensus mechanism is used to solve the circumstantial expert discrepancies by reaching a consensus between them lets consider the following scenario, Fig 3. When consulting the Glaucoma Expert System to determine the follow-up for the current patient, the expert is faced with a completely new case. Accordingly, the system will inform the user that an accurate follow-up time cannot be determined, so it needs to learn a new rule. To enable this, the expert initiates a set of interaction rounds with other experts connected to the *Canadian Glaucoma Ring*, Fig 3. First the expert facing the case suggests a follow-up based on the current Patient's chart. Then he makes public the to the other experts (via the advanced Cyberinfrastructure [CAN]) the patient's electronic medical record, the images obtained from the advanced ophthalmic machines and the rule proposed by the expert. After evaluating the data, all the experts are capable to enter their opinions about this new case, Fig. 3 and participate in discussions until an acceptable degree of consensus is reached.

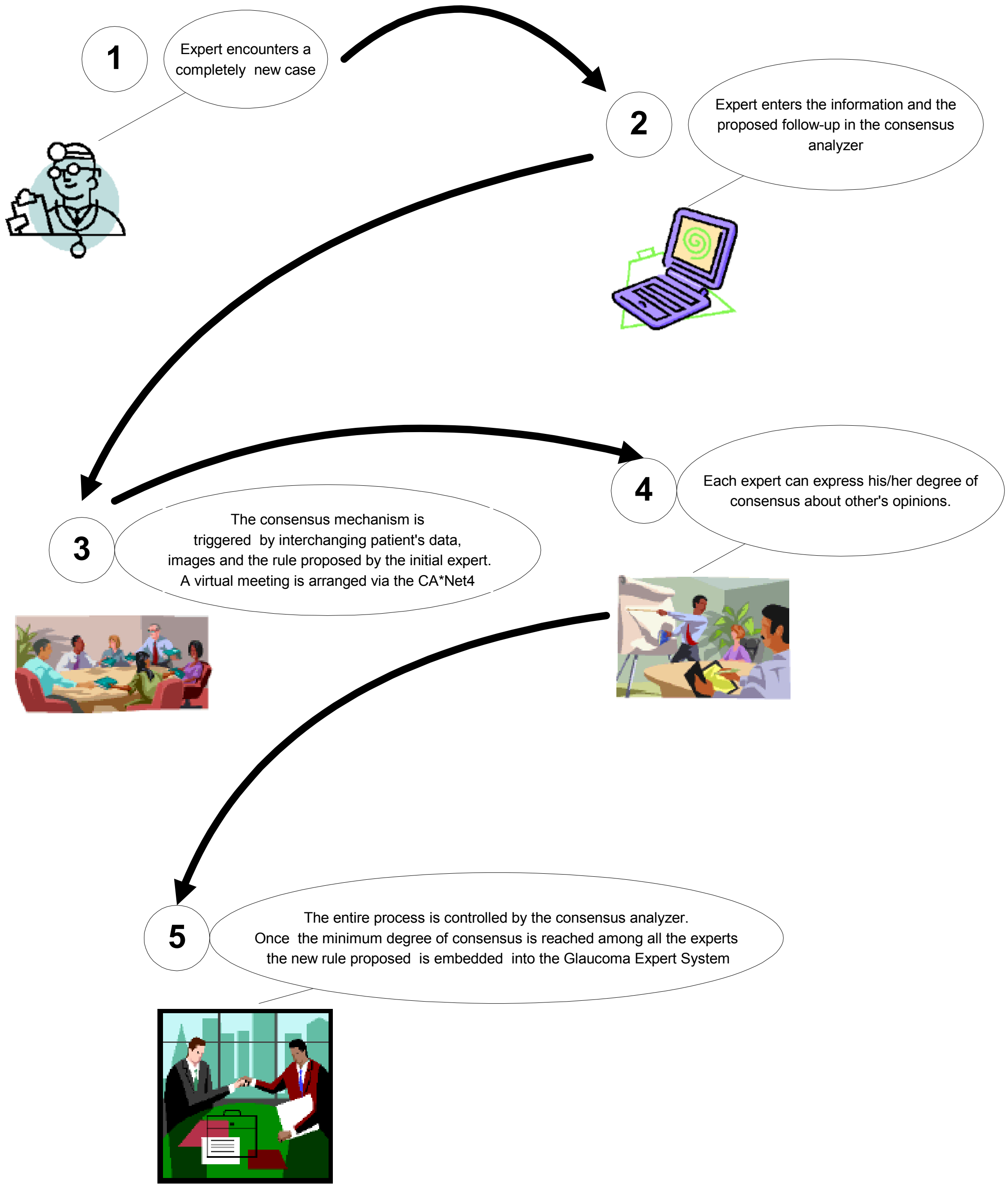

Fig. 3: Consensus Scenario

To avoid deadlocks and long trivial discussions this process is managed and controlled by the consensus mechanism which is detailed in the next Section.

4. THE CONSENSUS ANALYZER AT A GLANCE

The goal of group decision making typically is to reach a consensus concerning a desired action or alternative from among those considered in the decision process. In this context, consensus is taken to mean *a unanimous agreement by all those in the group concerning their choice*.

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 (Fig. 2) which evaluates the *distance* between each expert's opinion and the point of minimum consensus [Fries02] (the point of maximum conflict – where the expert opinions are most distant.) To evaluate this distance we use *soft competitive learning,* a very powerful methodology [Princi00][Ross95] which gives a fuzzy measure of the divergence in the expert opinions.

In contrast to the concept of *hard competition* that allows only one winner *soft competition* not only gives a clear winner but more "neighbours" who are winners with a lower degree. The neighbour rules are used as inputs into a consensus procedure (to be presented in the next section) that performs fuzzy measures of the consensus obtained for each rule. Based on this information a decision about the rule being considered is made. The rule awarded the highest degree of consensus is selected and then incorporated into the knowledge base. The *not neighbours* opinions are discarded.

5. CONSENSUS METRICS BY SOFT COMPETITION

Our goal is to define a typical value of distance to consensus by asking the experts to indicate their preferences for each characteristic of the fuzzy rule, expressing each preference as a fuzzy value.

We will consider the individual preferences as fuzzy relations. Lets suppose we are developing consensus in a universe X = {x1 ,x2 ,...,xn}; 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 $rij = rji = 0.5$.

Two common measures of preference are defined here as average fuzziness in R and average certainty in **R:**

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

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

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 pairwise rankings. Conversely the measure C(R) averages the individual dominance of each distinct pair of rankings.

The two measures are dependent:

$$F(R) + c(R) = 1$$

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

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

Where:

$$m(R) = 1 - (2/n)^{1/2} \quad \text{for a Type I consensus relation}$$
$$m(R) = 0 \quad \text{for a Type II consensus relation}$$

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 (which 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.

6. ENABLING EXPERT INTERACTIONS

To enable expert interaction we use a previously developed web-centric extension of the glaucoma expert system [Uli03a] [UliGra03] [UliGer02] (GlaucoMAX[1], Fig. 4) into which we pluged the users interface for the Consensus Analyzer enabling expert opinions reconciliation (Fig. 5).

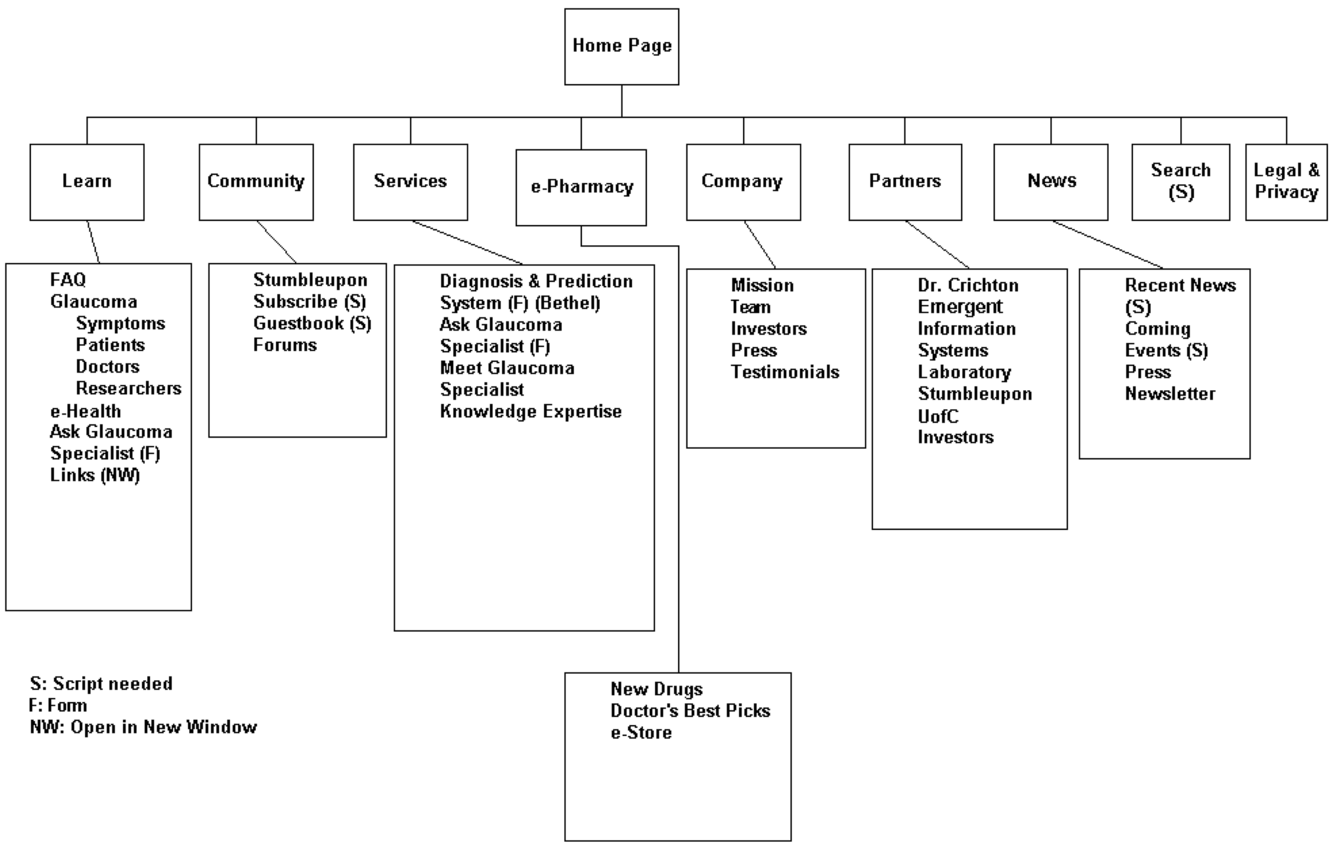

Fig. 4: GlaucoMAX.com: Web-based services for glaucoma communities

[1] www.GlaucoMAX.com

GlaucoMAX is an interactive portal supporting the web-based accessibility to our Glaucoma Expert System as well as a broader spectrum of services for the glaucoma community such as: discussion groups, forum, document management, community services, E-Pharmacy and lots more.

GlaucoMAX visitors and community members can actively discuss different issues, exchange experiences, meet often and get to know each other better. GlaucoMAX users can collaborate with each other using built-in tools like listings of available communities, threaded discussion groups, live chats, online meetings, event scheduling, online business cards (user profiles), user search, surveys, document folders, special interest groups, and a calendar of all scheduled events.

Exchange of expert information and expertise among the CANARIE Glaucoma Ring for the improvement/validation of the Canadian standard of care (Fig. 5). The initial Core Glaucoma Ring will be subsequently expanded to encompass other Canadian and International glaucoma experts that will join our GlaucoMAX system to benefit from the shared expertise.

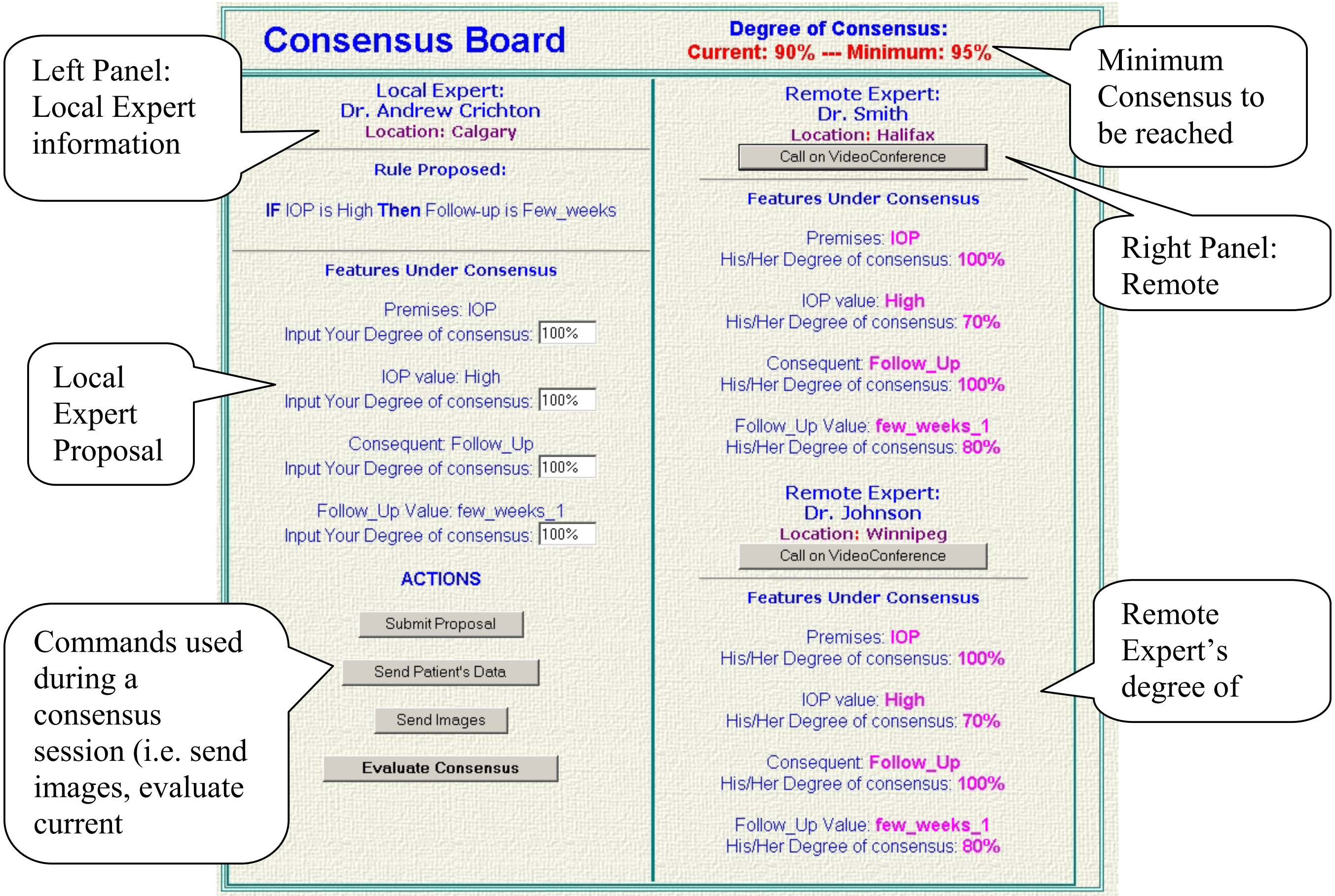

Figure 5: User Interface Enabling Expert Interaction to Reach Consensus

7. CONCLUSIONS

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 experts located in different parts of the world has to be supported by an adequate Cyberinfrastructure, various expert opinions have to be reconciled, eliminating contradictions and choosing the most encompassing solution in each case. This paper introduced a methodology capable to deal with different expert opinions and consolidate the results in a rule set with each rule weighted by the *degree of consensus* reached among the experts. Application to the definition of standards of care for glaucoma monitoring and follow-up has proven the success of our methodology.

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