27

Fuzzy Cognitive Map Decision Support System for Successful Triage to Reduce Unnecessary Emergency Room Admissions for the Elderly

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Abstract. This work presents a Fuzzy Cognitive Map Medical Decision Support System (FCM-MDSS) for the hospital admission procedure of elderly patients. The FCM-MDSS is applied to the Emergency Department (ED), where elderly patients arrive requesting medical assistance. Here a new hybrid methodology is introduced to develop FCM-MDSS exploiting human experience and accompanied by available bibliographic information. It is based on the widely applied Triage complex decision-making process and the generally accepted procedures while trying to minimize unnecessary admissions as well as over/under-triaging. The FCM-MDSS is evaluated for known cases of real patients arriving at the ED from the literature.

27.1 Introduction

Triaging involves an initial sorting of patients who arrive at the emergency room, usually called emergency department (ED), by rapidly identifying patients requiring immediate care due to urgent, life-threatening conditions as well as assessing the severity of the problem so as to ensure that care is appropriate and timely [11].

Triage is a complex decision-making process, and as a result several triage scales have been designed corresponding to decision support systems [5] to guide the triage nurse to a correct decision.

Unfortunately, in the emergency room elderly patients, as a general rule, undergo more diagnostic testing and have longer length of stays than younger ones, [4, 42] because of their multiple health problems and as a result, they usually use more resources. The Emergency Department (ED) all over the world is faced with a continuous increase in visits [22], partly due to its excessive use for non-urgent problems. The elderly frequently visit the ED because of their increased prevalence to chronic-degenerative diseases, susceptible to frequent exacerbations. Since the aging population is destined to increase further, providing quality

R. Seising and M.E. Tabacchi (Eds.): *Fuzziness and Medicine*, STUDFUZZ 302, pp. 415–436.
DOI: 10.1007/978-3-642-36527-0_27 © Springer-Verlag Berlin Heidelberg 2013

cost-effective care of these patients with multiple, complex conditions is a very crucial problem [36, 40].

Elderly patients are admitted to the hospital, most of the times, unnecessarily due to the complexity of decision-making about their health conditions (since the clinical problems and needs of older patients are often substantially different from those of younger patients) and they may be accompanied by cognitive or functional deterioration. In addition to this, many older patients have multiple co-morbidities, polypharmacy and further complex health and social care needs. Thus, they have higher readmission rates. Many physicians and junior doctors are not specially trained in geriatric medicine so they may have difficulty in assessing the patient's condition as being of an intermediate risk or requiring just monitoring and observation [8, 9, 26].

Besides the various clinical tests and laboratory exams run in the ED and the medical history taking, various questionnaires are used to assess patient status. For example, risk factors known to have often-adverse health outcomes are used by the questionnaire Identification of Seniors at Risk tool to detect impaired functional status and depression at the evaluation [37].

It is significant to mention that in a sample of 50 randomly selected cases of ED admissions patients 65 years or older, discrepancies were found between the medical staff and expert nurses in 20 cases: where staff nurses had undertriaged 13 patients and overtriaged 7 patients [23].

Nowadays, the new technological advances, the utilization of ICT in the hospital and all the new technology based diagnostic tests produce a huge amount of data being available to make decisions. But under the tight time constraints, as is the case of Emergency Department, only part of this data is utilized. On the other hand, the limited number of medical professionals requires the efficient exploitation of human resources to make the right decisions and leads to the need to develop automatic decision making systems, such as in the process of triage in the emergency departments.

Generally speaking, Medical Decision Support Systems have a crucial role in today's complex health systems, since it is required to combine the human clinical experience acquired through hospital practice with widely accepted systematic analytic approaches. Such hybrid methods that combine both of them are in favor of medical professionals. One such approach is the soft-computing modeling methodology of Fuzzy Cognitive Maps, which is discussed in the next section.

The aims of this research is to present a Fuzzy Cognitive Map Medical Decision Support System (FCM-MDSS) for supporting in the triaging of elderly patients arriving in the emergency room for medical assistance while trying to minimize unnecessary admission and/or over/undertriaging. A Fuzzy Cognitive Map MDSS architecture is developed and described here based on existing medical protocols on patient triaging, along with the consultation and support of emergency care nurses and physicians.

27.2 Fuzzy Cognitive Maps

Fuzzy Cognitive Maps (FCMs) belong to Soft Computing approaches that are introduced to create advanced modeling systems aiming to resemble human-like reasoning. FCMs have successfully been applied to a wide range of problems in many engineering application domains, mainly to model complex systems and develop advanced diagnosis and/or decision support systems. Human knowledge and experience is reflected in the creation procedure and the infrastructure of FCMs, making them suitable for modeling the decision-making and reasoning approach in a human-like manner. Especially in the medical field, the decision-making procedure is often crucial and must be achieved in a timely manner.

Fuzzy Cognitive Maps with their modifications integrate aspects of fuzzy logic, neural networks, semantic networks, expert systems and they are usually supplemented with other soft and hard computing methodologies. An FCM is illustrated as a causal graphical representation consisting of interrelated concepts [19]. FCMs are fuzzy signed directed graphs permitting feedback, where the weighted edge w_{ij} from causal concept C_i to affected concept C_j describes the degree with which the first concept influences the latter, as is illustrated in Fig. 27.1. FCMs are characterized as fuzzy feedback models of causality, where the weighted interconnections among concepts of the FCMs present causality among concepts and creating an interconnected network of interrelated entities, like an abstract mental model. Feedback interconnections are permitted along with if-then inferencing; that permits FCMs to model complex nonlinear dynamic systems. FCMs have the ability to include hidden nonlinear dynamics.

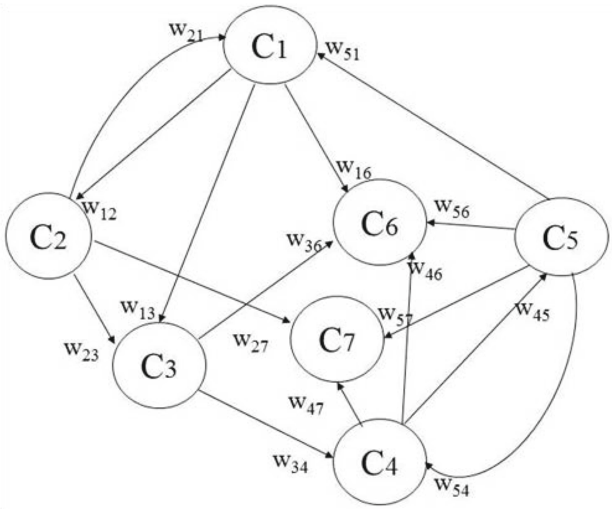

Fig. 27.1 The Fuzzy Cognitive Map model

The concepts of the Fuzzy Cognitive Model stand for the main characteristics comprising an abstract model of any system; each concept of the FCM represents a granular entity such as state, variable, input, output, event, action, goal, trend of the system that is modeled as an FCM. The value of every concept C_i is A_i and it results from the transformation of the real fuzzy value of the system's variable, for which this concept stands for, in the interval $[0,1]$. Thus, when the initial concept value is produced, then this value is updated as it is computed through the interaction of the interconnected concepts with the corresponding weights. Generally, between two concepts there are three possible types of causal relationships that express the type of influence from one concept to the other. The weight of the arc between concept C_i and concept C_j could be positive $(W_{ij} > 0)$ which means that an increase in the value of concept C_i leads to the increase of the value of concept C_j, and a decrease in the value of concept C_i leads to the decrease of the value of concept C_j. Or there is negative causality $(W_{ij} < 0)$ which means that an increase in the value of concept C_i leads to the decrease of the value of concept C_j and vice versa. The value A_i of concept C_i expresses the degree of its corresponding physical value. Fuzzy Cognitive Map is used to model the behavior of a system; during the simulation step, the value A_i of a concept C_i is calculated by computing the influence of the interconnected concepts C_j's on the specific concept C_i following the calculation rule:

$$A_i^{(k+1)} = f(A_i^{(k)}) + \sum_{j=1, j\neq i}^{N} A_j^{(k)} \cdot w_{ji} \tag{27.1}$$

where $A_i^{(k+1)}$ is the value of concept C_i at simulation step $k+1$, $A_i^{(k)}$ is the value of concept C_i at simulation step k, w_{ij} is the weight of the interconnection from concept C_i to concept C_j and f is the sigmoid threshold function:

$$f = \frac{1}{1+e^{-\lambda x}} \tag{27.2}$$

where λ is a parameter that determines its steepness. In this approach, the value $\lambda = 1$ has been used. This sigmoid function is selected since the values A_i of the concepts lie in the interval $[0,1]$.

27.2.1 Fuzzy Cognitive Maps and Decision Support Systems

Fuzzy Cognitive Maps have been successfully used to develop Decision Support Systems (FCM-DSS) for control engineering applications [20, 45]; urban design [55] in banking Business [54]; IT projects risks scenarios [35]; qualitative dynamic systems in humanities, social sciences and economics [6, 7]. Especially in the medical decision support systems, FCMs have been used for differential diagnosis [13], to determine the success of the radiation therapy process estimating the final dose delivered to the target volume [30]; for decision making in obstetrics [43] and many other applications. FCMs are particularly well suited for such applications, since medical systems are complex systems involving inexact, uncertain, imprecise and ambiguous information [15].

Fuzzy Cognitive Maps have been successfully used to develop Medical Decision Support System (MDSS). A specific type for Medical Diagnosis is the Competitive Fuzzy Cognitive Map (CFCM) [14, 15] which consists of two main types of concepts: diagnosis-concepts and factor-concepts. Fig. 27.2 illustrates an example CFCM model that is used to perform medical diagnosis. Here the concepts of the FCM and the causal relations among them that influence concepts and determine the value of diagnosis concepts indicating final diagnosis are illustrated.

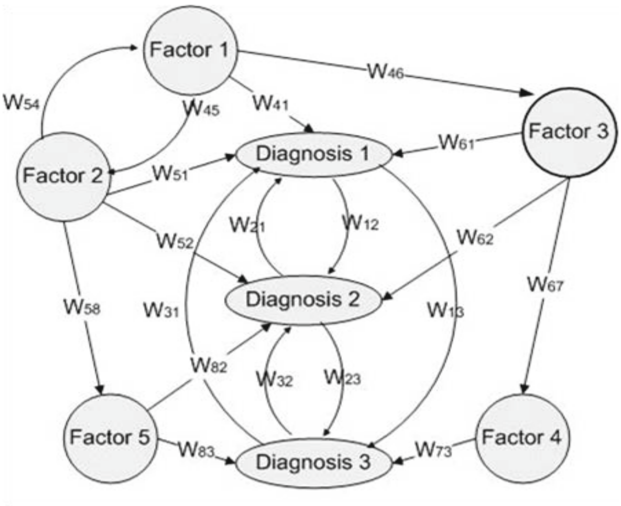

Fig. 27.2 A CFCM model for Medical Diagnosis

In the CFCM model each diagnosis concept represents a single diagnosis, which means that these concepts must be mutually exclusive because the main intention is to infer always only one diagnosis. This is the case of most medical applications, where, according to symptoms, medical professionals conclude to only one diagnosis and then they decide accordingly the most appropriate the treatment. Actually, this comes from the medical axiom: “every patient has only one disease” but may represent many symptoms related to different diseases but all are results of the primitive disease. The general diagnosis procedure is a complex process that has to take under investigation a variety of interrelated factors, symptoms and functions. Usually, in any real world diagnosis and decision problem, many different factors have to be taken into consideration to conclude the most appropriate diagnosis. In accomplishing any diagnosis process, some of these factors are complementary, others are similar and even others are conflicting.

In the Competitive Fuzzy Cognitive Map model, the factor-concepts represent inputs into the MDSS, their values correspond topatient data, observed symptoms, patient records, experimental and laboratory tests etc. These can be dynamically updated based on the system interaction, whereas the decision-concepts are considered as outputs where their estimated values outline the possible diagnosis for the patient. It should be mentioned that the real strength of FCMs is their ability to model and describe complex systems and handle successfully with situations where there are feedback relationships and interrelationships between the factor concepts. Thus, interrelations between factor-concepts can be included in the proposed medical decision-support model. Such interconnections are shown in Fig. 27.2 where the "competitive" interconnections between diagnosis concepts are also illustrated.

27.3 Emergency Department Triaging

27.3.1 Typical Scenario for Patient Arriving at Emergency Department

When a patient first arrives in the Emergency Department (former known as the emergency room), the first stop is triage. In triage, a trained and experienced registered nurse typically prioritizes each patient's condition into one of five general categories. This is done according to the Emergency Severity Index (ESI) which was designed for use in ED triage by the US Department of Health & Human Services. The ESI is a five-level categorization algorithm that prioritizes patients into five groups from 1 (most urgent) to 5 (least urgent) on the basis of acuity (i.e. seriousness) and the number of resources that the patient may need to receive proper care [53]. A well-implemented ESI program helps hospital ED rapidly identify patients in need of immediate attention, while at the same time also identify patients who could safely and more efficiently be transferred to other departments rather than the Emergency Department. Triage staff use specific criteria to determine each patient's acuity. For example they rapidly interview the patient, take patient's vital signs (blood pressure, pulse, oxygen saturation level and respiratory rate). If the patient is complaining about pain they are asked to self-assess on a scale of 1-10 and to identify the location of the pain. Additionally, nurses ask them what the major complaint was that brought them into the ED. From the above and other information collected, the triage nurse produces an Emergency Severity Index (ESI) score [16], assessing the patient's condition. Based on the ESI score, the clinical staff schedules to check back with the patient on a timely basis based on the patient's condition [52].

27.3.2 Emergency Department Triaging Details

To ensure patient safety and provide quality services, hospitals must be certain that each patient entered to the emergency department (ED) receives the appropriate care at the right time. Triage is a means by which this is ensured. An experienced triage nurse evaluates the patient's condition, as well as any changes, and determines their priority for admission to the ED and their need for treatment [3]. This is necessary to make patient assessments in order to properly anticipate the resources needed for each patient and recognize abnormal vital signs; thus, tools such as the ESI are "only as good as the person using them" [39]. For example, a study conducted among 305 triage ratings comparing triage nurses' ratings to retrospective ratings assigned by an expert panel of emergency department triage nurses revealed an agreement in approximately half of the cases [47].

Of course the primary goal of triage is to decrease morbidity and mortality for all ED patients. However, a gap in the knowledge exists regarding the real time reasoning process of clinical decision making that occurs during ED triage [5, 17].

The ESI uses the following scale based on decision points to determine its categories [3, 16]:

- *ESI category 1-Emergent:* patient intubated, without pulse or respiration, or unresponsive. i.e the patient requires immediate life-saving intervention so as to prevent loss of life, limb, or eyesight,
- *ESI category 2-Urgent:* patient is in a high-risk situation, or confused, lethargic or disoriented, or in severe pain, or danger zone vital signs.
- *ESI category 3-Acute:* patient is in need of many resources to be taken care of. These may include, for example, Laboratory Tests, ECG, X-rays, CT-MRI-ultrasound-angiography, IV fluids, specialty consultation, complex procedures etc.
- *ESI category 4-Routine:* patient is in need of one resource.
- *ESI category 5-Non urgent:* patient is in need of no resources.

It is interesting to note that specific guidelines do not exist within the triage procedure and a great deal is relied on the experience of the triaging nurse. For example the Joint Commission on Accreditation of Healthcare Organizations does not specifically state a standard for vital signs. The organization does assert that physiologic parameters should be assessed as determined by patient condition but JCAHO does not require vital signs to be done during triage. Vital signs are usually recorded if the triage nurse determines they may be useful [16].

27.3.3 Triaging Elderly Patients

In a study of 929 Emergency Department visits of patients older than 65, it was found that in general the ESI algorithm demonstrates validity. However, patients, particularly elderly ones (but not only), frequently present to emergency departments (EDs) with non-specific complaints (NSCs) such as "not feeling well," "feeling weak," "being tired," feeling "dizzy,"or simply being unable to cope with usual daily activities [49]. Studies have shown that up to 20% of older individuals presenting to the ED have no specific complaints [50] while 50% of older individuals without specific complaints suffered from an acute medical problem [33] and were at a particularly high-risk group for adverse outcomes (e.g. functional decline, dependence, and death) [24]. The difficulty arising from the uncertainty in the diagnostic process for these patients may lead to ineffective or suboptimal triage of these patients [27].

Weakness is a common presenting symptom in patients in the emergency department (ED), and is an obvious challenge to ED physicians [28]. A number of all non-trauma patients (19.7%) admitted to the ED complained of some form of weakness easily recognized by ED nurses and ED physicians. Localized weakness is well described and may be called a “stroke-like symptom” [34]. Generalized weakness is most often caused by serious disease requiring immediate attention [28].

Frail elderly patients admitted without specific complaints are at risk of inappropriate or delayed evaluation due to undertriage at the door of the ED. A more specific geriatric assessment should be integrated early in the triage process of these patients. Emergency department admission decisions for elderly adults rely on various medical and social factors, along with the availability of timely follow-up [31]. These may include:

- *Patient data and test results* (e.g., Age, ESI level, Heart rate, Diastolic blood pressure, lab results)
- *Patient Chief complaints* (e.g. General weakness, Fainting (syncope), Chest pain, Neurologic weakness, Shortness of breath, Labored or difficult breathing, Vomiting, Abdominal pain, Decreased appetite, Blood in stool, Blood in urine, Painful urination, Patient History (e.g.Nonischemic heart disease, Cerebrovascular disease (stroke), Pneumonia, Anemia, Diabetes)
- *Cognitive/Psychiatric state*
- *Injury* (e.g. Leg / hip fracture / dislocation, Head / neck / facial injury)
- *Index scores* (e.g. Charlson Comorbidity Index Score)
- *Other factors such as:* patient lives alone, suspected elderly abuse/neglect, recently discharged, polypharmacy, adverse drug affects, alcohol abuse.

These general components contribute with varying degrees to the decision an emergency care physician makes to admit or discharge the elderly patient after a visit to the ED.

27.3.4 Decision Support Systems for ED Triage

The significance of the ED triage assessment has lead researchers to investigate and developed Decision Support Systems for ED Triage. A Web-based triage decision support tool (eTRIAGE) based on the Canadian Triage and Acuity Scale (CTAS) has been developed in Canada and is now used in a number of ED regional hospitals. Decision support, such as an electronic triage tool, can assist the medical staff performing triage by displaying the key elements for each complaint, so that to help define the criteria for each triage level. It is expected that experienced triage staff are better able to estimate a triage level based on their initial clinical assessment than those with less experience, giving them greater confidence to override the tool if required [56].

Wilkes and colleagues [52] proposed a system of cognitive agents and a supervisor, dubbed the TriageBot System that would gather both logistical and medical information, as well as take diagnostic measurements, from an incoming patient for later use by the triage team. TriageBot would also give tentative, possible diagnoses to the triage nurse, along with recommendations for non-physician care.

San Pedro and colleagues [38] proposed a Mobile Decision Support for Triage in Emergency Departments based on decision support strategies that include the use of heuristic and fuzzy reasoning that allow the system to support nurse's ability to use his/her expert judgment and justify his/her decision using natural language.

Finally, Aronsky et al. [1] described an integrated, computerized triage application which exchanges information with other information systems, including the ED patient tracking board, the longitudinal electronic medical record, the computerized provider order entry, and the medication reconciliation application. The application includes decision support capabilities such as assessing the patients' acuity level, age-dependent alerts for vital signs, and clinical reminders.

Research using empirical results from a clinical trial of an emergency DSS with a decision model based on expert knowledge has shown [18] that there are differences in how clinician groups of the same specialty, but different level of expertise, elicit necessary emergency DSS input variables and use these variables in their clinical decisions.

The following sections will introduce a novel development approach for a Decision Support System based on Fuzzy Cognitive Maps and will describe, in detail, how to include actual factors taken into consideration, as well as to present the outcomes for case studies presented to the emergency room.

27.4 Fuzzy Cognitive Maps Designing and Development Procedure

Since the ESI instrument categorizes ED patients into 5 mutually exclusive categories, the type of Fuzzy Cognitive Map that will be used here is the Competitive Fuzzy Cognitive Map (CFCM) where the possible decision outcomes are mutually exclusive and compete with each other [14, 15].

Many different approaches have been proposed to develop and construct FCMs either based only to human experts who are invited to design conceptual structures that correspond the operation and model of a system or based on available quantitative historical data or both of them [25, 41, 44, 45]. The construction methodology and the possible implementation of learning algorithm has great importance to sufficiently model any system. Here a new hybrid method for it is proposed developing Fuzzy Cognitive Map Decision Support Systems (FCM-MDSS) mainly based on a group of experts who are used to transform their reasoning approach on inferring decision into an aggregated decision making model. The proposed methodology extracts the knowledge from the experts and exploits their experience on decision-making and evaluating diagnosis [44] and it is further complemented with generally expected bibliographic input.

The proposed approach here is not only based on the human experts, but, also, it introduces the use of existent widely accepted procedures and bibliographic data, constituting a hybrid methodology. It is proposed to use the experience and human reasoning procedure, in order to determine the importance of every factor and so its degree of influence on the corresponding assignment. Usually every individual, in order to conclude to a decision, doesn't take into consideration all the possible factors but focuses on the most important factors, a procedure that is dependent on the specific conditions; that means the same expert, in another case, may select another set of essential factors.

In order to generalize the procedure and produce a generic decision making procedure, the following approach is introduced. First, the possible factors that may influence a decision are determined based on bibliographic and general accepted methodologies, then specific cases are presented to a group of experts, asking them to select the most important factors for each case and coming to a decision based on these factors. Thus, for every case, each expert usually selects 3-5 factors, based on his or her experience, from which decision/ diagnosis is concluded. So for every factor / concept, we introduce its *importance weight*, which will be used then to determine its influence to the final decision:

$$iw = \frac{\text{\# of experts considering this factor}}{\text{total number of cases}}. \tag{27.3}$$

Moreover, we introduce a complementary second weight, the "influence to specific decision" *specific weight – sw*, which represents how much the specific factor leads towards a specific decision / diagnosis. The procedure to calculate the is the following, every expert who considers one factor as important and he takes it into consideration, he is asked to present the degree with which the specific factor leads the expert to select one decision. Every expert describes the degree of influence of one factor towards one decision using a linguistic variable, such as "strong influence", "medium influence", "weak influence", etc.

More specifically, the causal interrelationships from one factor/ concept towards a decision/ diagnosis concept are declared using the variable *Influence* which is interpreted as a linguistic variable taking values in the universe $U = [-1, 1]$. Its term set *T(influence)* is suggested to comprise nine variables so that to permit to experts to explicitly describe the degree of influence, actually using nine linguistic variables, an expert can describe in detail the influence of factor concept towards decision concept and can discern between different degrees of influence. The nine variables used here are: *T(influence)* = negatively very strong, negatively strong, negatively medium, negatively weak, zero, positively weak, positively medium, positively strong and positively very strong. The corresponding membership functions for these terms are shown in Figure 27.3 and they are μ_{nvs}, μ_{ns}, μ_{nm},μ_z,μ_{pw},μ_{pm},μ_{ps}, and μ_{pvs}.

Thus, every expert describes the *specific weight sw* of each interconnection with a fuzzy linguistic variable from the above mentioned set, which stands for the relationship between the two concepts and determines the grade of causality between the two concepts. Then, all the proposed linguistic weights for one interconnection suggested by experts are aggregated using the SUM method and an overall linguistic weight is produced. The overall linguistic weight with the defuzzification method of Center Of Gravity (COG) [21], is transformed to a numerical weight *sw*, belonging to the interval $[-1,1]$. A similar approach was initially presented for the description of the development of FCM model in [45].

Then the overall weight describing the influence from one factor concept towards a decision concept is calculated using the form:

$$w_{ji} = sgn(sw)\,(l_1 * iw + l_2 * |sw|) \tag{27.4}$$

where the two parameters l_1, l_2 are introduced to represent the participation of the *importance weight iw* and the *specific weight sw*, on the overall weight describing the influence of every factor concept towards the decision/diagnosis concept. It is mentioned that the value of w_{ii} has to be normalized in the interval $[-1,1]$, where the weight takes values.

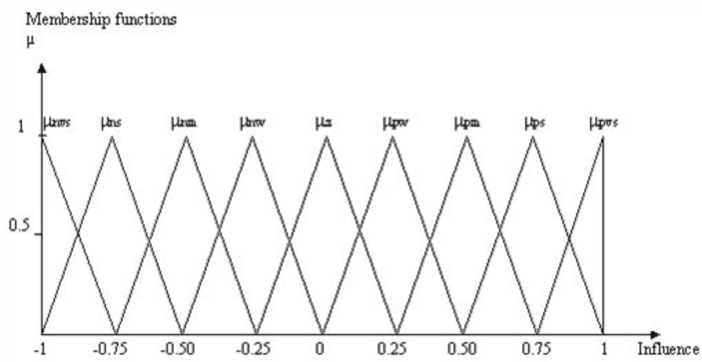

Fig. 27.3 Membership functions of the linguistic variable Influence

27.4.1 *Developing Fuzzy Cognitive Maps Model for the 5-Level ESI Triage System*

The described methodology on developing FCMs is implemented for the case of constructing a medical decision making system for the 5-level Emergency Severity Index (ESI) triage system [10, 16, 46, 53]. The ESI describes the main factors and based on them provides a standardized algorithm for the triage process using a systematic approach and utilizes both intuitive and analytical approaches to clinical decision making.

Based on the literature as presented in sections 27.3.2 and 27.3.3, as well as a study of 18 triage nurses [12], a series of factor concepts were concluded to be part of the Competitive Fuzzy Cognitive Map Medical Decision Support System for ESI (CFCM-ESI) for triage. Twenty-two (22) factors are selected that represent the potential concepts of the Fuzzy Cognitive Map decision model, but they do not all have the same importance in order to infer an assignment on the severity of the patient based on the 5-level triage system.

In the research of Garbez et al. [12], only ESI level 2 or level 3 were studied, where triage nurses were asked to select 3 to 4 factors that they rated as important in their clinical decision making process as they assigned an acuity level for each individual patient. Examples of these cases are shown in Table 27.1 as well as the calculation of the corresponding *iw* values (# of experts of considering this fac-tor)/(total number of patient cases, i.e. 334), which will be included as factor concepts of the CFCM-ESI, according to equation 27.3.

Table 27.1 The *importance weight iw* for Factor Concepts

Physical meaning	$iw = \frac{\text{\# of experts considering this factor}}{\text{total number of cases}}.$
Patient chief complaint	0.67 = 224/334
Vital signs	0.4 = 136/334
Medical history	0.35 = 120/334
Other factor	0.32 = 110/334
Expected number of resources	0.31 = 106/334
Patient age	0.16 = 54/334
Required timely intervention	0.15 = 53/334
Additional symptoms other than chief complaint	0.14=49/334
Severe pain or distress	0.12 = 42/334
Patient referred to ED from outside	0.08 = 29/334
Behavioral or psychiatric issue	0.07 = 25/334
No additional symptoms to chief complaint	0.05=18/334
Absence of medical history	0.05 = 18/334
Patient medications	0.05 = 17/334
Hospital or ED discharge < 3 days	0.04 = 15/334
Patient immune-compromised	0.04 = 14/334
Alcohol or illicit drug use	0.03 = 13/334

However, based on bibliographic data and in order to develop an integrated advanced FCM-ESI, some additional Factor Concepts mostly related to the other 3 ESI levels but not exclusively are included:

- Life or organ-threatening condition, $iw = .45$. It is concluded based on prevalence statistics of emergency room triaging of elderly [32] in conjunction with the fact that this is a very significant determining factor for ESI level 1.
- Limb threatening state $iw = 0.40$, based on prevalence statistics of limb loss in the general population [29] and elderly visits to the ED in conjunction with the fact that this is a very significant determining factor for ESI level 1.
- Weakness, $iw = 0.20$ [28]
- No recent change mental state, $iw = 0.75$ [51]
- Patient can walk or sit for prolonged periods $iw = 0.12$, based on non-urgent presentations [2]

The *importance weight*, *iw*, values for these factors were calculated on incidence % of arrivals in an ED and refers to patients over 65 years of age.

It is concluded that the CFCM-ESI will consist of these total 22 Factor Concepts and thus, based on them, a possible triage Decision will be assigned. More accurately each patient is assigned one of the 5 ESI levels, therefore the CFCM-MDSS will include 5 Decision Concepts (DC), each one for every ESI level:

Table 27.2 Decision Concepts

Decision concept (DC)	**Physical meaning**
DC1	ESI Level 1 (ESI1)
DC2	ESI Level 2 (ESI2)
DC3	ESI Level 3 (ESI3)
DC4	ESI Level 4 (ESI4)
DC5	ESI Level 5 (ESI5)

After determining the concepts of the Fuzzy Cognitive Map, the most important issue is the assignment of the influence among concepts, which is the second step of FCM development [45]. The FCM development procedure is very important since this model is then used for decision making and diagnosis. Here, we further apply the designing methodology presented in section 27.4 in order to assign weight values between the Factor Concepts (FC) and the Decision Concepts (DC).

This designing methodology utilizes the data used and provided in the study of Garbez et al., [12], where 334 cases of patients were examined and 18 experts assigned them to ESI levels. According to this designing methodology, the first stage is the assignment of the *importance weight*, at every concept using equation 27.3, which is depicted in Table 27.1. Then the *specific weight*, *sw*, representing the influence from a Factor Concept FC to a Decision Concept DC must be determined. Subsequently equation 27.4 is applied in order to calculate the weight from Factor Concept to Decision Concepts. Here, for this case, in order to calculate the overall weight from FCs to DCs, a simplified version of equation 27.4 is used along with the normalization to 1, where $l_1 = 1$ and $l_1 = 0.5$. Thus:

$$w_{ji} = sgn(sw)\,(iw + 0.5 * |sw|) \tag{27.5}$$

The overall weight after the normalization to 1, is then fuzzified according to the membership functions of Fig 27.3. The weights from FCs to DCs are depicted in Table 27.3 which are used to produce the CFCM-ESI illustrated in Figure 27.4.

At this stage of the research we only assign weights from Factor Concepts to Decision Concepts, but the FCM capabilities permit us to introduce weights among the Factor Concept themselves, that create a more accurate but too complex model, which is part of ongoing research.

The weights of Table 27.3 are based on membership functions of Figure 27.3:

- VVS positive very very strong (high end of the *pvs* membership function)
- VS positive very strong (*pvs* membership function)
- S positive strong (*ps* membership function)
- MS positive medium strong (high end of the *pm* membership function)
- M positive medium (*pm* membership function)
- - M negative medium (*nm* membership function)
- MW positive medium weak (low end of the *pm* membership function)
- W positive weak (*pw* membership function)
- -W negative weak (*nw* membership function)
- VW positive very weak (*pvw* membership function)
- VVW positive very weak (low end of the *pvw* membership function)

Table 27.3 Specific weights sw from FCs to DCs of the CFCM-ESI

FC#	Name of concept	ESI1	ESI2	ESI3	ESI4	ESI5
FC1	Life threatening	VVS	0	0	0	0
FC2	Limb threatening	VVS	0	0	0	0
FC3	Patient chief complaint	0	MS	MS	0	0
FC4	Vital signs	0	M	MW	0	0
FC5	Medical history	0	MW	MW	0	0
FC6	Other factor	0	MW	MW	0	0
FC7	Expected number of resources	0	W	MW	-W	-M
FC8	Patient age	0	W	VW	0	0
FC9	Required timely intervention	0	W	VW	-W	-M
FC10	Weakness	0	VS	S	VVW	0
FC11	Additional symptoms other than chief complaint	0	W	VW	0	0
FC12	Severe pain or distress	0	VW	VW	0	0
FC13	Patient referred to ED from outside	0	VVW	VW	0	0
FC14	Behavioral or psychi-atric issue	0	VVW	VVW	0	0
FC15	No additional symptoms to chief complaint	0	VVW	VVW	M	MS
FC16	Absence of medical history	0	VVW	VVW	0	0
FC17	Patient medications	0	VVW	VVW	0	0
FC18	Hospital or ED discharge 3days	M	VVW	VVW	0	0
FC19	Patient immunocompromised	M	VVW	VVW	0	0
FC20	Alcohol or illicit drug use	0	VVW	VVW	0	0
FC21	No recent change mental state	0	0	0	M	M
FC22	Patient can walk or sit	0	0	W	VS	VVS

In the following subsection the CFCM-ESI is applied to real patient cases, arriving at the Emergency Department.

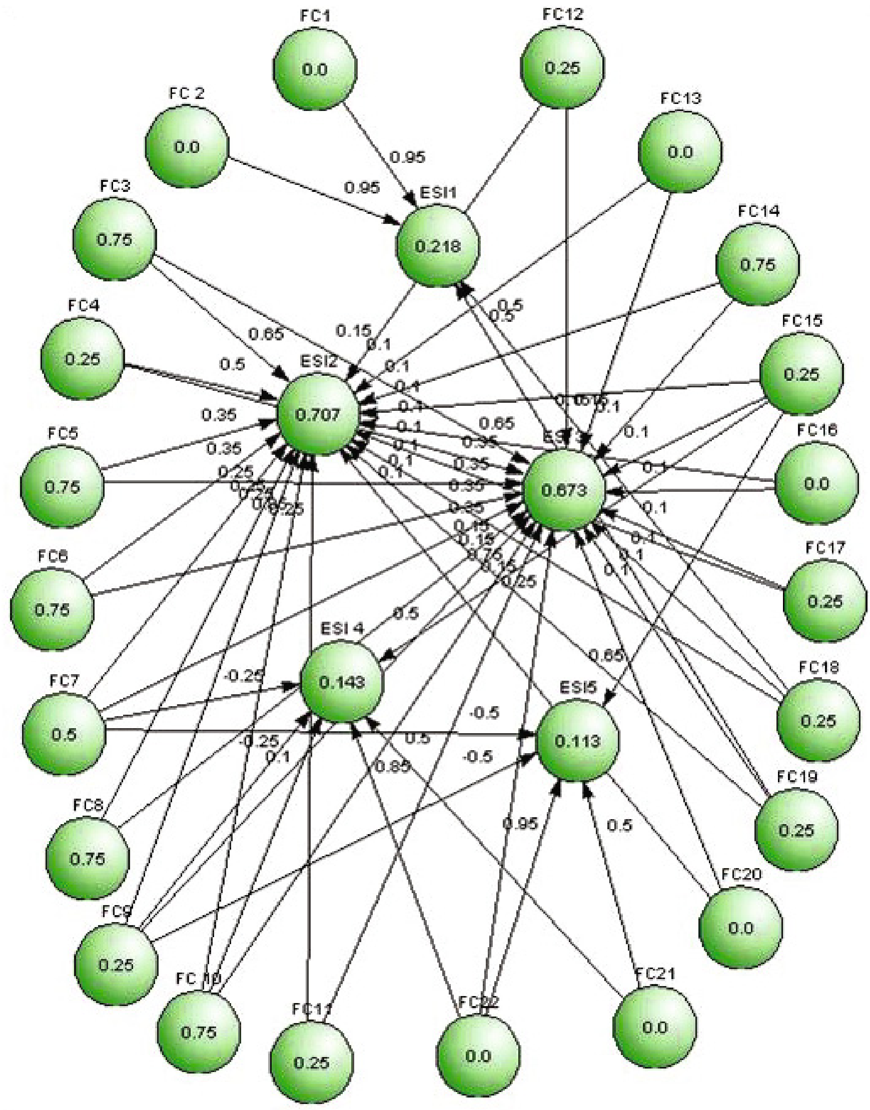

Fig. 27.4 The CFCM-ESI for the first case

27.4.2 Implementing the CFCM-ESI for Real Patient Cases

In this section, we present two real cases of patients who entered the ED in order to illustrate the function of the CFCM-ESI for ED triage. Both cases involve elderly patients.

Case 1

An 80 year-old male, accompanied by a relative, presented to the emergency department with the chief complaint of altered mental status [48]. The patient's relative stated that the patient woke up the day before very forgetful with subsequent improvement while the previous evening the patient had developed numbness to the jaw. Also, that he has been very depressed since the death of a family member in the past year. The patient denied experiencing pain. Triage vital signs were found to be:

BP 138/78 mm Hg,
HR 66 beats/min,
RR 16 breaths/min,
Temperature 97.8F (36.5C),
Oxygen saturation 97%.

Using a 5-level triage acuity scale he was assigned a Level 3-Acute triage acuity.

According to the source however, this patient, based on the minimal information provided in the triage assessment, should have been assigned a Level 2 (Urgent) triage acuity according to the criteria for ESI (Emergency Severity Index).

The competitive FCM-ESI was run using the initial factor concept values:

FC1=0	FC2=0	FC3=S	FC4=W	FC5=S
FC6=S	FC7=M	FC8=S	FC9=W	FC10=S
FC11=W	FC12=W	FC13=0	FC14=S	FC15=W
FC16=0	FC17=W	FC18=W	FC19=W	FC20=0
FC21=0	FC22=0			

The results are shown in Fig. 27.5 where the ESI acuity level assigned by the CFCM-ESI is Level 2 since the output values of the ESI nodes were calculated to be:

ESI 1 = 0.2181
ESI 2 = 0.7072
ESI 3 = 0.6726
ESI 4 = 0.1432
ESI 5 = 0.1131

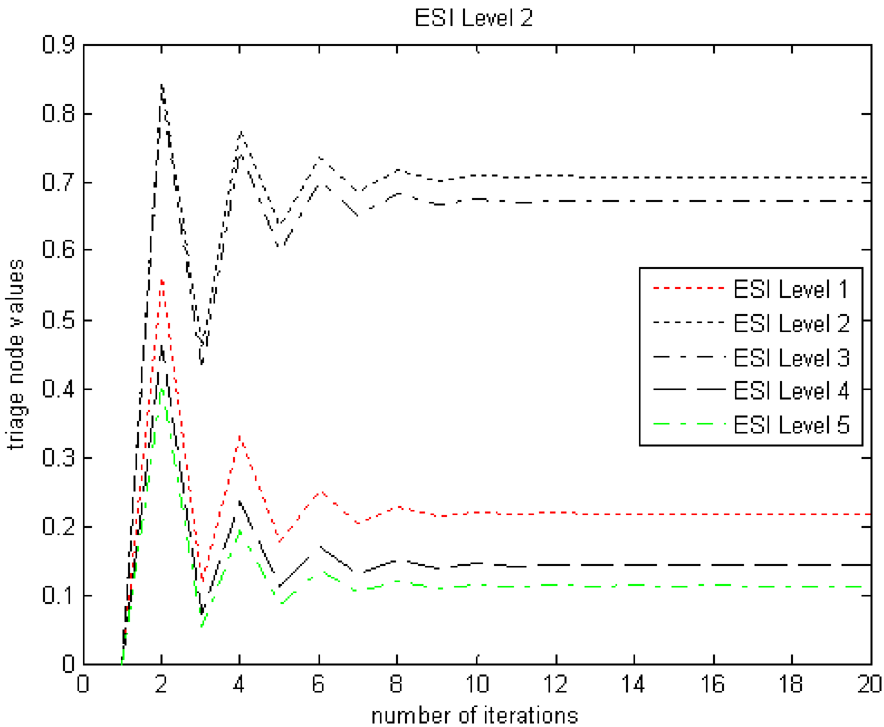

Fig. 27.5 CFCM-ESI output for case 1, patient is correctly triaged at ESI2

Case 2

A 63-year-old cachectic male was brought to the ED from the nursing home because his feeding tube fell out again. The patient is usually unresponsive and has been in the nursing home since he suffered a massive stroke about 4 years ago [16].

The patient was triaged at ESI level-4-Routine, which means that the patient was sent back to the nursing home after the feeding tube was reinserted. There was no acute change in his medical condition, even though he was unresponsive, since that is the patient's baseline mental status and so he was not triaged at ESI level 1.

The Competitive FCM-ESI was run using the initial fuzzy factor concept values based on the case information:

FC1=0	FC2=0	FC3=0	FC4=W	FC5=W
FC6=W	FC7=W	FC8=S	FC9=W	FC10=0
FC11=W	FC12=0	FC13=0	FC14=S	FC15=W
FC16=0	FC17=W	FC18=0	FC19=W	FC20=0
FC21=VVS	FC22=0			

The results are shown in Fig. 27.6 where the ESI acuity level assigned by the CFCM-ESI is Level 4 since the output values of the ESI nodes were calculated to be:

ESI 1 = 0.2931
ESI 2 = 0.4483
ESI 3 = 0.4356
ESI 4 = 0.6158
ESI 5 = 0.5109

This is a very important case because the patient could easily be over-triaged by an inexperienced nurse whereas consulting the CFCM-ESI the patient gets his problem taken care of and is not unnecessarily hospitalized.

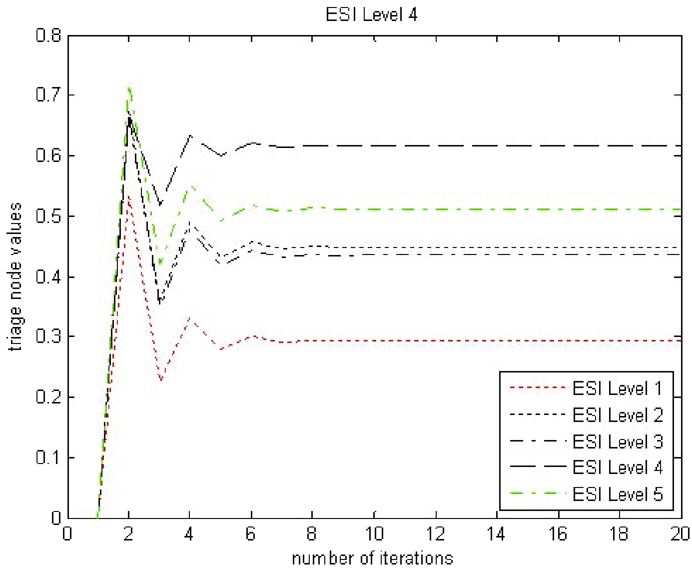

Fig. 27.6 FCM DSS output for case 2, patient is correctly triaged at ESI4

27.5 Conclusions

Here, the Soft Computing methodology of Fuzzy Cognitive Maps (FCMs) is applied for the first time to develop a Medical Decision Support Systems for the ESI Triage, a significant procedure during patient admission at the Emergency Department (ED) of hospitals. The main focus of this application is the older patients, who are admitted quite frequently at the ED suffering from chronic problems, presenting many complementary and/or controversial symptoms and not presenting a high level communication ability that increases the complexity of any assessment and decision about their health condition, the emergency and the required treatment.

FCMs have been successfully used to develop Medical Decision Support Systems and here the general framework of Competitive FCM is used. In addition to this, here a novel hybrid design methodology for FCM is applied that combines the knowledge and experience of human experts along with information and bibliographic data, in order to create a more efficient CFCM-MDSS.

The clinical decision support system based on CFCM for the 5-level ESI triage scale was developed and presented in detail: it considers 22 factors and concludes to one of the 5 ESI triage levels. The CFCM for ESI triage was tested using real patient cases from the literature and the assessment results showed that it reached the correct triage decision. It is considered that the CFCM is an efficient modeling method for the complex decision-making process of triage, and it is developed and evaluated into an advanced CFCM-ESI system for the ED. This advanced CFCM-ESI, following the designing methodology presented here, will take into consideration more factors and will also interaction between factors, so that to create a generic integrated CFCM-MDSS. This CFCM-ESI was tested and its accuracy was compared with the rating of experienced triage nurse. Further, comparison of CFCM-ESI to the rates of undertriage and overtriage will be analyzed, in future work.

Acknowledgement. This work is partially supported by the programme "Greece-Czech Joint Research and Technology projects 2011-2013" of the General Secretariat of Research & Development, Greek Ministry of Education, Lifelong Learning and Religious Affairs co-financed by the Greece and the European Union.

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