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Application of Intuitionistic Fuzzy Sets for Conflict Resolution Modeling and Agent Based Simulation

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Abstract: *Very topical nowadays is the modeling and simulation of conflict situations. The aim is their peaceful prevention and conflict resolution. Different mathematical approaches are used. One of them is the application of multi-agent systems. The multiagent system consists of software agents, which are autonomous subjects working together. In our application the agents represents police officers and civilians in case of protest. In this work we propose application of intuitionistic fuzzy sets for representation of the movement and interaction of the agents. The intuitionistic fuzzy sets are extension of the fuzzy sets including level of uncertainty. Thus the model becomes more realistic. The conflict situation can cause disturbances and casualties. Crowd simulation is very difficult and important research topic.*

Keywords: *Multiagent system, Conflict resolution, Intuitionistic fuzzy set.*

Introduction

Crowd control and conflict situation prevention and elimination are very important when some protest appears. Some of the factors are difficult to be predicted, even when it is expected that the crowd is well managed. Various approaches are applied for researching crowd behavior, fuzzy-theory-based method [9], bandit strategy [5], cellular automata [12], crowd motion simulation [11].

Multi-agent systems is one of the methods which is applied on modelling crowd behaviour. A multi-agent system consists of various kind of agents and environments. The behaviour of an agent can be changed by the interaction with other agents and with environment. The agents can be passive or active and can react in different manner according to the situation [20].

Intuitionistic Fuzzy Sets (IFS) were proposed by Atanassov [2] (see also [3,4]) as a generalization of the fuzzy sets, incorporating degree of hesitation margin. Later, many extensions and developments have been proposed, among them [14–16,25,27]. Some applications of IFS are given in [1,17–19,21,24]. Description of a problem or process by IFS is more realistic. In this paper IFS are used for modelling and simulation of conflicts, based on agents.

The rest of the paper is organized as follows. In Section 2, we give short description of IFS. In Section 3 the problem is defined. In Section 4 the IFS are applied for modeling and simulation of conflicts based on agents. Section 5 gives an example for intuitionistic fuzzy estimation of conflict situation. At the end we give some conclusions.

Short description of the intuitionistic fuzzy sets

Fuzzy sets [28] have meaningful application in many fields of study, but in some real applications it is possible that the sum of the degree of membership and non-membership to be less than 1. Sometimes there is a hesitation degree. Thus, Atanassov [2] proposed generalization of fuzzy sets called intuitionistic fuzzy sets, which incorporate the degree of hesitation. So IFS has three components, degree of membership, degree of non-membership and degree of hesitation (uncertainty) and the sum of the values of the three components is equal to 1. The notion of IFS is useful in many applications. In [22] the usefulness of IFS in problem with linguistic variables is shown. IFS are tool for a more consistent reasoning under imprecisely defined facts [23]. In [7] an IFS application in medical diagnosis is given.

To have an idea about IFS first we will give an illustrative example. A good example for IFS is weather forecast. Let the weather forecast for today is 60% cloudy, 30% sunny and 10% partially sunny and partially cloudy. Thus there is 10% uncertainty. The formal definition of the IFS is as follows:

Definition. Let E be a set. An IFS A in E is defined as an object of the following form:

$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle | x \in E\}$,

where $\mu_A : E \to [0,1]$, $\nu_A : E \to [0,1]$, define the degree of membership and the degree of non-membership of the element $x \in E$, respectively, and for every $x \in E$:

$0 \leq \mu_A(x) + \nu_A(x) \leq 1$.

The value of $\pi_A(x) = 1 - \mu_A(x) - \nu_A(x)$ is called the degree of uncertainty of the element $x \in E$ to the IFS A.

There are operations and relations over IFS. The most important are inclusion, intersection, equality, negation, conjunction, disconjunction, product, scalar multiplication, etc. [3, 4].

Problem formulation

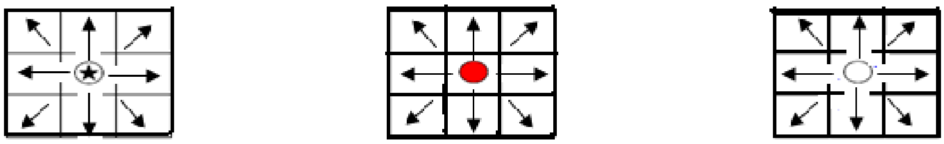
A conflict is an active disagreement between people with opposing opinions or principles. It is a dynamic process. In this paper we try to understand the human behaviour and its variations according to the situation. We try to represent different groups in a conflict with a help of IFS and will simulate collective behaviour. We focus on development of multi agent system to learn the behaviour caused by the interaction between the agents. Some computer models exist for concrete protests: model of trade protest [10]; the model of violence in London [6]; model of revolution [13].

We create more individuals which interact between themselves, to model civil violence. The structure consists of individuals, environment and empirical rules. Our software agents model police officers and civilians. The accurate modelling of their attributes is crucial to the description which is as much as possible close to human life and behaviour in situations of unrest. Peaceful civilians are neutral participant, but they can react to external or internal stimulus. Police officers retain the order by arresting the activists and through strategies that are chosen depending on the success of the management and control of violence. The police officers perform two tasks in a direct way: active arrest of protesters and movement in space.

Civilians are much more complex individuals than the police officers. Civilian agent decides whether to be active or not. Typical for civilian agents is communication. The civilian agents can change from active to passive and from passive to active. The functioning of the system depends on the empirical rules. Empirical rules guide the interactions of agents and ensure the functioning of the system.

Intuitionistic fuzzy sets for conflict resolution

We will apply IFS to represent the movement of the individuals, taking in to account the rules in the network, which represents the space where the agents are moving. This representation is similar to the example of game of chess in [4]. We specify three types of agents: peaceful civilians; police officers and active civilians. On Fig. 1 are shown possible movements of the agents.



(a) (b) (c)

Fig. 1 Possible movements of agents

Every one of the agents has rules of movement. There are 8 possible directions. We will describe the agents movement in a 10×10 grid, which has 100 patches. This means that the all possible movements for one agent are 99, $n = 99$, and the possible directions are $m = 8$, thus there are 91 impossible patches for one step movement. In the case when there is no other agent around and the current agent is not at the border of the grid (region), where some of the movements are impossible, then:

$$V(agent) = \left\langle \frac{8}{99}, \frac{91}{99} \right\rangle.$$

If the agent is on the border of the grid or in some of the corners or there is other agent on the neighbouring patches, than the possible directions are less. For example, let an agent be in the corner of the grid, then the possible directions are 3 and:

$$V(agent) = \left\langle \frac{3}{99}, \frac{96}{99} \right\rangle.$$

If an agent is on the grid border, then the possible directions are 5 and:

$$V(agent) = \left\langle \frac{5}{99}, \frac{94}{99} \right\rangle.$$

We will introduce the terms active and peaceful and level of discontent (NAI) and threshold ($AThreshold$) for danger [8], where $NAI = Rev - N$; Rev-tendency to revolt and N is a net risk (the risk of imprisonment). There are several kind of interactions between the agents:

- the police officer agent (P) approaches the active civilian agent to arrest him;
- the active civilian agent (A) tries to stay far from the police officers;
- the peaceful civilian agent (M) moves depending on the value of $NAI - AThreshold$. If it is greater than 0, then it will become an active civilian. If it is less than 0, it continues to be peaceful and will circumnavigate the active civilians.

When we apply IFS for concrete cases there will be concrete situations, according to the conditions which we examine. Every movement can be estimated as useful, harmful or indifferent. The main three types of agents will be defined according the three main situations to which they correspond:

- agents police officers a_p with $f_1^p, f_2^p, \ldots, f_{a_p}^p$;
- agents active civilians a_A with $f_1^A, f_2^A, \ldots, f_{a_A}^A$;
- agents peaceful civilians a_m with $f_1^m, f_2^m, \ldots, f_{a_m}^m$.

Let $\phi(f^x,t)$ be the number of the possible movements of the agent f^x at the moment t, where $x \in \{A, p, m\}$. Let $\phi_u(f^x,t)$, $\phi_h(f^x,t)$ and $\phi_i(f^x,t)$ be the number of the possible useful, harmful and indifferent movements in the network at time t, respectively, thus:

$$\phi_u(f^x,t) + \phi_h(f^x,t) + \phi_i(f^x,t) = \phi(f^x,t).$$

The summation is over all the possible movements:

$$\mu_x(t) = \frac{\sum \phi_u(f^x,t)}{\sum \phi(f^x,t)}, \tag{1}$$

$$\nu_x(t) = \frac{\sum \phi_h(f^x,t)}{\sum \phi(f^x,t)}, \tag{2}$$

$$\pi_x(t) = \frac{\sum \phi_i(f^x,t)}{\sum \phi(f^x,t)}. \tag{3}$$

Hence $\mu_x(t) + \nu_x(t) + \pi_x(t) = 1$ and the pair $(\mu_x(t), \nu_x(t))$ is an intuitionistic fuzzy estimation of the network, where are the agents in the moment t.

Example

Let our network be a 10×10 grid, which consists of 100 patches and let there are 8 agent of type P (police officers), 12 agents of type A (active) and 8 agents of type M (peaceful), which are located as it is shown on Fig. 2 ($\star$-corresponds to police officers, the red circles correspond to active and white circles correspond to the peaceful).

There are several possible movements for every type of agents. For the 8 agents of type P the possible movements in our example are:

- $b0 \rightarrow a0,\ a1,\ c0,\ c1$;
- $b1 \rightarrow a0,\ a2,\ c0,\ c1,\ c2$;
- $a3 \rightarrow a2,\ b3,\ b4$;
- $a4 \rightarrow a5,\ b3,\ b4,\ b5$;
- $b6 \rightarrow a5,\ a6,\ a7,\ b5,\ b7,\ c5,\ c6,\ c7$;
- $d7 \rightarrow c6,\ c7,\ c8,\ d6,\ d8,\ e6,\ e7,\ e8$;
- $f8 \rightarrow e7,\ e8,\ e9,\ f9,\ g7,\ g8,\ g9$;
- $j5 \rightarrow i4,\ i5,\ i6,\ j4, j6$.

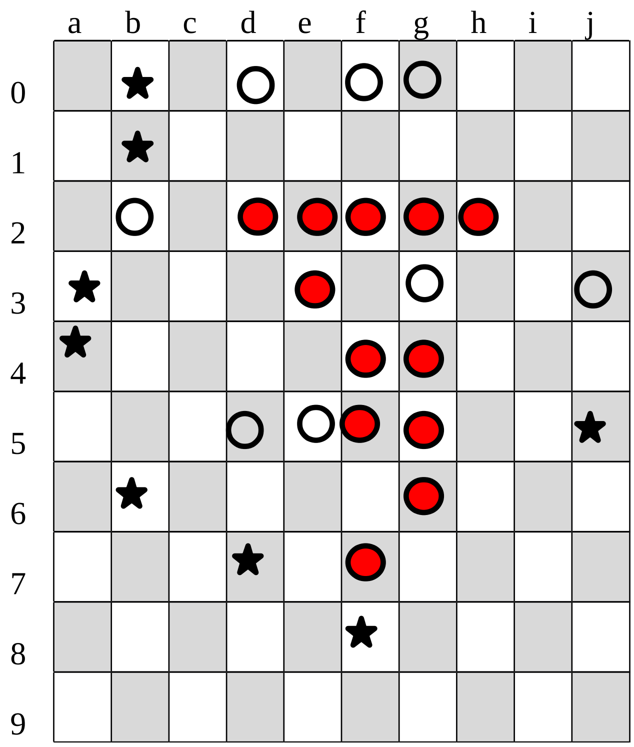


Fig. 2 Agents positioning

The number of possible useful, harmful and indifferent movements at moment t is shown in Table 1. According to Eqs. (1), (2) and (3), for the values of $\mu_x(t)$, $\nu_x(t)$ and $\pi_x(t)$ we obtain:

$$\mu_x(t) = \frac{\phi_{u_{b0}} + \phi_{u_{b1}} + \phi_{u_{a3}} + \phi_{u_{a4}} + \phi_{u_{b6}} + \phi_{u_{d7}} + \phi_{u_{f8}} + \phi_{u_{j5}}}{\phi_{b0} + \phi_{b1} + \phi_{a3} + \phi_{a4} + \phi_{b6} + \phi_{d7} + \phi_{f8} + \phi_{j5}} = \frac{14}{46},$$

$$\nu_x(t) = \frac{\phi_{h_{b0}} + \phi_{h_{b1}} + \phi_{h_{a3}} + \phi_{h_{a4}} + \phi_{h_{b6}} + \phi_{h_{d7}} + \phi_{h_{f8}} + \phi_{h_{j5}}}{\phi_{b0} + \phi_{b1} + \phi_{a3} + \phi_{a4} + \phi_{b6} + \phi_{d7} + \phi_{f8} + \phi_{j5}} = \frac{20}{46},$$

$$\pi_x(t) = \frac{\phi_{i_{b0}} + \phi_{i_{b1}} + \phi_{i_{a3}} + \phi_{i_{a4}} + \phi_{i_{b6}} + \phi_{i_{d7}} + \phi_{i_{f8}} + \phi_{i_{j5}}}{\phi_{b0} + \phi_{b1} + \phi_{a3} + \phi_{a4} + \phi_{b6} + \phi_{d7} + \phi_{f8} + \phi_{j5}} = \frac{12}{46}.$$

Table 1. Possible movements in different situations, 8 agents in type P

Agent position		***b*0**	***b*1**	***a*3**	***a*4**	***b*6**	***d*7**	***f*8**	***j*5**
possible movements	ϕ	4	6	3	4	8	8	8	5
useful movements	ϕ_u	1	2	1	2	1	3	1	3
harmful movements	ϕ_h	2	3	1	1	6	3	3	1
indifferent movements	ϕ_i	1	1	1	1	1	2	4	2

For the 12 agents of type A the possible movements in our example are:

- $d2 \to c1, c2, c3, d1, d3, e1$;
- $e2 \to d1, d3, e1, f1, f3$;
- $e3 \to d3, d4, e4, f3$;
- $f2 \to e1, f1, f3, g1$;
- $f4 \to e4, f3$;
- $f5 \to e4, e6, f6$;
- $f7 \to e6, e7, e8, f6, g7, g8$;
- $g2 \to f1, f3, g1, h1, h3$;
- $g4 \to f3, h3, h4, h5$;
- $g5 \to f6, h4, h5, h6$;
- $g6 \to f6, g7, h5, h6, h7$;
- $h2 \to g1, h1, h3, i1, i2, i3$.

The number of possible useful, harmful and indifferent movements at the moment t is shown in Table 2. According to Eqs. (1), (2) and (3), for the values of $\mu_x(t)$, $\nu_x(t)$ and $\pi_x(t)$ we obtain:

$$\mu_x(t) = \frac{\phi_{u_{d2}} + \phi_{u_{e2}} + \phi_{u_{e3}} + \phi_{u_{f2}} + \phi_{u_{f4}} + \phi_{u_{f5}} + \phi_{u_{f7}} + \phi_{u_{g2}} + \phi_{u_{g4}} + \phi_{u_{g5}} + \phi_{u_{g6}} + \phi_{u_{h2}}}{\phi_{d2} + \phi_{e2} + \phi_{e3} + \phi_{f2} + \phi_{f4} + \phi_{f5} + \phi_{f7} + \phi_{g2} + \phi_{g4} + \phi_{g5} + \phi_{g6} + \phi_{h2}} = \frac{22}{54},$$

$$\nu_x(t) = \frac{\phi_{h_{d2}} + \phi_{h_{e2}} + \phi_{h_{e3}} + \phi_{h_{f2}} + \phi_{h_{f4}} + \phi_{h_{f5}} + \phi_{h_{f7}} + \phi_{h_{g2}} + \phi_{h_{g4}} + \phi_{h_{g5}} + \phi_{h_{g6}} + \phi_{h_{h2}}}{\phi_{d2} + \phi_{e2} + \phi_{e3} + \phi_{f2} + \phi_{f4} + \phi_{f5} + \phi_{f7} + \phi_{g2} + \phi_{g4} + \phi_{g5} + \phi_{g6} + \phi_{h2}} = \frac{20}{54},$$

$$\pi_x(t) = \frac{\phi_{i_{d2}} + \phi_{i_{e2}} + \phi_{i_{e3}} + \phi_{i_{f2}} + \phi_{i_{f4}} + \phi_{i_{f5}} + \phi_{i_{f7}} + \phi_{i_{g2}} + \phi_{i_{g4}} + \phi_{i_{g5}} + \phi_{i_{g6}} + \phi_{i_{h2}}}{\phi_{d2} + \phi_{e2} + \phi_{e3} + \phi_{f2} + \phi_{f4} + \phi_{f5} + \phi_{f7} + \phi_{g2} + \phi_{g4} + \phi_{g5} + \phi_{g6} + \phi_{h2}} = \frac{12}{54}.$$

Table 2. Possible movements in different situations, 12 agents of type A

Agent position		***d*2**	***e*2**	***e*3**	***f*2**	***f*4**	***f*5**	***f*7**	***g*2**	***g*4**	***g*5**	***g*6**	***h*2**
possible movements	ϕ	6	5	4	4	2	3	6	5	4	4	5	6
useful movements	ϕ_u	2	3	2	3	1	0	1	2	2	0	1	5
harmful movements	ϕ_h	2	1	2	1	1	3	5	1	2	3	1	0
indifferent movements	ϕ_i	2	1	0	0	0	0	0	2	0	1	3	1

For the 8 agents of type M the possible movements in our example are:

- $b2 \to a1, a2, a3, b3, c1, c2, c3$;
- $d0 \to c0, c1, d1, e0, e1$;
- $d5 \to c4, c5, c6, d4, d6, e6$;

- $e5 \rightarrow d4, d6, e4, e6, f6$;
- $f0 \rightarrow e0, e1, f1, g1$;
- $g0 \rightarrow f1, g1, h0, h1$;
- $g3 \rightarrow f3, h3, h4$;
- $j3 \rightarrow i2, i3, i4, j2, j4$.

The number of possible useful, harmful and indifferent movements at the moment t depends of the value of $NAI - AThreshold$. If $NAI - AThreshold > 0$ the agent will be active, in other case it will be peaceful. If he is active the number of possible movements is shown in Table 3. According to Eqs. 1,2, and 3, for the values of $\mu_x(t)$, $\nu_x(t)$ and $\pi_x(t)$ we obtain:

$$\mu_x(t) = \frac{\phi_{u_{a1}} + \phi_{u_{d0}} + \phi_{u_{d5}} + \phi_{u_{e5}} + \phi_{u_{f0}} + \phi_{u_{g0}} + \phi_{u_{g3}} + \phi_{u_{j3}}}{\phi_{a1} + \phi_{d0} + \phi_{d5} + \phi_{e5} + \phi_{f0} + \phi_{g0} + \phi_{g3} + \phi_{j3}} = \frac{12}{38},$$

$$\nu_x(t) = \frac{\phi_{h_{a1}} + \phi_{h_{d0}} + \phi_{h_{d5}} + \phi_{h_{e5}} + \phi_{h_{f0}} + \phi_{h_{g0}} + \phi_{h_{g3}} + \phi_{h_{j3}}}{\phi_{a1} + \phi_{d0} + \phi_{d5} + \phi_{e5} + \phi_{f0} + \phi_{g0} + \phi_{g3} + \phi_{j3}} = \frac{16}{38},$$

$$\pi_x(t) = \frac{\phi_{i_{a1}} + \phi_{i_{d0}} + \phi_{i_{d5}} + \phi_{i_{e5}} + \phi_{i_{f0}} + \phi_{i_{g0}} + \phi_{i_{g3}} + \phi_{i_{j3}}}{\phi_{a1} + \phi_{d0} + \phi_{d5} + \phi_{e5} + \phi_{f0} + \phi_{g0} + \phi_{g3} + \phi_{j3}} = \frac{10}{38}.$$

Table 3. Possible movements in different situations, 8 agents of type M

Agent position		***b*2**	***d*0**	***d*5**	***e*5**	***f*0**	***g*0**	***g*3**	***j*3**
possible movements	ϕ	6	5	6	5	4	4	3	5
useful movements	ϕ_u	1	1	2	0	3	3	0	2
harmful movements	ϕ_h	5	3	3	2	0	0	1	2
indifferent movements	ϕ_i	0	1	1	3	1	1	2	1

With the above example the IF estimation of the reactions (movement) of different types of agents in case of protest is represented. This model and estimation can be applied to predict possible reactions in different situations, influence of number of police officers and their locations. The level of uncertainty can be predicted. The number of police officers and their positioning can be optimized according the expected number of protest participants. Intuitionistic fuzzy estimation of multi-agent system is useful also for training and simulating possible situations.

Conclusion

In this paper intuitionistic fuzzy estimation of multi-agent system in case of protest is proposed. The estimation consists of three components: degree of membership; degree of non-membership; degree of uncertainty. In a future work the system will be extended with more types of agents (participants) and their influence in the system will be studied and estimated.

This model can be used for decision making when some protest is planned and for training the police officer, simulating different situations.

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