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Fuzzy Reasoning and Fuzzy Automata in User Adaptive Emotional and Information Retrieval Systems

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Abstract--**The application of behaviour-based control structures in emotional and information retrieval systems gives a simple way for handling online user adaptivity. The main idea of behaviour-based control systems – the intelligent adaptation of the system to the actual situation, by discrete switching to the most appropriate strategy, or by fusing the strategies appeared to be the most appropriate ones – can be easily extended to user adaptive emotional, or information retrieval systems. This case the actual user acts the environment to be adapted, while the emotional models, or the fuzzy thesauruses (in case of information retrieval systems) are the different "behaviours" handling the situations. For introducing the proposed application areas of the behaviour-based control structures, a fuzzy reasoning and fuzzy automata based control structure and its application highlights to user adaptive emotional and information retrieval systems are introduced briefly in this paper.**

Keywords: **Fuzzy automata, emotional systems, information retrieval, behaviour-based control.**

I. Introduction

In human-machine dialog based applications, the question of online personalisation could be crucial. During the steps of the interaction, the machine has to be able to build an "image" related its human partner to be able to at least partially "understand" his (her) commands. This image is a kind of relation between the highly individual dependent emotional human world and the dry physical data representation structures of the computers.

Practically, in case of emotion-based systems, this image could be the emotional model of the actual (online) user. While in information retrieval systems it could be a "personalised thesaurus" [13].

One of the main problems of personalisation beyond the high diversity of human beings during the human-machine dialog is the deficiency of the human interaction. In most cases, because of the inconvenience of the interface, the user feedback is very limited both in quantity and quality.

Moreover the system has to be able to build a rather sophisticated personalised model based on these limited data. One solution is giving up the user adaptivity and using a fixed model. This model could generated off-line, based on a wide user inquiry, as a statistical average of the different human opinions. Adaptivity could be also mounted by the structural analysis of the average model and the application of function approximation methods to modify a global user model based on the on-line interventions, or interactions of the actual user [5,6,7]. It seems, that during the step-by step approximation there are some chance of having situations, there modifying only a small region of the user model (as a part of the on-line adaptation) can lead to incoherence of the model (having unknown, or hidden relations inside the model, the locality of the modification could lead inconsistency). Solving the problem of the probable occasional incoherence and to give a simple way for implementing user adaptivity, the adaptation behaviour-based control structures are suggested. Behaviour-based control structures are achieving adaptivity by fusing some fixed existing (off-line collected) models. This fusion is done globally in the manner of "more similar the actual user to one of the existing user models, more similar must be the actual user model to that user model". Supposing, that all the off-line collected user models are appropriate, and the fusion (combination) is affecting coherently the entire user model, hopefully the global combinations of the valid user models are also valid user models – avoiding the above-mentioned accidental incoherence.

A short introduction to behaviour-based control is given below; in section 3 the proposed behaviour-based control structure is described more detailed; in section 4 and 5 two application examples, a user adaptive emotional system, and an adaptive (through relevance feedback) information retrieval system structure is introduced briefly.

II. Behaviour-based Control

In behaviour-based control systems (a good overview can be found in [1]), the actual behaviour of the system is formed as one of the existing system behaviours (which fits best the actual situation), or a kind of fusion of the known behaviours appeared to be the most appropriate to handle the actual situation. This structure has two main tasks. The first is a decision, which behaviour is needed in an actual situation, or the levels of their necessities in case of behaviour fusion, the second is the way of the behaviour fusion. The first task can be viewed as an actual system state approximation, where the actual system state is the approximated level of similarities of the actual situation to the prerequisites of all the known strategies (the level of necessity and the type of the strategy needed to handle the actual situation). The second is the fusion of the existing partial strategies based on these similarities.

The applications of behaviour-based control structures for user adaptive emotional and information retrieval systems are based on the premise, that the interpolative combinations of the emotional models, or fuzzy thesauruses are also valid emotional models or thesauruses. This case having some relevant emotional models, or thesauruses of representative humans or human groups, there are a chance to cover the "taste" of numerous individuals by interpolation.

In online personalizable systems the behaviour-based control style adaptivity has the benefit of quick and "global" user adaptation.

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The adaptation is quicker, because instead of adapting the complex model (or thesaurus), the actual user is identified (approximated). This identification is based on the similarity of the actual user (user feedback) to the existing individual dependent opinions (user models, or thesauruses). Moreover since the actual model is created as an interpolated combination of the existing models (in the manner of the identified similarities), the model is always changing "globally" (not only in parts related to the limited user feedback).

Hopefully this kind of "global" model modification keeps the model coherent during the user identification steps, as a consequence of the different parts of the model having hidden relations are changing together in the same interpolative manner. I.e. in spite of having a very limited user feedback only – even if the feedback interacts only with a small part of the model - all parts of the model are changing together (and hopefully keeping their hidden relations too).

III. The Applied Behaviour-based Control Structure

For the first task of the behaviour-based control structure applied for emotional systems, we suggest the adaptation of finite state fuzzy automata [11], where the state variables are the corresponding similarities, and the state transitions are driven by fuzzy reasoning (State Transition Rulebase on fig.1.). A similar idea - adapting crisp finite state automata, and crisp states for the actual situation approximation - *Discrete Event Systems* is introduced in [2]. In our case the adaptation of finite state fuzzy automata supports the potentialities of strategy fusion, instead of the crisp strategy switching. For the second task, the application of interpolative fuzzy reasoning is suggested [9,10,11]. Having the approximated similarities of the actual situation to the prerequisites of all the known strategies, the conclusions of the different strategies could be simply combined as an upper level interpolative fuzzy reasoning in a function of the corresponding similarities to get the actual final conclusion (Interpolative Fuzzy Reasoning on fig.1.). A similar idea - adapting fuzzy rulebase for conclusion fusion – fuzzy metarules for activating (fusing) control schemes is introduced in [3], and a fuzzy inference method for conclusion fusing "*Fuzzy Damn*" is introduced in [4]. Both method is based on classical fuzzy reasoning methods. In our case the adaptation of interpolative fuzzy reasoning gives the benefit of simple built conclusion fusing rulebase (in case of interpolative fuzzy reasoning the rulebase is not needed to be complete [8]) and the needless of defuzzification (in case of some interpolative fuzzy reasoning methods [9]).

A. The system state approximation

The first step of the system state approximation in classical behaviour-based control applications is the symptom evaluation. The task of symptom evaluation is basically a series of similarity checking between an actual symptom and a series of known symptoms (in case of behaviour-based control applications, the prerequisites - symptom patterns - of the known strategies). In case of user adaptive emotional and information retrieval systems the symptom evaluation is simply the calculation of the similarities between the user interaction (feedback) and the existing knowledge (existing emotional model, or thesaurus).

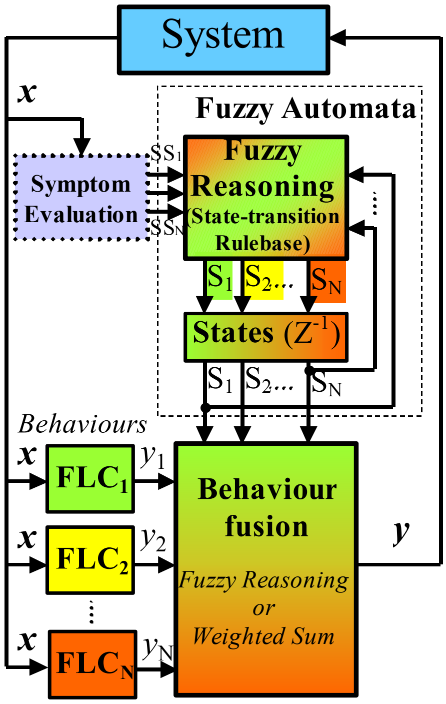

Fig. 1. The proposed behaviour-based control structure.

For the system state approximation the adaptation of the fuzzy automata is suggested. This case the state vector of the automata could be the approximated system state (it is the vector of the approximated similarities of the actual user and the existing knowledge), and the state transition could be driven by fuzzy reasoning (see fig.1.). Having an approximated system state and the conclusions of the symptom evaluation, a decision about the new approximated system state can be evaluated. This automata is a fuzzy automata, because its state variables are fuzzy membership values (similarities) and the state-transitions are driven by fuzzy rules.

The rulebase applied for the state-transitions of the fuzzy automata for the i^{th} state S_i (R_{Ai}):

If S_i=One **And** SS_i=One **Then** S_i=One (1.1)
If S_i=Zero **And** SS_i=Zero **Then** S_i=Zero

If S_i=Zero **And** SS_i=One **And** (1.2)
S_k=One **And** SS_k=One **Then** S_i=Zero
$\exists k \in [1,N], k \neq i$

If S_i=Zero **And** SS_i=One **And** (1.3)
S_k=Zero **And** SS_k=Zero **Then** S_i=One
$\forall k \in [1,N], k \neq i$

If S_i=One **And** SS_i=Zero **And** (1.4)
SS_k=Zero **Then** S_i=One
$\forall k \in [1,N], k \neq i$

where SS_i is the calculated similarity of the actual user opinion to the i^{th} existing user opinion (model), N is the number of the models (states). The structure of the state-

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transition rules is similar for all the states. `Zero` and `One` are linguistic labels of fuzzy sets (linguistic terms) representing high and low similarity. The interpretations of these fuzzy sets can be different in each S_i, SS_i universes. The structure of the state-transition rules is similar for all the states.

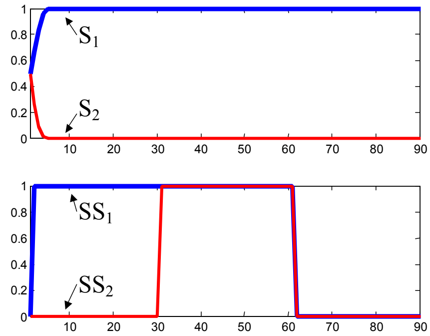

Fig. 2. Do not “pick up” a new state - rule (1.2).

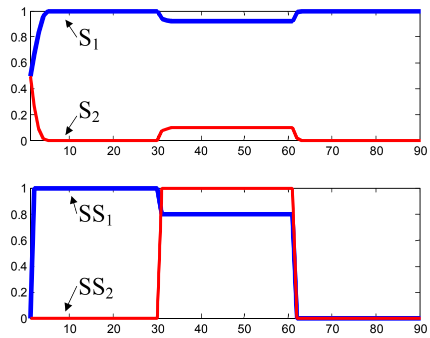

Fig. 3. Do not “pick up” a new state - rule (1.2).

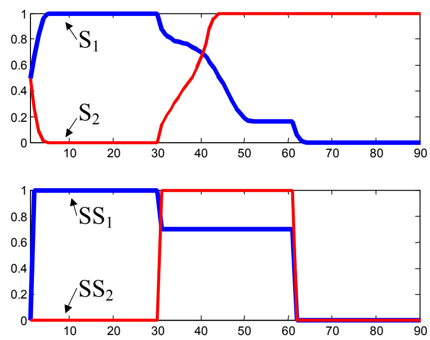

Fig. 4. “Pick it up” if it seems better - rule (1.3).

The heuristic behind the rules are the following:

The rule pair of (1.1) simply says: If we are in a state S_i=`One` (with a high value) and the similarity evaluation suggest to keep this state SS_i=`One` (with a high level), we have to keep this state with a high value (S_i=`One`). And its opposite, if we are not in a state and the similarity evaluation suggest not keep this state, we have to set it to be low value (S_i=`Zero`). The goal of the rule (1.2) is avoiding to “picking up” a “new” state (which had a low value previously) just because the similarity evaluation suggest to use it in the case if there other states with high values and high similarities are exist ($\exists k \in [1, N], k \neq i$, S_k=`One` **`And`** SS_k=`One`) (see fig. 2, fig. 3 for an example) – and pick the new state if there are no better solutions exist (rule 1.3) (see fig. 4, fig. 5 for an example). The rule (1.4) is for keeping the existing states, if there are “no better solutions” (see fig. 6 for an example).

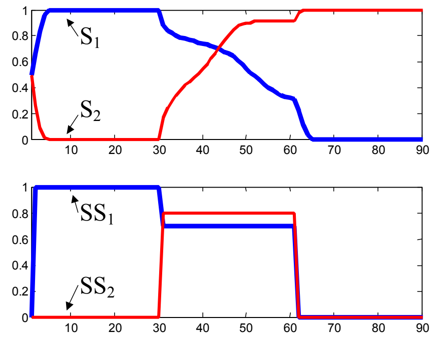

Fig. 5. “Pick it up” if it seems better - rule (1.3).

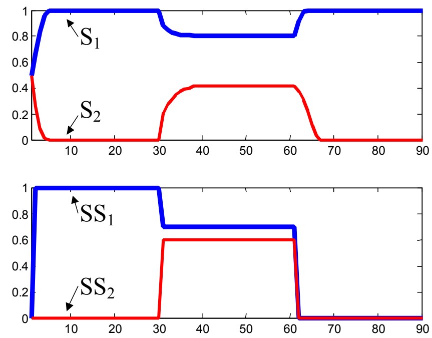

Fig. 6. Keeping the existing states, if there are “no better solutions” - rule (1.4).

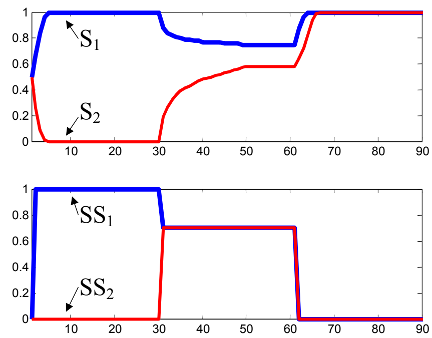

Fig. 7. Keeping the existing states, and pick up a new one the same time - rule (1.3) and (1.4).

B. The model fusion

The conclusion of the system state approximation (the approximated state itself) is a set of similarity values, the level of similarities of the actual user opinions and the existing knowledge (user models or thesauruses). Having all the known models, the actual model could be simply fused from them in the function of the corresponding similarities (S_i), as an upper level interpolative fuzzy reasoning [9] (see fig.1.). The rulebase for the fusion of the conclusions (y_i) of the different behaviours in case of interpolative fuzzy reasoning could be simply the following:

(2)

`If` S_1=`One` **`And`** S_2=`Zero` **`And`** ... **`And`** S_N=`Zero` **`Then`** $\boldsymbol{y}$=y_1

```
If S1=Zero And S2=One And ... And SN=Zero
                                    Then y=y2
...
If S1=Zero And S2=Zero And ... And SN=One
                                    Then y=yN
```

where S_i is the ith state variable, y_i is the conclusion of the ith behaviour, or one element of the ith user model, or thesaurus and $\boldsymbol{y}$ is the fused conclusion (model element). `Zero` and `One` are linguistic labels of fuzzy sets (linguistic terms) representing high and low similarity. The interpretations of these fuzzy sets can be different in each S_i universes.

Comments: instead of interpolative fuzzy reasoning a kind of weighted average, (where the weights are functions of the corresponding similarities) is also applicable (even it is not so flexible in some cases).

For example:

$$\boldsymbol{y} = \frac{\sum_{i=1}^{n} S_i \cdot y_i}{\sum_{i=1}^{n} S_i}. \tag{3}$$

IV. User Adaptive Emotion-based System Example

The first application example, is a user adaptive emotion-based system – an interactive furniture selection system [12]. It is handling user adaptivity, as a kind of combination of existing (off-line collected) human opinions (user models) in the function of the approximated similarity to the actual user opinions. As an analogy to the behaviour-based control applications, the different existing strategies are the different existing user models, and the actual situation is the similarity of the actual user to the evaluators, gave the existing user models.

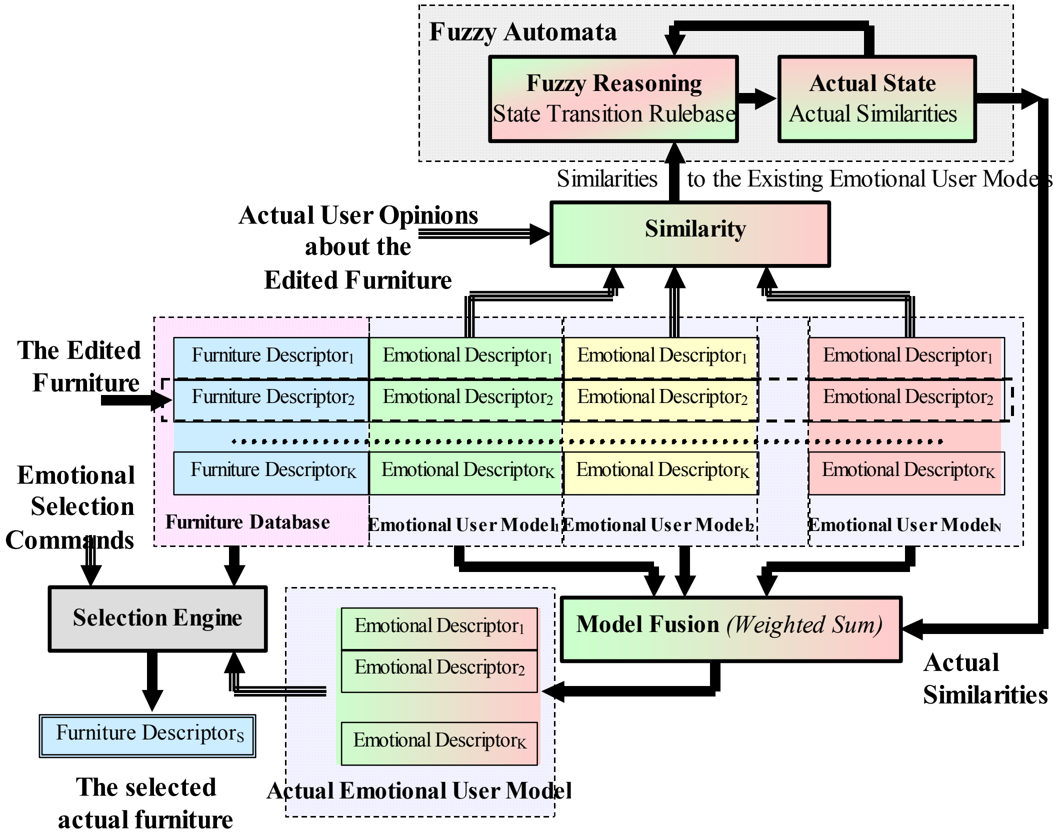

Fig. 8: Structure of the proposed adaptive emotional model generation.

The suggested behaviour-based control structure (see fig.1.) implementation is introduced on fig.8. The main differences (compare fig.1.-fig.8.) are the substitution of the known strategy controllers (FLC_i) by existing user models (Furniture Descriptor – Emotional descriptors), and the direct similarity checking (similarities of the actual user opinions to the content of the existing models) instead of symptom evaluation.

Using the selection system, the user can search a furniture database by giving emotion-related requests (like "friendly" or "convenient"). These requests are translated to physical parameters (characterising the real furniture objects) by the actual emotional model. The user adaptivity of the actual emotional model (see fig.8.) is provided by the proposed behaviour-based control structure. (Please note, that the physical meanings of the emotional words are highly user dependent.) This case the state of the fuzzy automata (actual similarities, see fig.8.) is interpreted as, the actual approximated similarities of the actual user and the existing user opinions (emotional models). For the state-transitions rulebase (1) was applied.

For the conclusion (user model) fusion, both interpolative fuzzy reasoning and the earlier mentioned weighted average (3) were tested [12]. In the final example application, because of the simplicity of the conclusion fusion rulebase (no need for the flexibility of the rule-based fusion), and the need of the quick response of the interactive program, the weighted average (3) was implemented.

V. Adaptive Information Retrieval System Example

The second application example is a user adaptive information retrieval system structure. It is handling user adaptivity, as a combination of existing (off-line built) Related Term Fuzzy thesauruses. These thesauruses are used for implicit query expansion [13,14] during the information retrieval (the original query is automatically expanded by the related terms fetched form the actual fuzzy thesaurus). As an analogy to the behaviour-based control applications, the different existing strategies are the different existing Fuzzy thesauruses, and the actual situation is the similarity of the Retrieval Status Value (RSV, relevance of the document) calculated for a relevant document based on the actual thesaurus and the RSVs calculated for the same document based on the existing Fuzzy thesauruses [14]. (The relevant document is presented by the user during the relevance feedback procedure.)

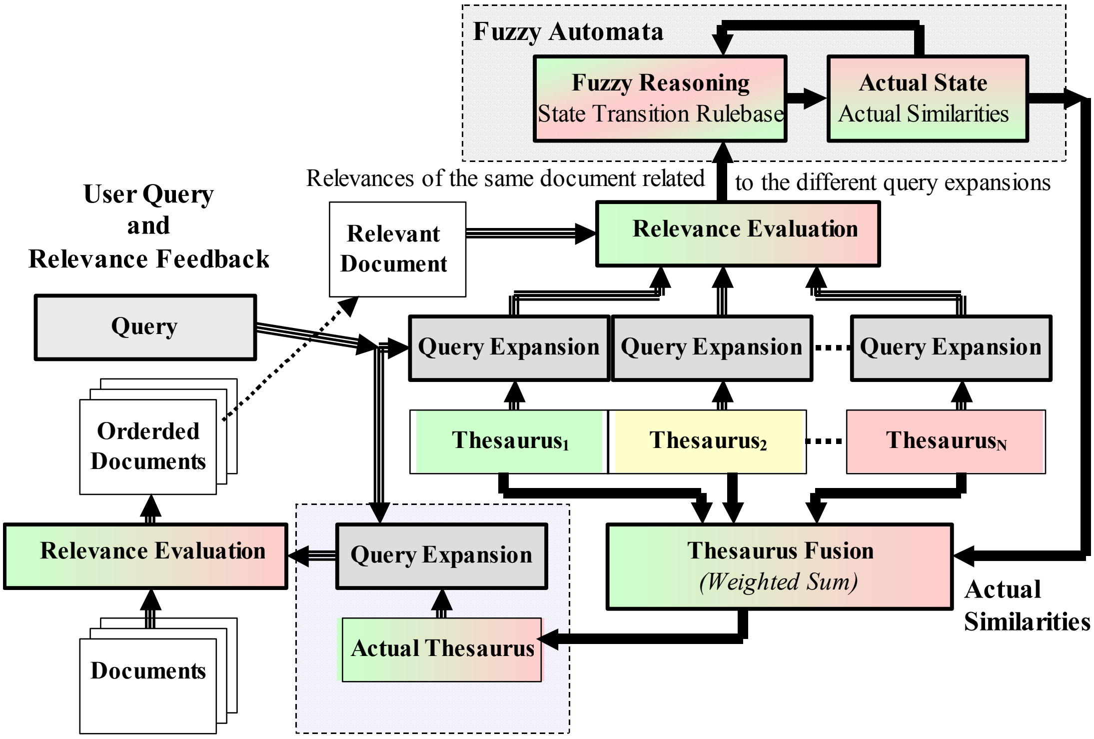

Fig. 9: Structure of the proposed information retrieval system.

The suggested behaviour-based control structure implementation is introduced on fig.9. The structure itself is very similar to the previous example.
The main difference (compare fig.8.-fig.9.) is the lack of direct similarity checking – in this example the existing and actual opinions are compared through the relevance values calculated based on the same query and document, but the different fuzzy thesauruses.
Using the information retrieval system, as an answer for his (her) query, the user first gets an ordered document set (ranked to be relevant by the system based on an initial actual thesaurus). Then the user can select a document to be a relevant one based on his (her) opinion. Having this document, and the original query, the system is recalculating all the Retrieval Status Values (relevance) for all the existing thesauruses. Based on these RSVs and the fact that the user selected the corresponding document to be relevant, the actual state and the actual thesaurus can be updated.

VI. Conclusions

The goal of this paper was to introduce a simple and flexible behaviour-based control structure and its possible application areas in user adaptive emotional and information retrieval systems.
From the viewpoint of the actual user, the main goal of these solutions is to tune the system to be closer to his/her opinions (feelings) by modifying the underlying emotional model, or the thesaurus used for query expansion. Practically the system is starting from an initial stage (where the similarities to the existing models, or thesauruses are equal), and in the case the user is disagree with the evaluation of the actual object (furniture, or document) given by the system, he (she) has the possibility to modify the actual user model (thesaurus) by giving his (her)

opinions. In most cases the given opinions are related to one or a few elements of the model. But because of the proposed structure, all the changes are done globally. Hopefully this kind of strategy adaptation keeps the actual user model (thesaurus) coherent, and able to avoid the incoherence - could cause by step-by-step partial modifications. E.g. if one of the users have exactly the same opinions as one of the existing user model (even his opinions were given through some of the parameters only), then (after a few modification, detection steps) as the best fitting existing model, the system will use it exactly. Basically the "adaptive knowledge" of the system related to the actual user is not a new adapted user model, but the actual system state, a set of approximated similarities of the actual user opinions to the existing models. Because of the interpolative properties of the knowledge fusion, the proposed system is unable to follow user requirements outside the area covered by the existing user models. In other words, the system cannot go beyond its existing "knowledge". The only solution of this problem is extending the number and the variety of the existing models, to cover the state space by models as much as it is possible.

VII. Acknowledgement

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