Fuzzy Cognitive Map Scenario-Based Medical Decision Support Systems for Education

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Abstract— **Soft Computing (SC) techniques are based on exploiting human knowledge and experience and they are extremely useful to model any complex decision making procedure. Thus, they have a key role in the development of Medical Decision Support Systems (MDSS). The soft computing methodology of Fuzzy Cognitive Maps has successfully been used to represent human reasoning and to infer conclusions and decisions in a human-like way and thus, FCM-MDSSs have been developed. Such systems are able to assist in critical decision-making, support diagnosis procedures and consult medical professionals. Here a new methodology is introduced to expand the utilization of FCM-MDSS for learning and educational purposes using a scenario-based learning (SBL) approach. This is particularly important in medical education since it allows future medical professionals to safely explore extensive "what-if" scenarios in case studies and prepare for dealing with critical adverse events.**

I. Introduction

Medical Decision Support Systems are mainly used to consult and support medical professionals. Most of the times they are developed in methodologies to resemble human-like decision making procedures. Soft Computing modelling methodologies such as Fuzzy Cognitive Maps (FCMs) are similar to the human reasoning approach and they have been successfully employed in the development of sophisticated systems and have been effectively applied in a variety of application domains. Human knowledge and experience are reflected in the development procedure and the infrastructure of FCMs, making them suitable for modelling the decision-making and reasoning approach in a human like manner. Human experts that have observed and know the operation of a system and its behavior under varying circumstances develop the FCM structure. Especially, in the medical field, the decision making procedure is often critical and time-sensitive.

FCM MDSSs are constructed based on an approach that formalizes understandings of conceptual and causal relationships [1]. Such a FCM Medical Decision Support System can be used to teach reasoning and decision-making skills and to prepare students as future problem-solving clinicians. This usage of FCM-MDSSs is proposed here and how it could be achieved by introducing Scenario-Based Learning within an FCM MDSS is presented. Scenario-based learning (SBL) uses interactive scenarios to support active learning strategies in such a way that learners apply their subject knowledge, critical thinking and problem solving skills in a safe, real-world context (Errington, 2010). Therefore, the learning takes place without the pressure, constraints and stress of being actually involved with a patient in a critical situation.

Scenario-based learning (SBL) refers to any educational approach that involves the intentional use, or dependence upon scenarios to bring about desired learning intentions. Scenarios within this context may be a given set of circumstances, a description of human behavior, trigger events, critical incidents or even a human dilemma, [2-4]. SBL could be particularly useful for medical decisions that are complex and potential outcomes have a degree of uncertainty. Therefore, within the context of this work scenarios are given circumstances, trigger events and behaviors for a particular Medical Decision Support case study that has been modeled using the soft computing modeling tool of Fuzzy Cognitive Maps. These scenarios can be preselected by the trainer in order to expose the learners to potential critical events or may be explored by the learners on their own as "what-if" questions allowing altering of a set of conditions and following how the outcome of the case is altered.

Fuzzy Cognitive Map- Medical Decision Support Systems (FCM-MDSSs) have been successfully used for differential diagnosis [5], making decisions during labor [6-8], decision making choices in external beam radiation therapy [9], emergency room triage [10] and post-triage decisions [11], and many other medical applications. FCMs have been used as an education tool for improving the perception of a complex socioscientific issue related to climate change for student teachers [12]. Here FCMs as education tools are taken one step further to allow education of Medical Decision Support procedures based on Scenarios

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and as an example a FCM-MDSS previously developed by the authors for Labor is explored.

This paper is organized in 5 sections including this introduction. Section 2 introduces and justifies the procedure of learning using scenario-based FCM-Medical Decision Support System. Section 3 applies the methodology for scenario-based learning for a known medical decision problem i.e. the MDSS for labor and section 4 describes a learning scenario for the specific application. Finally section 5 concludes the paper and presents some further future research directions.

II. Learning Using Scenario-Based FCM-MDSS Models

Once a Fuzzy Cognitive Map MDSS for a particular application area is developed based on the input (data/information) and output (decision) concepts, this can be adjusted to provide user manipulability and interactivity, i.e. the ability to selectively alter values of the concepts, based on real-life situations and observe the effect of factor-concepts at decision-concepts. Learning scenarios can be constructed by manipulating various parameters/ factor concepts of the FCM model to reflect changes in, for example, patient status, trigger events, human intervention. The outcomes of each particular change are reflected by the new values of the outcome concepts as well as the interrelated factor concepts that are directly or indirectly affected by the change introduced by the scenario.

This type of learning model allows integration of theoretical knowledge with in depth exploration of the decision making process as well as critical analysis of "what-if" situations [13]. These speculative-based scenarios could prepare medical professionals for clinical practice allowing them to experience a much wider range of potentially critical situations in comparison to a typical education setting. At the same time this particular kind of case based-process allows them to follow the impact that various changes have not only on the final outcome, but also on the intermediate values of components of the model.

The use of FCM for case learning scenarios has important characteristics:

- They are easy to understand, develop and apply since they are designed in a highly intuitive manner.
- FCMs have a high level of information integration allowing a wide variety of types of information to be represented using discrete and continuous scales.
- They can easily be adjusted for new information and new situations.
- The availability of feedback and non-linearities within the system model uncovers potentially critical situations that may arise.

Here, the FCM-MDSS that has been developed and used in Obstetrics area [7-8] is used to develop scenario-based learning. Through the rich scenario building capabilities, a medical doctor is able to manipulate parameters that are measurements or events and follow through to the output decision (outcome) comparing to his own and at the same time explore "what-if" scenarios.

The FCM Scenario-Based DSS model is run using a series of preset sets of parameter values representing the various cases and aiming to mirror the authentic clinical reasoning process; these can easily be expanded with scenarios simulating the evolving of many different patient situations.

III. FCM Scenario-Based MDSS for Modeling Labor

During the crucial stage of labor, obstetricians evaluate the entire situation involving the mother and the baby and they take into consideration a wide variety of factors in order to conclude to a decision. The decisions, for example, may be related to the well-being of the infant requiring as close to full-term delivery or to the risk to the maternal health of continuing with the pregnancy outweighing the risk to the infant being delivered.

Therefore, a very significant decision of obstetricians is to determine whether they will proceed with a Caesarian section or a natural delivery based on physical measurements, including fetal heart rate (FHR), the interpretation of the cardiotocograph (CTG) and other essential indications and measurements. The decision, in essence, is based on "weighing" the risks of maternal and/or fetal health complications. This particular Case Study refers to the decision of an emergency Caesarean section when there is a fetal distress (because of abnormal CTG and/or acidosis and/or cord prolapse and/or abruption) or obstructed labor or prolonged labor or delivery at maternal risk rather than that of a routine predetermined caesarean section. The factors that are taken into consideration, in many cases, have intrinsic fuzziness, they are described by obstetricians using linguistic terms and they are characterized such as: stable, moderate, intense, increased etc.

Obstetricians consider a variety of maternal indications and fetal indications; the labor surveillance monitoring has three main components: fetal condition, progress of labor and maternal conditions. Fetal condition is mainly reflected in the interpretation of the Fetal Heart Rate (FHR) signal and some physiological measurements, e.g. color of liquor (meconium) and vaginal examinations. Progress of labor is based on physiological examinations (descent of head, dilatation of the cervix) measurement of the strength and frequency of uterine contractions, the drugs given to augment/induce the labor and the time passed. Maternal conditions measured include pulse rate and blood pressure.

Decision Support Systems and particularly those based on Fuzzy Cognitive Maps have successfully modeled the labor procedure. They are able to handle situations where clinicians are not always in agreement on importance of parameters for example for normal FHR and uterine activity, especially in situations involving induction or augmentation of labor. Clinical disagreements exist as well as to what constitutes excessive FHR because of uterine activity and what management strategies to undertake when it occurs [14]. Therefore, the FCM Scenario-Based MDSS is particularly well suited for training medical clinicians.

Here, the specific Fuzzy Cognitive Map Case Study Model has been developed to model the way by which the obstetrician makes a decision for a normal delivery or a caesarean section. It is a dynamic procedure, where the obstetrician evaluates whether either the mother or the fetus are at serious risk and thus, he/she has to intervene by stopping the physiological delivery and performing an emergency caesarean section instead of continuing with natural delivery. According to evidence based practice, labor abnormalities and unnecessary caesarean birth, can be associated with risks to the mother and/or infant thus making it important for the best decision to be made for both.

The FCM-MDSS takes into consideration factors based on the main parameters that an obstetrician evaluates. These parameters constitute the 13 concepts of the FCM Case Study model [7-8], shown in Figure 1, which are:

- C1- Decision for Normal Delivery
- C2- Decision for Emergency Caesarian section
- C3- Fetal Heart Rate (FHR) evaluation
- C4- Meconium (Color of liquor) (from clear to mild blood staining and to heavier bleeding)
- C5- Time duration of labor in comparison to progress of the delivery
- C6- Contractions of the uterine (strength and frequency)
- C7- Medication (quantity of oxytocine given to mother)
- C8- Diastole of Cervix (measurement)
- C9- Evaluation of Cervix effacement (4 linguistic values)
- C10- Position of placenta (3 linguistic values)
- C11- Position of fetus (5 linguistic values)
- C12- Contraindication
- C13- Fetal weight estimation (3 linguistic values)

It is important to note that concepts are interrelated; these interrelations are illustrated through a corresponding weight, W_{ij}, representing the influence of Concept C_i to concept C_j. The value of each interrelation is included in the FCM-MDSS model according to clinical evidence based practice through an assignment procedure where experts suggest linguistic values that are aggregated and transformed into numerical ones.

An FCM-MDSS developed by experts and used to support obstetricians' decision making [6-7] may also be used for building different training scenarios. Given the different values that concepts C3-C13 may take and the interrelation among concepts, scenarios are built on cases by varying the parameters appropriately to reflect changes. Figure 1 presents a training scenario where only the concepts indicated by the yellow squares are tested: C3- Fetal Heart Rate (FHR) evaluation, C4- Meconium (Color of liquor), C7- Medication, and C8- Diastole of Cervix

The values of these concepts are manipulated by the learner to match the case scenario; then the FCM MDSS for labor is allowed to run step-by-step observing the changes of the various concepts as the FCM algorithm evolves. The final outcome is one of the decision concepts C1- Caesarian Section or C2- Normal Delivery.

Due to the fact that in complex systems, such as medical systems, there are unexpected events, the FCM Scenario-

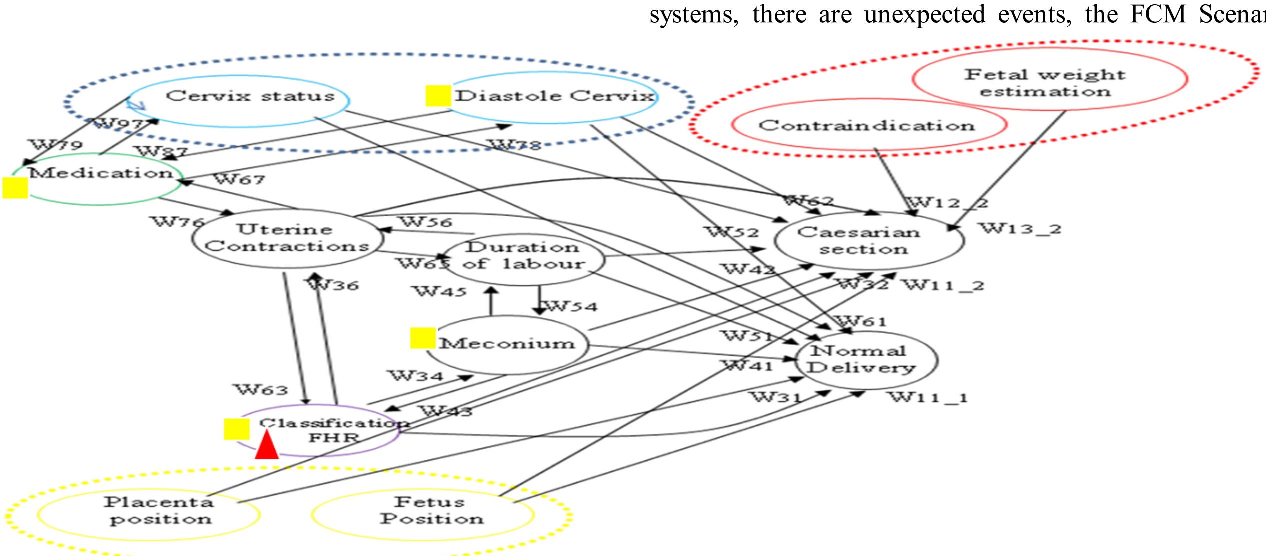

Figure 1. FCM Scenario-Based MDSS with alarm triggers for Labor Decision Support

Based MDSS allows the possibility of trigger/alarm events that may alter the outcome unexpectedly. Such an event is, for example, Concept 3- Fetal Heart Rate (FHR) evaluation, as indicated by the red triangle. These trigger events occur while the user is running the FCM Scenario-Based MDSS and as a result may affect a number of concept values, as well as the outcome. This provides the learner the opportunity to observe how dynamic high-risk and unusual case scenarios evolve, allowing learning in a safe environment without placing actual patients at risk.

Here, the development of a Fuzzy Cognitive Map to model the way by which the obstetrician makes a decision for a normal delivery or a caesarean section is investigated. It is a dynamic procedure, where the obstetrician evaluates whether either the mother or the fetus are at serious risk and thus, he/she has to intervene by stopping the physiological delivery and performing an emergency caesarean section instead of continuing with natural delivery. According to evidence based practice, labor abnormalities and unnecessary cesarean birth, can be associated with risks to the mother and baby, whereas excessive uterine activity may have a negative effect on fetal oxygenation during labor and fetal acid-base status at birth [14]. Also, decision support developed by Warrick et al. [15] focuses on hypoxia detection based on recordings of the uterine pressure and fetal heart rate, which are routinely monitored during labor.

IV. Example Scenario

As an example learning scenario we consider a patient at 40 weeks gestation period in the first stages of labor with: temperature 36.7◦C, BP 120/80 mm Hg, pulse rate of 110 beats/min and having clear liquor draining. The fetal heart rate according to the monitor is 155 beats/min. The estimated birth weight is 3 kg. All these indications would lead to a normal delivery and thus, the FCM MDSS for labor is run and concludes to the decision of Normal labor. But according to the scenario, during the labor procedure: the liquor becomes meconium stained while the other parameters would initially remain the same would require a careful examination of factors that are influenced by this change. Presence of meconium is an indication of fetal distress. Within the FCM Scenario-based MDSS, this is a trigger event altering the FHR to 114 beats/min, implying the fetus is in distress; thus, the FCM MDSS would now conclude to emergency caesarean delivery. Therefore, the learner is able, through this approach, to follow easily the cause-effect of trigger events to outcomes.

V. Conclusion

A Medical Decision Support System combines the human clinical experience acquired through practice with widely accepted systematic analytic approaches. Fuzzy Cognitive Maps have been extensively used for Decision Support in a variety of clinical applications. Here the learning usage of a Fuzzy Cognitive Map scenario based Medical Decision Support System (FCM-MDSS) is explored. A variety of scenarios many be included that reflect the decision making process by using "what-if" approach and/or trigger events to understand how a decision is made and what conditions need to be addressed in order to avoid adverse patient events.

The scenario-based FCM-MDSS learning procedure has been presented for the training of labor decision making procedure. The development the learning procedure for this FCM-MDSS and a learning scenario are presented. In future work, an integrated learning system for the scenario-based obstetrician FCM-MDSS will be developed that will include many different scenarios and would be used in training medical professionals.

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