EPICE an Emotion Fuzzy Vectorial Space for Time Modeling in Medical Decision

Joël Colloc*
Normandie Univ, UNIHAVRE, UNICAEN, UNIROUEN, CNRS, IDEES
Le Havre, France
joel.colloc@univ-lehavre.fr

Relwende A. Yameogo†
Normandie Univ, UNIHAVRE, UNICAEN, UNIROUEN, CNRS, IDEES
Le Havre, France
relwende-aristide.yameogo@univ-lehavre.fr

Peter F. Summons‡
Faculty of Engineering and Built Environment
The University of Newcastle
Newcastle, Australia
Peter.Summons@newcastle.edu.au

Ying Shen§
School of Electronics and Computer Engineering
Peking University Shenzhen Graduate School
Shenzhen, China
shenying@pkusz.edu.cn

Mira Park¶
School of Electrical Engineering and Computing
The University of Newcastle
Newcastle, Australia
mira.park@newcastle.edu.au

Janine E. Aronson‖
Terry College of Business
The University of Georgia
Athens, USA
jaronson@uga.edu

ABSTRACT

EPICE is a decision support system in medicine several knowledge bases that must cooperate together. The model takes into account the emotions of the patient and the physician involved in the care relationship during the evolution of the disease of the patient. The knowledge of clinical pictures are depicted with an object oriented time clinical model while the care relationship : the emotions of the patient and the caregivers are based on a psychological model. Both models rely on a fuzzy vectorial space that avoids fuzzification and defuzzification steps of the rule-based approaches and allows time modeling. We propose a fuzzy vectorial space to model the emotion felt by the patient during his care course and the relationship with the caregivers. [1]

CCS CONCEPTS

• Theory of computation → Modal and temporal logics; **• Computing methodologies → Vagueness and fuzzy logic**; **Temporal reasoning**; **• Applied computing → Health care information systems**; *Health informatics*;

*MD,PHD, Unitwin UNESCO Complex System, Human Trace Complex Digital Campus
†MD, cardiologist,PHD Student
‡PHD, Member of Applied Informatics Research Group
§PHD, Netlab, ECE, PKU (Shen Zhen)
¶PHD, School of Design, Communication and IT
‖PHD,Departement of MIS

IML '17, October 17-18, 2017, Liverpool, UK

ACM ISBN 978-1-4503-5243-7/17/10…$15.00
https://doi.org/10.1145/3109761.3109790

KEYWORDS

Fuzzy vectorial space, Fuzzy logic, Emotion, Care relationship, Clinical model, Diagnosis, Prognosis, Therapy, Decision support system in medicine

ACM Reference Format:
Joël Colloc, **Relwende A. Yameogo**, **Peter F. Summons**, **Ying Shen**, **Mira Park**, and **Janine E. Aronson**. 2017. EPICE an Emotion Fuzzy Vectorial Space for Time Modeling in Medical Decision. In *Proceedings of IML '17*. ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3109761.3109790

1 INTRODUCTION

Most of decision support systems in medicine uses a deductive approach while physician mainly use analogical reasoning, comparing previous cases with new ones as in case-based reasoning [1]. Another tricky problem is the relationship between the patient and the caregiver. The confidence the patient gives to the caregivers is essential to reach healing. In previous works we proposed a clinical model for knowledge modeling. EPICE is a framework that aims to provide emotion modeling of the patient during the care route. We propose a fuzzy vectorial space approach to combine fuzzy membership functions in a dynamic way for emotion modeling with the OCC model. This approach is an alternative to using fuzzy rules with fuzzification,defuzzification stages. Our approach provides a means of simulation of the emotion evolution during the route of care involving several caregivers. Our model is a new path towards the integration of knowledge and emotion in decision support systems and the implementation of analogic reasoning modes by comparing scenarios in a case based reasoning context. The paper is organized as follows. In section 2 a time clinical model to describe the evolution of the diseases is presented. Section 3 depicts how to use the OCC model for emotion modeling during the care relationship according to the relational flower of the patient implemented with a P-Graph. In section 4 a fuzzy vectorial space (FVS) is defined as an extension of the Zadeh's fuzzy logic theory [15–18], the generalization to n parameters and consideration of time. In section 5 the clinical modeling of the patient-caregivers relationship and the evolution of the emotion felt by the patient during the route of care with a FVS is proposed. The benefits and limitation and future works of this approach are discussed. Finally, in section 6 conclusions are derived.

2 A TIME CLINICAL MODEL

2.1 Medical context

Medicine is an art that uses science. It is based on observation of the patients and the diseases show variations: each individual patient story is a unique case. Topography: a disease is often multifocal and shows various clinical pictures according to the damaged organ or apparatus. For example tuberculosis can reach bones, lungs, kidneys and other organs, Periodicity: diseases are dynamic processes, while clinical syndromes are only pathology snapshots corresponding to specific evolution steps of the dynamic process. For example, syphilis displays three successive stages. Other diseases, such as a duodenal ulcer or a herpes infection, progress in a cyclic manner. Therefore, time is a major factor when describing pathologies [3]. Chosen treatment: another underlying disease or another treatment can interfere (enhance or mask) and give unusual clinical aspects or provoke a iatrogenic diseases. In previous works, we have proposed a multi-agent decision support system implementing a case based reasoning approach and clinical ontologies for diagnosis, prognosis, treatment and patient follow-up [5, 14].

2.2 Object oriented model of disease evolution

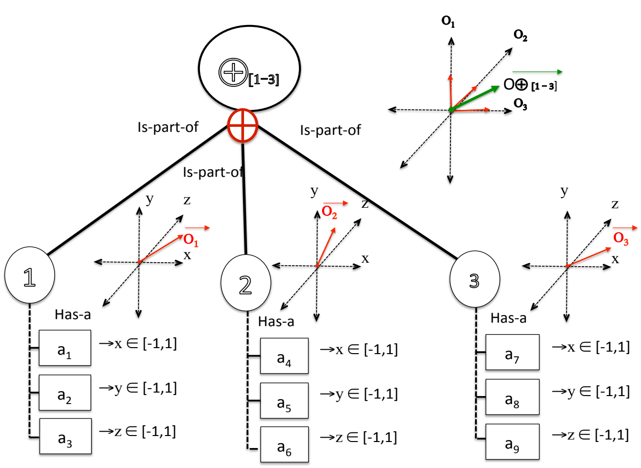

Figure 1: Evolution of disease D composed of their clinical pictures CP, syndromes Sd and signs S

The disease (D) is composed of a succession of Clinical Pictures (CP) composed of Syndromes (Sd) and composed of signs (S). Each component can change value and appear or disappear during each stage of the disease evolution. Some signs S, syndromes Sd only match with classical stored scenarios. At each level of the composition hierarchy, distances are computed and used to evaluate their similarity and then provide an analogical reasoning diagnosis that is more convenient and understandable than the deductive reasoning mode of rule based systems (see Figure 1) [4].

3 MODEL OF EMOTION IN THE CARE RELATIONSHIP

3.1 OCC Model for emotion modeling

The OCC model was proposed by Ortony Clore and Collins in 1988 [11]. The model defines events, agents and objects. Events are considered to induce emotional consequences. Agents are able of actions that have effects on the environment. Objects have imputed properties. The OCC model represents emotions as balanced reactions to the perception of the situation [12]. Some can be pleased about the consequences of an event or not (pleased/ displeased). For example if an action relieves pain or is painful; one can endorse or reject the actions of an agent (approve/disapprove) or one can like or not aspects of an object (like/dislike). Then, the events can have consequences for others or for oneself and on acting agents. Thus, the different emotional balances are depicted by couples of (positive/negative) reactions represented by variables x,y,z... For brevity, we do not provide the specialization tree of the OCC model but we just summarize the couples of variables in table 1.

Table 1: Couples of emotion variables of the OCC model

		+	-
Consequences of events	For others	Happy for	Resentment
		Gloating	Pity
	For self	Hope	Fear
		Joy	Distress
Actions of Agents	Self Agent	Pride	Shame
		Gratification	Remorse
		Gratitude	Anger
	Other Agent	Admiration	Reproach
		Gratification	Remorse
		Gratitude	Anger
Aspects of Objects		Love	Hate

3.2 The Relational Flower

The relational flower represents the relationships between the patient and the care-givers in the center of Figure 2. Several layers successively show the relationship with: the relatives, friends and other known people. During the life, the relational flower is changing and become less and less rich when the person is getting older. Sometimes, in a retirement home, where the rest of the family is far away or dead, the caregivers are the only persons remaining in the relational flower of the patient and they become the referees of the person, which is a great responsibility. Figure 3 shows a semantic model for modelling the relational flower of a person with a semantic P-graph. These same techniques are implemented on a much larger scale in social networks to represent the social ties of a person. The evolution of the emotions between the patient and caregivers are represented by fuzzy membership functions.

4 A FUZZY VECTORIAL SPACE

In this section we propose a fuzzy vectorial space as an extension of Zadeh's fuzzy logic [15, 16, 18]. Zadeh's membership functions

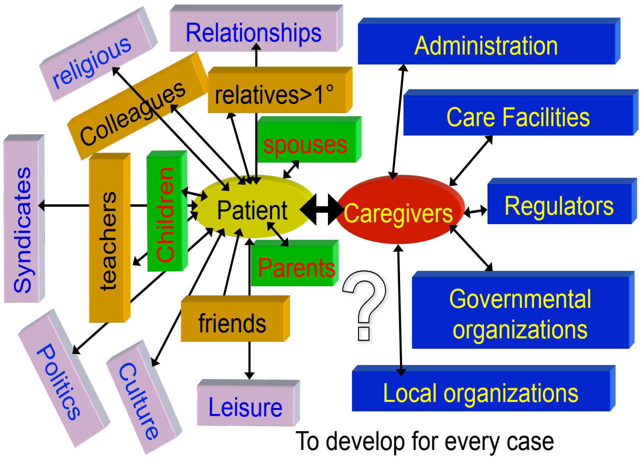

Figure 2: The relational flower

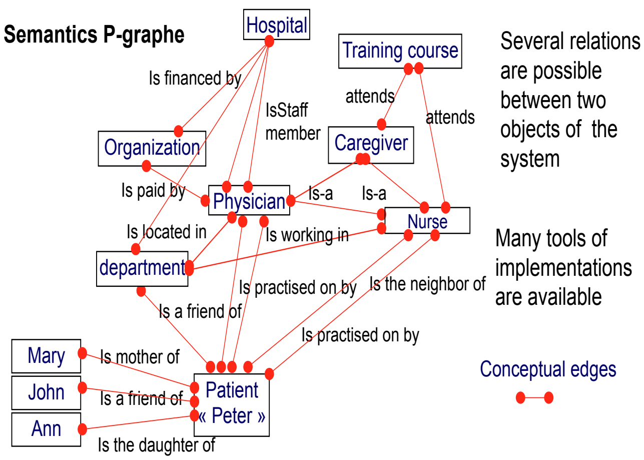

Figure 3: a p-graph to model the relational flower

are defined on [0,1]. Our membership functions are defined on [-1,1], taking into account a full specific characteristic of an object (value=1) and its contrary (value=-1), where the value 0 is considered to be neutral. The set $\mathbb{F}$ contains all the membership functions. Thus $\forall f \in \mathbb{F}\ \exists f' = -f$ defined in $[-1, 1]$ that represents the opposite function of the f function. Let be three functions of $\mathbb{F} f : [-1, 1] \to [-1, 1], x \to f(x), g : [-1, 1] \to [-1, 1], y \to g(y), h : [-1, 1] \to [-1, 1], z \to h(z)$. We propose a fuzzy vector space among which vectors $\vec{f}, \vec{g}, \vec{h}$ express forces (as a physical metaphor) having as *mode* the "intensity" based on the value of the fuzzy membership functions $f(x), g(y), h(z)$ related to the values x, y, z corresponding with specific properties (attribute, or characteristics) of an object of the domain of the discourse. $\mathbb{R}$ is a commutative corpus. Let E be a vector space on $\mathbb{R}^3$ associated to an orthonormal coordinate system $(O, \vec{i}, \vec{j}, \vec{k})$ from the set of membership functions $\mathbb{F}$. The vector $\vec{f}$ overlaps the vector $\vec{i}$ (X axis), $\vec{g}$ the vector $\vec{j}$ (Y axis) and $\vec{h}$ the vector $\vec{k}$ (Z axis). The norm of the vector $\vec{f}$ is given by $\|\vec{f}\| = \sqrt{f(x)^2} = f(x)$ and in the same way $\|\vec{g}\| = \sqrt{g(y)^2} = g(y)$ and $\vec{h}$ est $\|\vec{h}\| = \sqrt{h(z)^2} = g(z)$. Because the system is orthonormal the dot product (or scalar product) of vectors $\vec{f}, \vec{g}$ and $\vec{h}$ is nil. Consequently, we can combine three forces represented by vectors $\vec{f}, \vec{g}$ and $\vec{h}$ with an inner additive operator named +. $\forall \vec{f}, \vec{g}, \vec{h} \in E$. A vector space E possesses the following properties : associativity of + , neutral element ($\vec{0}$),the opposite vector, commutativity of + in E, scalars, neutral element,distributivity of scalars on addition. Separation : $\forall \vec{f} \in E, N(\vec{f}) = 0 \Rightarrow \vec{f} = \vec{0}_E$; Homogeneity : $\forall(\lambda \vec{f} \in \mathbb{R} \times E, N(\lambda \vec{f}) = |\lambda| N(\vec{f})$. Sub-additivity or triangular inequality: $\forall(\vec{f}, \vec{g}) \in E^2, N(\vec{f}, \vec{g}) N(\vec{f})$.

4.1 Calculation of the resultant vector of three fuzzy forces

Let f be a membership function $f : [0, 1] \to [0, 1] / f(x) = \dfrac{1}{1 + e^{-k(x-s)}}$ which is defined and continuous and where x is a specific characteristic of an object, s is the threshold that expresses the median value for the parameter x and k is a constant expressing the precision with which x is known. To adapt this function to the interval $[-1, 1]$, a change of coordinate system and scale is necessary: $F(x) = 2f(x) - 1$ gives $F(x) = \dfrac{2}{1 + e^{-k(x-s)}} - 1$. F(x) is an odd function defined and continuous on [-1,1], thus on intervals [-1,0] et [0,1] having 0 for intersection. F(x) allows us to build two opposite functions $f : [0, 1] \to [0, 1], f(x) = \dfrac{2}{1 + e^{-k(x-s)}} - 1$ and $f' : [-1, 0] \to [-1, 0] f'(x) = \dfrac{2}{1 + e^{-k(x-s)}} - 1$. It follows that $\forall x \in [-1, 1], f(x) = -f'(-x)$. In the same manner, we define $G(y), g(y), g'(y)$ and $H(Z), h(z), h'(z)$. Note that x and also the parameters y and z correspond to different relevant characteristics of the studied object. Then according to the sign of a characteristic x, it is always possible to build the corresponding membership function f and its opposite function f' that expresses the contrary characteristic -x (for example: x: to be tall corresponds to the opposite -x: to be small and y: to be joyful, -y: to be sad). The vector $\vec{f}$ is defined from f(x) and the opposite vector $\vec{f'}$ is defined from f'(x) and respectively vectors $\vec{g}$ and $\vec{g'}$ from functions g(y) and g'(y) and vectors $\vec{h}$ and $\vec{h'}$ from functions h(z) and h'(z). This adaptation allows to satisfy the property of having an opposite vector: $\forall \vec{f} \in E, \exists \vec{-f} / \vec{f} + \vec{-f} = \vec{0}$ that is necessary to build a fuzzy vector space.

4.2 Properties of f(x), g(y) and h(z)

Let E be the vector space on $\mathbb{R}^3$, $E(O, \vec{i}, \vec{j}, \vec{k})$, the resultant vector $\vec{u} = \vec{f} + \vec{g} + \vec{h}$. $\|\vec{u}\| = \sqrt{f(x)^2 + g(y)^2 + h(z)^2}$. Because $f(x), g(y), h(z) \in [0, 1]$, $\max(\|\vec{u}\|) = \sqrt{3}$, $\|\vec{u}\| \in [0, \sqrt{3}]$. The resultant function r of the membership functions f(x), g(y) and h(z) is $\forall(x, y, z) \in [0, 1]^3, r(x, y, z) = \frac{1}{\sqrt{3}} \|\vec{u}\| = \frac{1}{\sqrt{3}} \sqrt{f(x)^2 + g(y)^2 + h(z)^2}, r(x, y, z) \in [0, 1]$. In the vector space E, we can associate a scalar to a vector that express the importance of the component in the linear combination of vectors. $\alpha, \beta, \gamma \in R^{+*}, \vec{u} = \alpha\vec{f} + \beta\vec{g} + \gamma\vec{h}$ and the norm becomes $\|\vec{u}\| = \sqrt{\frac{|\alpha| f(x)^2 + |\beta| g(y)^2 + |\gamma| h(z)^2}{|\alpha| + |\beta| + |\gamma|}}$. Regardless the use of scalars or not, we verified that $r(x, y, z) \approx \frac{1}{\sqrt{3}} \|\vec{u}\|$. The study of the properties of the opposite functions f'(x), g'(y) and h'(z) defined on $[-1, 0]$

is similar. Because each function f(x) comes with its opposite function f'(x), $\alpha f(x) = -\alpha f'(-x)$, the sign of α allows to set up if the function f is agonist or antagonist and in the same manner β for g(y) and γ for h(z).

4.3 Generalization in n parameters

The model can be adapted to take into account n parameters or characteristics of objects $n \ll \infty$, $x_i \in [0,1]$ and n membership functions $f_i(x_i)$ with a scalar $\alpha_i \in \mathbb{R}^n$. A vector space E is defined on $\mathbb{R}^n$ where two vectors $\vec{f} = (x_1 \dots x_n)$ and $\vec{g} = (y_1 \dots y_n)$ have the inner scalar product (dot product) $\langle \vec{f}, \vec{g} \rangle = x_1 y_1 + \dots + x_n y_n$. E is provided with an orthonormal coordinate system $O(\vec{i_i}, \dots, \vec{i_n})$. Let be the vector $\vec{u}$ in the vector space E on $\mathbb{R}^n$ to be the sum of vectors $\vec{f_i}$ provided with the corresponding scalar α_i. Thus comes $\forall \vec{f_i} \in E, \vec{u} = \sum_{i=1}^{i=n} \alpha_i \vec{f_i}$. The norm $\|\vec{u}\| = \sqrt{\frac{\sum_{i=1}^{i=n} |\alpha_i|(f_i(x_i))^2}{\sum_{i=1}^{i=n} |\alpha_i|}}$. The resultant function r of n membership functions is: $\forall (x_i, \dots, x_n) \in [-1,1]^n, r(x_i, \dots, x_n) = \frac{1}{\sqrt{n}} \sqrt{\frac{\sum_{i=1}^{i=n} |\alpha_i|(f_i(x_i))^2}{\sum_{i=1}^{i=n} |\alpha_i|}}$. The main inconvenience is when n becomes big, the value of the resultant function r becomes very tiny. Indeed, $\lim_{n \to +\infty} r(x_i, \dots, x_n) = 0$. However, this inconvenience is not important because in practice the number n of membership functions $n \ll \infty$ and is some tens of parameters at most. The Fuzzy Vectorial Space is a new way of combining efficiently fuzzy vectors without using fuzzification/defuzzification steps as in [10] and it maintains all the benefits of the fuzzy sets proposed by Zadeh as well as to take time into account as described in the next section.

4.4 Consideration of time

We saw that the evolution of the characteristic parameters of objects requires the consideration of time. During time t, parameters can evolve quickly or slowly, or sometimes remain constant. The resultant vector $\vec{u}$ undergoes modifications during time t. The absolute time is expressed by an additional variable t (in seconds) which is calculated from 6 variables: year (aaaa), month (mm), day (jj), the hour (hh), minutes (mm), seconds (ss). An extension in the subdivisions of second may be envisaged for special applications but is mostly useless and expensive in computation time. The other temporal units (for example, week, month, half-year) associated with the various parameters can easily be converted in absolute time by appropriate conversion functions. Most programming languages offer such time function libraries. The variable t is used to define every membership function $f_i(x_i)$ which becomes $f_i(x_i, t) : [0,1] \to [0,1], f_i(x_i, t) = \frac{2}{1 + e^{-k(x_t - s)}} - 1$. Some functions remain constant on an interval of time while others are evolving. For all time t, the vector $\vec{u_t}$ evolves according to its component functions:$\forall \vec{f_{i,t}} \in E, \vec{u_t} = \sum_{i=1}^{i=n} \alpha_{i,t} \vec{f_{i,t}}$. The norm $\|\vec{u_t}\| = \sqrt{\frac{\sum_{i=1}^{i=n} |\alpha_{i,t}|(f_{i,t}(x_{i,t}))^2}{\sum_{i=1}^{i=n} |\alpha_{i,t}|}}$. The resultant function r of n membership functions is: $\forall (x_{i,t}, \dots, x_{n,t}) \in [-1,1]^n, r(x_{i,t}, \dots, x_{n,t}) = \frac{1}{\sqrt{n}} \sqrt{\frac{\sum_{i=1}^{n} |\alpha_{i,t}|(f_{i,t}(x_{i,t}))^2}{\sum_{i=1}^{i=n} |\alpha_{i,t}|}}, r(x_{i,t}, \dots, x_{n,t}) \in [-1,1]$.

4.5 kinematic of a point in the fuzzy vector space

This part is inspired from physics and more precisely from classical mechanics. Therefore, we use a three-dimensional cartesian vector space to illustrate our proposal. Let time t be in the interval $[t_0, t_n]$ and the vector space E provided with the orthogonal coordinate system $(O, \vec{i}, \vec{j}, \vec{k})$. The vector function $\vec{U}(t)$ in E is defined as $\vec{U}(t) = F(x,t)\vec{i} + G(y,t)\vec{j} + H(z,t)\vec{k}$. As previously, x_t, y_t, z_t are the characteristics of an object at the moment t and the components are defined as $x_t, y_t, z_t \in [0,1]^3, t \in [t_0, t_n], \vec{F}(t) = F(x_t, t).\vec{i}, \vec{G}(t) = G(y_t, t).\vec{j}$ *and* $\vec{H}(t) = H(z_t, t).\vec{k}$ of $\vec{U}(t)$. All of them are fuzzy membership functions of time. According to our previous definition of fuzzy forces in a vector space E, that is the case. Indeed $F(t) : [-1,1] \to [-1,1], F(t) = \frac{2}{1 + e^{-k(x_t - s)}} - 1$ and G(t) and H(t) are defined and continuous in the same way. So $\vec{U}(t)$ is a continuous vector function. O is the origin of the orthogonal coordinate system of the vector space where a point $M = (F(x_t, t), G(y_t, t), H(z_t, t)) = F(x_t, t)\vec{i} + G(y_t, t)\vec{j} + H(z_t, t)\vec{k} / \vec{OM} = \vec{U}(t)$ depicts a curve which is called the hodograph of the vector function $\vec{U}(t)$ which is the position vector at time t in the fuzzy vector space E. An example of the trajectory of the M point in the fuzzy vector space E shown in Figure 4 where the right-hand rule orientation is used.

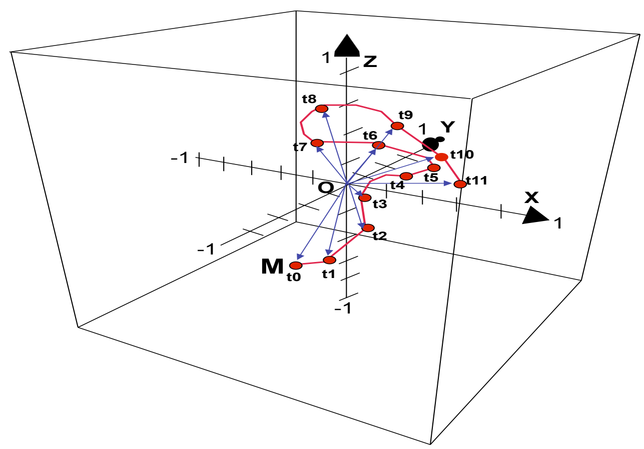

Figure 4: Hodograph of the vector function $\vec{U}(t)$ and dot M in the fuzzy vector space E

4.6 Velocity and speed in the vector space

The derivative of $\vec{U}(t)$ is $\frac{d\vec{U}}{dt} = lim_{t \to t'} = \frac{\vec{U}(t) - \vec{U}(t')}{t - t'}$. $\frac{d\vec{U}}{dt}$ exists, if its components $\vec{F}(t), \vec{G}(t)$ and $\vec{H}(t)$ denote the derivatives $\frac{d\vec{F}(t)}{dt}, \frac{d\vec{G}(t)}{dt}$ and $\frac{d\vec{H}(t)}{dt}$. The average velocity becomes the derivative of the position vector $\frac{d\vec{U}(t)}{dt} = \frac{d\vec{F}(t)}{dt} + \frac{d\vec{G}(t)}{dt} + \frac{d\vec{H}(t)}{dt}$. Thus, the velocity is the time rate of change of position in the vector space E and $\frac{d\vec{F}(t)}{dt}, \frac{d\vec{G}(t)}{dt}, \frac{d\vec{H}(t)}{dt}$ denote the derivative in the three components, so called dimensions with respect to time. The speed S of the point M is defined as the magnitude $S = |\vec{U}(t)| = \frac{ds}{dt}$ where s is the arc-length measured along the trajectory of the point M in the vector space E which is a non-decreasing quantity. Therefore $\frac{ds}{dt}$ is non-negative, which implies that the speed S is also positive or zero.

4.7 acceleration

The acceleration A of M relies on the rate of change of the velocity vector $\frac{d\vec{U}}{dt}$ so, $A = \frac{d^2\vec{U}}{dt^2}$. The acceleration is the first derivative of the velocity vector $\frac{d\vec{U}}{dt}$ and the second derivative of the position vector $\vec{U}(t)$. In the following sections we present an example of application of our model to build an emotion fuzzy vector space.

4.8 Derivative of the sigmoid fuzzy membership function

Each component $\vec{F}(t), \vec{G}(t), \vec{H}(t)$ of the vector $\vec{U}(t)$ is defined by the same sigmoid membership function :
$\vec{F}(t) = F(x_t, t) = \frac{2}{1+e^{-k(x_t-s)}} - 1.$
Its derivative is calculated according to
$x_t, \frac{dF(x_t,t)}{dt} = \frac{2k.e^{-k(x_t-s)}}{(1+e^{-k(x_t-s)})^2}.$
Provided that k is a positive constant, we notice that the derivative $F'(x_t, t)$ is strictly positive.Therefore, $F(x_t, t)$ is always derivable and strictly increasing on $\mathbb{R}$. Obviously, the same properties are verified for the function $G(y_t, t)$ and $H(z_t, t)$.

4.9 Gradient of the vector U in an emotion fuzzy vector space E

Consider an emotion vector space E with three parameters representing (positive/negative) couple of emotions of a person (X=1: joy, X=-1: sadness), (Y=1: gratitude, Y=-1: anger), (Z=1:love, Z=-1:hate). These parameters are not exhaustive, in the next section we propose a more complete presentation of an emotion model. However, these parameters are changing under the influence of unpredictable events occurring during an interval of time $[t_0, t_n]$. To model the situation, we propose to use the framework presented beforehand. According to the previous subsection 4.5 and figure 4, at each moment the position of the point M and the vector $\vec{U}(t) = F(x,t)\vec{i} + G(y,t)\vec{j} + H(z,t)\vec{k}$ are defined with the membership sigmoid functions as $\vec{F}(t) = F(x_t, t)$, $G(y_t, t)$ and $H(z_t, t)$ described in subsection 4.8. The further the point M is from the origin O, the more favourable are the conditions that are available to make an appropriate decision. We define a gradient named **ability** that correspond to the vector $\vec{U}(t)$. At any moment, the ability depends of the level of each component vector. In the cartesian coordinate system, the gradient of ability named

$$\nabla U(x_t, y_t, z_t) = \left(\frac{\partial U}{\partial x_t} + \frac{\partial U}{\partial y_t} + \frac{\partial U}{\partial z_t}\right) = \frac{2k.e^{-k(x_t-s)}}{(1+e^{-k(x_t-s)})^2} + \frac{2k.e^{-k(y_t-s)}}{(1+e^{-k(y_t-s)})^2} + \frac{2k.e^{-k(z_t-s)}}{(1+e^{-k(z_t-s)})^2} \quad (1)$$

k is a positive constant defining the scale and s is the pivot (neutral value), zero in our example. The calculus of sum of the partial derivative according to the direction X, Y and Z allows to calculate at each moment t the gradient of ability is a value always defined on [0, 1] (see Figure 5).

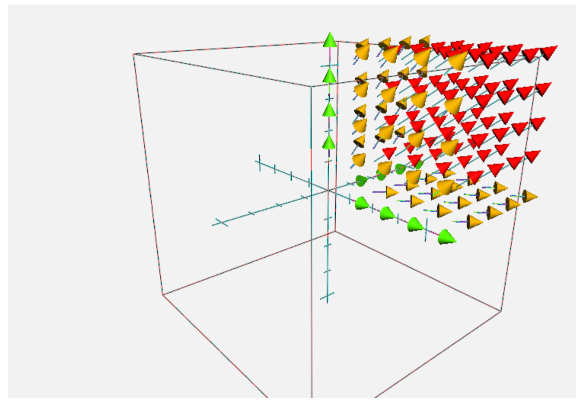

Figure 5: Gradient of the vector U in the fuzzy vector space E = $\nabla U(x_t, y_t, z_t)$ with the scale k=10

4.10 An example of decision making relying on an emotion fuzzy vector space

The Ortony Clore Collins (OCC) model of appraisal is the most widely accepted [11][12]. The OCC model defines a set of 22 emotion parameters (table 1) in subsection 3.1 representing a certain positive and negative intensity of 11 items[2]. The emotion quickly changes over time which makes our model particularly useful.We use the sigmoid fuzzy logic function defined in subsection4.1 to describe each couple of parameters of the OCC model listed in the table 1. To illustrate our approach, we propose a scenario which shows the evolution of the feelings of a patient undergoing care. Some of the care treatments could be painful (lumbar puncture, bone marrow draining etc.) or disgraceful (urography, colonoscopy etc.). In every stage of this scenario, our model allows the simulation of the feelings of the patient concerning the attitude of caregivers (appropriate or not) which may be expressed as the patient appreciating the treatment or not. At any time, the immediate global relationship between the patient and the caregiver concerning the clinical relationship is taken into account in order to analyse the patient's feeling and enhance the attitude of the caregiver. The Figure 7 depicts the Patient-Caregiver relationship and Treatment-Act composition. Consequently, the membership function LoveHateT (Treatment) is represented by a resultant vector $\vec{U}(t)$ of the membership functions that compute loveHateA of the acts that compose the treatment. In the same manner, a resultant LoveHateCG is defined according the caregiver who delivers the treatment see Figure 7. These membership functions are defined with sigmoid functions as in subsection 4.1 and combined in a FVS as shown for the disease in Figure 1.

Scenario		
Care Giver	Event	time t
None	Initialization	0
Dr Martin General Practioner	First Consulation	1
Dr Bernard Radiologist	Lumbar Radiology	2
Léa Saunier Nurse	Blood tests	3
Dr Martin General Practioner	Diagnosis Consultation	4
Dr Bernard Radiologist	Lombo-sciatic MRI	5
Léa Saunier Nurse	Anti-inflammatory Injection	6
Paul carnet Physiotherapist	spinal manipulation (painful)	7
Léa Saunier Nurse	Anti-inflammatory Injection	8
Paul carnet Physiotherapist	Massage	9
Dr Dubois Rheumatologist	Disc herniation L4-L5 diagnosis	10
Dr Dubois Rheumatologist	Chemonucleolysis	11
Dr Martin General Practioner	Analgesic Prescription	12
Dr Martin General Practioner	Therapy Follow-up	13

Figure 6: Description of the route of care of the patient

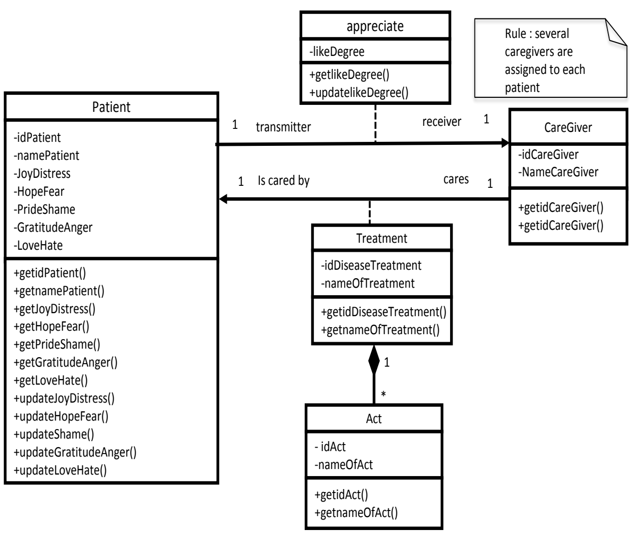

Figure 7: UML diagram class of Patient-CareGiver emotion relationship (synchronic diagram at each t)

5 EXAMPLE OF CLINICAL MODELING AND RESULTS

This section provides the modeling of the emotions of a male patient suffering from sciatica during the route of care with several caregivers. His emotions are represented with five sigmoid membership functions that depict the emotion evolution during his different stages of treatment (several consultations and events). Figure 6 describes the stages and the variation of feeling during the whole treatment (diagnosis, treatment, follow-up). Figure 9 gives the corresponding values of the "appreciate caregiver" sigmoid membership functions and their derivatives. Figure 9 depicts the part of each of emotion in percentage of the gradient at each time. Figure 8

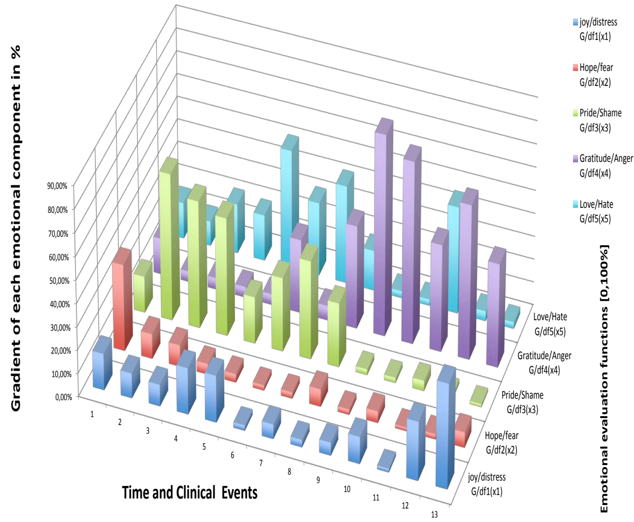

Figure 8: Diagram of differential membership functions of patient emotion

	Gradient %					
time t	joy/distress G/df1(x1)	Hope/fear G/df2(x2)	Pride/Shame G/df3(x3)	Gratitude/Anger G/df4(x4)	Love/Hate G/df5(x5)	sum
1	15,67%	37,31%	15,67%	15,67%	15,67%	100,00%
2	10,68%	10,68%	63,48%	4,48%	10,68%	100,00%
3	9,26%	9,26%	55,03%	4,94%	21,51%	100,00%
4	19,93%	4,58%	50,98%	4,58%	19,93%	100,00%
5	20,13%	3,64%	20,13%	4,62%	51,48%	100,00%
6	2,25%	2,25%	31,83%	31,83%	31,83%	100,00%
7	6,24%	2,69%	42,42%	6,24%	42,42%	100,00%
8	3,14%	7,47%	27,58%	44,43%	17,37%	100,00%
9	5,50%	2,31%	2,46%	86,80%	2,94%	100,00%
10	11,56%	4,98%	2,22%	78,58%	2,66%	100,00%
11	1,56%	1,56%	4,39%	46,24%	46,24%	100,00%
12	25,06%	2,25%	1,88%	66,59%	4,22%	100,00%
13	44,67%	6,57%	1,26%	44,67%	2,83%	100,00%

Figure 9: Gradient G and values of partial differential functions of Emotion membership functions (t1 to t13)

dysplays a chart showing the evolution of each emotion during the route of care.

5.1 discussion

The system FLAME proposed in [7] is also based on the same type of psychological model as the OCC [11]. The authors use fuzzy rules where events and emotions are connected with AND operators. The drawback of this model is the lack of temporal modelling and that the mental states of the agents are potentially limited to a predetermined set of predictable situations. Moreover, the use of the AND operator is semantically inappropriate. Some other authors propose similar approaches [8, 9, 13].

5.2 Benefits and limitation

This paper proposes a definition of a fuzzy vectorial space as a new extension of fuzzy logic that allows an easy and direct combination of fuzzy membership functions as fuzzy vectors, in a similar manner as forces combined in physics. This approach is particularly useful where multiple attributes and characteristics of objects are opposite. Our approach makes unneccessary the use of multiple fuzzy rules and intervals of values and steps of fuzzification/defuzzification required to have the rules triggered by an inference engine [8, 10]. Moreover, the fuzzy vectorial space offers real-time modeling of the membership functions as vectors to simulate the attribute evolution and the behavior of the objects of the system. The current limitations of our approach are:

- The model was not tested with a great number of attributes and in the example each attribute had the same weight. However, at each level of a composition tree a new FVS with a resultant vector can be reused in more complex objects.
- The test of the use of scalars needs to be further evaluated in future works.
- The model is particularly interesting in the combination of continuous attributes. When the attribute values are discrete or boolean, they should be transformed in a sigmoid membership function rather than classical fuzzification methods (triangles, trapezoid curves). This work is currently in progress.

5.3 Future works

In a previous work [2] we proposed a model of personality and behavior that will be adapted and will complete the emotion layer presented in this paper. The ability of vectorial spaces to model the continuous flow of changing emotions is essential for dynamically expressing the mental states of the agents involved in a situation and to simulate the evolution of their relationships. The espace vectorial space is used to develop medical knowledge bases where time modeling of diseases is essential [6] [4]. This model can be used in a great number of domains where decision making is based on knowledge and emotion modeling.

6 CONCLUSION

In this article we proposed a model of "fuzzy vectorial space" which constitutes a new approach to combine fuzzy membership functions in situations where it is essential to have the ability to aggregate the properties and features of objects as a supplement to the use of the operators of conjunction and disjunction (which can be obviously jointly used when it is semantically needed). It is in particular the case for the associations of composition and aggregation, which are widely used in object oriented models and multi-agents systems. The fuzzy vectorial space model does not use fuzzy rules to represent the object features but instead determines a resultant vector which represent the evolution of the object components over time. We trust that the use of the kinematics modeled with fuzzy vectorial spaces, which is inspired by physics, constitutes an enhancement to take into account the evolution of the structure, and the properties and behavior of complex objects while profiting from the advantages of fuzzy logic. The evolution of the gradient of the resultant vector can be studied to globally evaluate the object state according to the semantics of the membership functions. This humble contribution offers a new naive pragmatic way to combine object properties and to compare them together. In a future work our approach leads to develop a model of analogy allowing to compare objects and situations in complex environments where the time is an essential factor such as medical diagnosis or the follow-up of treatments.

REFERENCES

[1] A. Aamodt and E. Plaza. 1994. Case-Based Reasoning, Foundational Issues, Methodological Variations, and System Approaches. *AI Communications* 7(1) (1994), 39–59.

[2] J. Colloc and C. Bertelle. 2004. Multilayer Agent-Based Model for Decision Support System Using Psychological Structure and Emotional States. In *proceedings of the 2004 European Simulation and Modelling Conference ESMc2004, Oct 25-27 2004, UNESCO, Paris, pp 325-330*.

[3] J Colloc and Peter Summons. 2006. An Object Oriented Time Model of a Decision Support System for Intoxication Diagnoses. In *Proceedings of Industrial Simulation Conference, Palerme*. 387–392.

[4] J. Colloc and P. Summons. 2015. An Analogical Model to Design Time in Clinical Objects. In *RITS' Dourdan France*. 124–125.

[5] J. Colloc and C. Sybord. 2003. A Multi-Agent Approach to Involve Multiple Knowledge Models and the Case Base Reasoning Approach in Decision Support Systems. In *proceedings of 35th IEEE Southeastern Symposium on System Theory SSST03 WVU, Morgantown, USA*.

[6] P. Summons J. Colloc. 2006. Modelling Temporal Aspects of Clinical Objects. In *Industrial Simulation Conference ISC*, EUROSIS (Ed.). 454–458.

[7] M. S. El-Nasr, J. Yen, and T. R. Ioerger. 2000. FLAME - Fuzzy Logic Adaptive Model of Emotions. *Autonomous agents and multi-agent systems* 3 (2000), 219–257.

[8] I. Iancu. 2012. A Mamdani Type Fuzzy Logic Controller. In *Fuzzy Logic - Controls, Concepts, Teories and Applications*, Prof Elmer Dadios (Ed.). Intech, 325–350.

[9] A. N. Lorestani, M. Omide, S. Bagheri Shoobaki, A. M. Borghei, and A. Tabatabaeefar. 2006. Design and Evaluation of a Fuzzy Logic Based Decision Support System for Grading of Golden Delicious Apples. *International Journal of Agriculture and Biology* 8(4) (2006), 440–444.

[10] E. H. Mamdani and S. Assilian. 1975. An Experiment in linguistic synthesis with fuzzy logic Controll. *International Journal Man-Machine Studies* 7 (1975), 1–13.

[11] A. Ortony, G. Clore, and A. Collins. 1988. *The cognitive structure of emotions*. Cambridge University press.

[12] R. W. Picard. 1997. *Affective Computing Cambridge*. MA: The MIT Press.

[13] J. Ropero, A. Gomez, A. Carrasco, and C. Leon. 2012. A Fuzzy Logic intelligent agent for Information Extraction: Introducing a new Fuzzy Logic-Based term weighting scheme. *Expert Systems with Applications* 39(4) (2012), 4567–4581.

[14] Y. Shen, J. Colloc, A. Jacquet-Andrieu, and K. Lei. 2015. Emerging Medical Informatics with Case-Based Reasoning for Aiding Clinical Decision in Multi-Agent System. *Journal of Biomedical Informatics* 56 (2015), 307–317.

[15] L. A. Zadeh. 1965. Fuzzy Sets. *Information and Control* 8 (1965), 338–353.

[16] L. A. Zadeh. 1968. Fuzzy algorithms. *Information and Control* 12 (1968), 99–102.

[17] L. A. Zadeh. 1972. *Outline of a new approach to the analysis of complex systems and Decision processes. E.R.L. Memo M 342.* Technical Report. University of California, Berkeley.

[18] L. A. Zadeh. 1999. Fuzzy Sets As a Basis For a Theory of Possibility. *Fuzzy Sets and Systems* 100 (1999), 9–34.