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Decision Making Methods in Agent Based Modeling

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Abstract. The aim of the work is to investigate how agents can become more intelligent using contemporary methods for decision making in electronic commerce auctions. The idea is to implement fuzzy logic for agents' evaluations of market conditions and sort their preferences using difference combinations of fuzzy input data to make rational choice which is the best behavior under given market conditions. The task is to prove that a family of decision making algorithms, created in the Bulgarian Academy of Sciences, can be embedded in existing prototype of multi-agent simulator for online auctions for change of agents' bidding strategy.

1 Introduction

The behavior of agents in an auction is based on their bidding strategies. A strategy is a methodology which the agent implements to achieve its goals while following the auction rules. Strategies are private and are chosen by auction participants (agents' owners). Various protocols for bidding are used in practice, so there is no universal strategy for successful negotiation. A given strategy can be effective under one protocol and ineffective under another. Creation of an optimal strategy for continuous double auction (CDA) is a complex task that still challenges electronic commerce researchers. The aim is creating strategies that would pick the "right" deal sides, so that the CDA efficiency would be maximized and there would be quick deal price convergence toward the equilibrium price. The goal of this work is to investigate two alternative algorithm families for multi-criteria analysis with fuzzy logic for bidding strategy selection in CDA. The described methods for decision making can be used in electronic auctions not only for preliminary selection of the most suitable strategy from a given set of agent strategies, but also for changing the used strategy during auction.

2 Related Work

For detailed investigation of intelligent agents' behavior as participants in electronic commerce, various auction models have been simulated. The suggested methods for bidding strategies evaluation are based on two different approaches. The first one of them is essentially a comparison between strategies' efficiency in a static agent population (the strategies are selected in advance and cannot be changed once an auction has begun). The second approach investigates agent populations in which change of the used strategy after the beginning of an auction is allowed using dynamics replicator.

Anthony and Jennings, who follow the first approach, generate biddings that depend on the following parameters: time left until the end of the auction; number of open auctions; agent's intention towards deal and agent's attitude towards risk. The combination of these four indices through relative weighting coefficients, defined by the user, gives a bidding strategy. Later, the two authors suggest a genetic algorithm for search of an effective strategy from the solution set defined by the specific market conditions [1]. As followers of the second approach, Walsh et al. use an evolutionary variant of game theory and investigate experimentally an agent's preference towards three bidding strategies. The main disadvantage of their work is that the time complexity of the suggested algorithms for strategy comparison depends exponentially on the number of investigated strategies [8]. Muchnick and Solomon create the NatLab platform using the principle of Markov's nets. In order to make a smooth transition from computer simulation to experimental economics, they generate eight different bidding strategies using avatars. In order for the emulation to be more realistic, the system makes adaptive actualization of the avatars [4]. Posada and Lopez suggest a portfolio comprised of three alternative bidding strategies. For strategy selection, they propose two heuristics –imitation and take-the-best. Imitation heuristic uses social learning taking into account the past collective experience. The other heuristic, take-the-best, uses individual rational learning taking into account previous experiences of the agent [7]. Goyal et al. use the term "attitude" analogically to the typical to agent technology terms "intention" and "commitment". Each agent has a definite attitude toward the bidding process. This helps it to adapt to the market dynamics more quickly. In order for a proper bidding to be chosen, a set of individual bids is generated in advance. The agents' attitudes towards the set of criteria and bids take part in the multi-criteria procedure for bidding selection [2].

In the current work, the applicability of two algorithms with fuzzy logic with a common purpose of solving the task of multi-criteria ordering of bidding strategies in an auction is investigated - algorithm with Fuzzy Techniques and Negotiable Attitudes (*FTNA*) [2] and Algorithm for aggregation of fuzzy Relations between Alternatives and a fuzzy relation between the weights of the CRriteria (*ARAKRI1*)[5],[6].

3 Application of algorithms for multi criteria ranking with fuzzy relations for bidding strategy selection

In this section, the methodology of software modeling and comparative analysis, both quantitative and qualitative, will be used. We will determine whether the mentioned algorithms for multi-criteria analysis can be embedded in existing prototype of software system for agent-based modeling MASECA [3] as a software procedure, accessible to the bidding agents. After completing the software implementation of algorithms, we start series of experiments to research the influence of the new decision making capability.

The input data for decision making procedure are:

n - a number of alternatives;

m - a number of criteria;

l – a number of bidding agents.

During the experiment, we use the next parameter values:

Five strategies as alternatives for agents' bidding in CDA:

A_1 – snipping strategy (Snipping),

A_2 – strategy with fixed markup (L),

A_3 - zero intelligence with budget constraints (ZIC),

A_4 - zero intelligence plus (ZIP) and

A_5 – risk based strategy (RB).

These strategies are the most cited in literature sources.

For example, we can use the next three criteria for strategies' evaluation:

C_1 – time complexity,

C_2 – price prediction,

C_3 – risk attitude.

All criteria are maximizing. Five bidding agents participate in the experiments.

3.1 Algorithm with Fuzzy Techniques and Negotiable Attitudes (***FTN*A**)

Step 1: The decision maker (DM) determines the relative weighting coefficients of the criteria for each strategy by using the method of analytical hierarchic process. The values of the weights depend on the degree of importance of the given criterion. The fuzzy relations (matrices for comparison) of the criteria are completed according to the degree of importance of the paired criteria. Evaluations vary in the range from 1 to 9: 1-insignificantly important; 3-more important; 5-equally important; 7-substantially more important; 9-absolutely more important, and ranks 2,4,6,8 represent values that are between the given ones. The weight of each criterion is given by the formula of geometric mean of the corresponding row of the comparison matrix. If we let *w* to be the set of weights and $w=\{w_1,w_2,..,w_m\}$, then here we will also have $w_i \in [0,1]$ for $i=1,2,..,m$ and $\sum_{i=1}^{m} w_i = 1$ (Figure 1).

To fulfill the matrices we use experts' knowledge of evaluation of bidding strategies features.

Snipping	t	h	r						
t	5	9	10	0.83	0.47	0.50	0.58	0.72	t
h	1	5	5	0.17	0.26	0.25	0.22	0.28	h
r	0	5	5	0.00	0.26	0.25	0.00	0.00	r
	6	19	20	1.00	1.00	1.00	0.80	1.00	

L	t	h	r						
t	5	9	9	0.71	0.47	0.47	0.54	0.56	t
h	1	5	5	0.14	0.26	0.26	0.21	0.22	h
r	1	5	5	0.14	0.26	0.26	0.21	0.22	r
	7	19	19	1.00	1.00	1.00	0.97	1.00	

ZIC	t	h	r						
t	5	6	5	0.63	0.38	0.33	0.43	0.56	t
h	3	5	5	0.38	0.31	0.33	0.34	0.44	h
r	0	5	5	0.00	0.31	0.33	0.00	0.00	r
	8	16	15	1.00	1.00	1.00	0.77	1.00	

ZIP	t	h	r						
t	5	8	5	0.42	0.67	0.42	0.49	0.44	t
h	2	5	9	0.17	0.42	0.75	0.37	0.34	h
r	5	1	5	0.42	0.08	0.42	0.24	0.22	r
	12	14	19	1.00	1.17	1.58	1.10	1.00	

RB	t	h	r						
t	5	2	1	0.23	0.15	0.10	0.15	0.15	t
h	8	5	4	0.36	0.38	0.40	0.38	0.39	h
r	9	6	5	0.41	0.46	0.50	0.46	0.46	r
	22	13	10	1.00	1.00	1.00	0.99	1.00	

Fig. 1. Fragment of the input data for the *FTNA* algorithm – comparison matrices between criteria for each strategy.

Step 2: The agent's attitude towards the bidding strategies and the criteria for their evaluation are determined. Here "attitude" represents the preference of agent *k* to choose a strategy *i* with criterion *j*. The evaluations of the attitudes a_{ij}^{k} (i=1,2,..,n, j=1,2,..,m, k=1,2,..,l) are presented through linguistic terms such as "very low", "low", "average", "high", and "very high". The fuzzy agent relations towards strategies and criteria are completed in the attitude matrices $A^{\kappa} = (a_{ij})_{nxm}^{\ k}$ (Figure 2). To fulfill the matrices we use historical data from auction deals until the present moment.

A^1	t	h	r									
Snipping	VH	VL	VL	0.9	1	1	0	0	0.1	0	0	0.1
L	VL	VL	VL	0	0	0.1	0	0	0.1	0	0	0.1
ZIC	VH	VL	VL	0.9	1	1	0	0	0.1	0	0	0.1
ZIP	H	H	VL	0.7	0.9	1	0.7	0.9	1	0	0	0.1
RB	L	VH	VH	0	0.1	0.3	0	0.1	0.3	0.9	1	1

A^2	t	h	r									
Snipping	ML	VL	L	0.1	0.3	0.5	0	0	0.1	0	0.1	0.3
L	ML	VL	L	0.1	0.3	0.5	0	0	0.1	0	0.1	0.3
ZIC	MH	ML	ML	0.5	0.7	0.9	0.1	0.3	0.5	0.1	0.3	0.5
ZIP	MH	M	ML	0.5	0.7	0.9	0.3	0.5	0.7	0.1	0.3	0.5
RB	MH	H	H	0.5	0.7	0.9	0.7	0.9	1	0.7	0.9	1

A^3	t	h	r									
Snipping	ML	VL	VL	0.1	0.3	0.5	0	0	0.1	0	0	0.1
L	ML	VL	VL	0.1	0.3	0.5	0	0	0.1	0	0	0.1
ZIC	MH	VL	L	0.5	0.7	0.9	0	0	0.1	0	0.1	0.3
ZIP	MH	VL	L	0.5	0.7	0.9	0	0	0.1	0	0.1	0.3
RB	H	H	VH	0.7	0.9	1	0.7	0.9	1	0.9	1	1

A^4	t	h	r									
Snipping	M	VL	VL	0.3	0.5	0.7	0	0	0.1	0	0	0.1
L	VL	VL	VL	0	0	0.1	0	0	0.1	0	0	0.1
ZIC	M	VL	VL	0.3	0.5	0.7	0	0.1	0.3	0	0	0.1
ZIP	ML	VL	VL	0.1	0.3	0.5	0	0	0.1	0	0	0.1
RB	M	VH	VH	0.3	0.5	0.7	0.9	1	1	0.9	1	1

A^5	t	h	r									
Snipping	VL	VL	VL	0	0	0.1	0	0	0.1	0	0	0.1
L	VL	ML	VL	0	0	0.1	0.1	0.3	0.5	0	0	0.1
ZIU	M	H	VL	0.3	0.5	0.7	0.7	0.9	1	0	0	0.1
ZIC	M	VL	VL	0.3	0.5	0.7	0	0	0.1	0	0	0.1
ZIP	ML	VL	ML	0.1	0.3	0.5	0	0	0.1	0.1	0.3	0.5
RB	M	VH	VH	0.3	0.5	0.7	0.9	1	1	0.9	1	1

Fig. 2. Matrices of agents' attitudes towards strategies.

Step 3: Each attitude matrix is aggregated into attitude vector A_i (1=1,2,..,n) as follows:

$A_i^k = w_1^k a_{i1}^k + w_2^k a_{i2}^k + ... + w_n^k a_{in}^k$ (Figure 3)**.**

1			2			3			4			5		
0.651	0.724	0.751	0.000	0.000	0.100	0.502	0.558	0.602	0.378	0.486	0.586	0.414	0.514	0.622
0.072	0.217	0.390	0.056	0.190	0.368	0.323	0.523	0.723	0.344	0.544	0.744	0.669	0.869	0.985
0.072	0.217	0.390	0.056	0.168	0.323	0.279	0.390	0.546	0.441	0.629	0.952	0.792	0.946	1.000
0.217	0.362	0.534	0.000	0.000	0.100	0.056	0.167	0.323	0.044	0.132	0.276	0.808	0.923	0.954
0.000	0.000	0.100	0.022	0.066	0.188	0.167	0.279	0.435	0.066	0.199	0.365	0.808	0.923	0.954

Fig. 3. The attitudes' vectors.

Step 4: We assume that all the agents are equally important and calculate the normalized vector of the fuzzy solution r. The normalized weight of the agents D_k (k=1,2,...,l) is denoted with (ν_1, ν_2 ,..., ν_l):

$$(r_1, r_2, .., r_n) = (\upsilon_1, \upsilon_2, .., \upsilon_l) \begin{pmatrix} a_1^1 & a_2^1 & .. & a_n^1 \\ a_1^2 & a_2^2 & .. & a_n^2 \\ .. & .. & .. & .. \\ a_1^l & a_2^l & .. & a_n^l \end{pmatrix}$$

r_1	0.203	0.304	0.433
r_2	0.027	0.085	0.216
r_3	0.265	0.383	0.526
r_4	0.255	0.398	0.585
r_5	0.698	0.835	0.903

Fig. 4. The normalized vectors of the fuzzy solution.

Step 5: The elements of the normalized vector of the fuzzy solution r_i are positive triangular fuzzy numbers and belong to the interval [0,1]. Then we calculate the distance between the fuzzy solutions r_i and the perfect ones, a positive and a negative solution. Let r^+ be the fuzzy positive perfect solution, r^- **-** the fuzzy negative perfect solution and r^+=(1,1,1) and r^-=(0,0,0). The distances d_i^+ between r_i and r^+ and d_i^- between r_i and r^- are calculated:
$d_i^+ = d(r_i, r^+)$ and $d_i^- = d(r_i, r^-)$, where *d* is the distance between two fuzzy numbers. To calculate *d* the vertex method is used (Figure 5).

d_1^+	0.6932
d_2^+	0.8944
d_3^+	0.6178
d_4^+	0.6029
d_5^+	0.2062

d_1^-	0.3271
d_2^-	0.1348
d_3^-	0.4057
d_4^-	0.4340
d_5^-	0.8166

Fig. 5. The distances between the fuzzy solutions *r* and the corresponding perfect positive and negative solutions.

Step 6: To determine the rank of each strategy the coefficient of closeness is calculated with the formula:
$CC_i = \frac{1}{2}(d_i^+ + (1 - d_i^-)$ for *i*=1,2,...,*n*.
The strategy with the largest coefficient of closeness is the most appropriate one for bidding at that moment (Figure 6, left – before, right – after sort).

Snipping	0.317
L	0.120
ZIC	0.394
ZIP	0.416
RB	0.805

RB	0.805
ZIP	0.416
ZIC	0.394
Snipping	0.317
L	0.120

Fig. 6. The solution (*right*) of the multi criteria analysis problem with the *FTNA* algorithm.

3.2 Algorithm with Fuzzy Numbers as Alternatives Evaluations and Real Numbers as Weighted Coefficients (*ARAKRI1*)

Step 1: The evaluations of the alternatives (strategies) by the criteria are fuzzy triangular numbers (Figure 7).

	t			h			r		
Snipping	1.4	2.1	2.8	0	0.0	0.5	0.0	0.1	0.7
L	0.2	0.6	1.3	0.1	0.3	0.9	0.0	0.1	0.7
ZIC	2.5	3.4	4.2	0.1	0.4	1.1	0.1	0.4	1.1
ZIP	1.9	2.9	3.8	1	1.4	2.0	0.2	0.7	1.5
RB	1.8	2.7	3.6	3.2	3.9	4.3	4.3	4.9	5.0

Fig. 7. Fuzzy evaluations by the three criteria.

According to [5] and [6], the G-index of the fuzzy number $\tilde{A} = (a_1, a_2, a_3, a_4),\ \ a_2 = a_3$ is computed using the following ranking function:
$F(\tilde{A}) = kF_1(\tilde{A}) + (1-k)F_2(\tilde{A}), \quad k \in [0,1]$, where:

$$F_1(\tilde{A}) = a_1 + S_{\tilde{A}} \sin[\mathrm{R}, g(x)] = a_1 + \frac{(a_4 - a_1) + (a_3 - a_2)}{2} \times \frac{1}{[(a_4 - a_3)^2 + 1]^{1/2}}$$ and

$$F_2(\tilde{A}) = a_4 + S_{\tilde{A}} \sin[\mathrm{R}, f(x)] = a_4 - \frac{(a_4 - a_1) + (a_3 - a_2)}{2} \times \frac{1}{[(a_2 - a_1)^2 + 1]^{1/2}}$$ (Figure 8).

	t	h	r
Snipping	0.475	0.058	0.070
L	0.137	0.116	0.070
ZIC	0.788	0.139	0.120
ZIP	0.663	0.349	0.170
RB	0.625	0.873	0.930

Fig. 8. G-indices of the fuzzy evaluations of the strategies.

Step 2: As the criteria evaluation can be expressed in different measurement units, for their unification is used the following transforming function:

$$\mu_k(a_i, a_j) = \begin{cases} 1 & \text{ако } i = j \\ 0.5 + \dfrac{x_{ik} - x_{jk}}{2(\max\limits_i\{x_{ik}\} - \min\limits_i\{x_{ik}\})} & \text{ако } i \neq j \end{cases}$$

where $x_{ik}, x_{jk},\ i, j = 1,2,...,n,\ k = 1,2,...,m$ are the evaluations of the alternatives a_i and $a_j,\ \ i, j = 1,2,...,n$ according to the criterion $c_k,\ k = 1,2,...,m$. The obtained fuzzy relations are $R_k, k = 1,2,...,m$. If a certain criterion, c_k, is minimizing, in order for the alternatives to be sorted in a descending order, the complement to the relation $R_k' = 1 - R_k$ is calculated, in other words, for this relation new membership function is calculated using the formula $\mu_k'(a_i, a_j) = 1 - \mu_k(a_i, a_j)$ (Figure 9).

		Snipping	L	ZIC	ZIP	RB
t	Snipping	1	0.760	0.260	0.356	0.385
	L	0.240	1	0	0.096	0.125
	ZIC	0.740	1	1	0.596	0.625
	ZIP	0.644	0.904	0.404	1	0.529
	RB	0.615	0.875	0.375	0.471	1
h	Snipping	1	0.464	0.450	0.322	0
	L	0.536	1	0.486	0.357	0.036
	ZIC	0.550	0.514	1	0.371	0.050
	ZIP	0.678	0.643	0.629	1	0.178
	RB	1	0.964	0.950	0.822	1
r	Snipping	1	0.500	0.471	0.442	0
	L	0.500	1	0.471	0.442	0
	ZIC	0.529	0.529	1	0.471	0.029
	ZIP	0.558	0.558	0.529	1	0.058
	RB	1	1	0.971	0.942	1

Fig. 9. Fuzzy relations of the preferences.

Step 3: All relations $R_1, R_2, ..., R_m$ are combined so that an aggregated relation ***R*** with the following matrix can be obtained with the membership function

$\mu(a_i, a_j) = Agg\{\mu_1(a_i, a_j), \mu_2(a_i, a_j), ..., \mu_m(a_i, a_j)\}$

Each element from matrix ***R*** is calculated by the aggregation operators' formula with weighting coefficients. The following operators are used: *WMean*, *WGeom*, *WMaxMin* and *WMinMax* with weighting coefficients-real numbers. If *w* is the set of average criteria weights from the *FTNA* algorithm and $w=\{w_1,w_2,...,w_m\}$, then $w_k \in [0,1]$ for k=1,2,…,*m* and $\sum_{k=1}^{m} w_i = 1$.

The calculations with the operators *WMean*, *WGeom*, *WMaxMin* and *WMinMax* for degree of membership to each of the aggregated relations *R* of the pair на двойката (a_i, a_j) are as follows:

$$\mu(a_i, a_j) = \text{WMean}\{\mu_1(a_i, a_j), \mu_2(a_i, a_j), ..., \mu_m(a_i, a_j)\} = \sum_{k=1}^{m} w_k \mu_k(a_i, a_j)$$

$$\mu(a_i, a_j) = \text{WGeom}\{\mu_1(a_i, a_j), \mu_2(a_i, a_j), ..., \mu_m(a_i, a_j)\} = \prod_{k=1}^{m} [\mu_k(a_i, a_j)]^{w_k}$$

$$\mu(a_i, a_j) = \text{WMaxMin}\{\mu_1(a_i, a_j), \mu_2(a_i, a_j), ..., \mu_m(a_i, a_j)\} = \max_k \{\min(\mu_k(a_i, a_j), w_k)\}$$

$$\mu(a_i, a_j) = \text{WMinMax}\{\mu_1(a_i, a_j), \mu_2(a_i, a_j), ..., \mu_m(a_i, a_j)\} = \min_k \{\max(\mu_k(a_i, a_j), w_k)\}$$

For the last two operators, *WMaxMin* and *WMinMax* the weights of the criteria are recalculated so that they belong to the interval [0,1] and the largest of them to be equal to 1 by the formula:

$$w_k' = \frac{w_k}{\max_{k=1}^{m}\{w_k\}}$$

Four obtained aggregated matrices are shown in Figure 10.

ARAKRI1_WMean	1	0.593	0.380	0.371	0.154
	0.407	1	0.287	0.278	0.061
	0.620	0.713	1	0.491	0.274
	0.629	0.722	0.509	1	0.283
	0.846	0.939	0.726	0.717	1
ARAKRI1_WGeom	1	0.578	0.366	0.368	0
	0.381	1	0	0.225	0
	0.612	0.677	1	0.482	0.116
	0.627	0.706	0.500	1	0.197
	0.823	0.938	0.659	0.685	1
ARAKRI1_WMaxMin	1	0.760	0.471	0.442	0.385
	0.536	1	0.486	0.442	0.125
	0.740	1	1	0.596	0.625
	0.678	0.904	0.629	1	0.529
	0.750	0.875	0.750	0.750	1
ARAKRI1_WMinMax	1	0.750	0.750	0.750	0.750
	0.750	1	0.750	0.750	0.750
	0.750	0.750	1	0.750	0.750
	0.750	0.750	0.750	1	0.750
	1	0.964	0.950	0.822	1

Fig. 10. The aggregated preferences' relations $R_1, R_2, ..., R_m$.

Step 4: The four matrices from Figure 10 are from type ***R***. Each of these matrices is recalculated so that matrices $R^{'}$ are obtained in the following way: if $\mu(a_i, a_j) \geq \mu(a_j, a_i)$, then $\mu'(a_i, a_j) = \mu(a_i, a_j)$ and $\mu'(a_j, a_i) = 0$. Every asymmetric fuzzy rearrangement *R'* of ***R*** is fuzzy partial order. *R'* can be rearranged into a triangular matrix. After the triangular matrix *R'* is rearranged, a relation is obtained which represents a fuzzy linear arrangement. A non-fuzzy order of the alternatives is the same as their order in the title raw of the obtained table and is the solution to the problem of multi criteria arrangement (Figure 11).

ARAKRI1_WMean	RB	ZIC	ZIP	Snipping	L
		0.72633	0.49106	0.62867	0.5932
ARAKRI1_WGeom	RB	ZIC	ZIP	Snipping	L
		0.65927	0.48185	0.62675	0.57812
ARAKRI1_WMaxMin	RB	ZIC	ZIP	Snipping	L
		0.750	0.59588	0.67834	0.75966
ARAKRI1_WMinMax	Snipping	L	ZIC	ZIP	RB
		0.750	0.750	0.750	0.750

Fig. 11. The solutions of the multi criteria analysis problem with the *ARAKRI1* algorithm.

4 Results Comparison from the Multi Criteria Analysis with the *FTNA* and *ARAKRI1* algorithms

5 Significance of the obtained results

The proposed method for bidding strategies selection is appropriate for the development and modeling of economic objects. The work can serve as a basis for the practical orientation of teaching in the following fields: Electronic Commerce, Electronic Business etc. As a result, this would sharpen the motivation and interest of students in those fields and would provide them with practical instruments. On the other hand, realization of these types of methods with fuzzy logic broadens the practical applicability of related mathematical tasks and will supply additional information for future theoretical research.

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