**Sz. Kovács**: *Fuzzy Reasoning and Fuzzy Automata in User Adaptive Systems*, Proceedings of the 18th Hungarian-Korean Seminar on Soft Computing & Computational Intelligence, October 2-3, Budapest, Hungary, ISBN 963 206 066 0, pp.63-72, (2002). – Draft version.

# FUZZY REASONING AND FUZZY AUTOMATA IN USER ADAPTIVE SYSTEMS

***Kovács, Szilveszter***

Department of Information Technology, University of Miskolc,
Miskolc-Egyetemváros, Miskolc, H-3515, Hungary, e-mail: szkovacs@iit.uni-miskolc.hu

***Abstract***

The application of behaviour-based control structures in user adaptive 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 adaptivity in emotional, or information retrieval systems. This case the actual user acts the environment to be adapted, while the existing user models are the different "behaviours" handling the actual 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.

## 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" [14], or other model of the actual user interest.

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 be 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].

Another view of online user adaptivity of the emotional user model – based on behaviour-based control structures – is introduced in [12], [13] as on-line variable combination of some fixed existing (off-line collected) models. In this case the user adaptation itself is handled as a kind of adaptive fusion of existing emotional models in the manner of "the more similar the actual user to one of the existing emotional model, the more similar must be the actual emotional model to that

model". In other words, instead of identifying the actual emotional model itself, the user is classified in the manner of existing emotional models (or user types).
The main benefit of this view is quick convergence, as in the most cases the problem of user classification related to some existing emotional models is much simpler than the identification of the complicated emotional model itself. The ability of proper depiction of user emotion is highly dependent on the number and diversity of existing emotional models available in the system.
In the following, the next section will give a short introduction to behaviour-based control structures, section three will discuss the proposed behaviour-based control structure more detailed, and the last two sections will briefly introduce three application examples, a user adaptive emotional system, and two adaptive (through relevance feedback) information retrieval system structure.

## 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.
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).

## 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 methods are 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]).

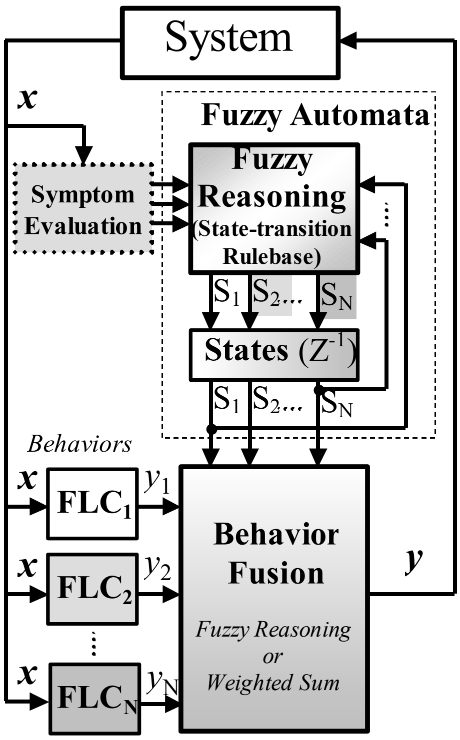


**Fig. 1. The proposed behaviour-based control structure.**

### *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).

For the system state approximation the adaptation of the fuzzy automata is suggested.

In this case the actual state of the automaton is a set of similarity values (e.g. see similarity calculations, similarities on fig.4.), the iteratively approximated similarities of the user opinions and the existing user models (e.g. emotional descriptor sets on fig.3.). The state-transitions of the fuzzy automata are driven by fuzzy reasoning (Fuzzy state transition rulebase on fig.4.), as a decision based on the previous actual state (the previous iteration step of the approximation) and the similarities of the user opinions (user feedback) to the existing user models. In practice the automata is starting from an initial state (e.g. all the similarities are equal to 0.5), and during the events of the user feedback (e.g. giving his/her opinions related to an "edited object" – see fig.4.) the actual similarities are recalculated. A possible rulebase structure for the state-transitions of the fuzzy automata (rules for interpolative fuzzy reasoning [9]) is the following:
For the $i^{th}$ state variable $S_i$, $i \in [1, N]$ of the state vector **S**: (1)

```
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                (1.2)
If S_i=One  And SS_i=Zero                  And SS_k=Zero   Then S_i=One   ∀k∈[1,N],k≠i (1.3)
If S_i=Zero And SS_i=One  And S_k=Zero     And SS_k=Zero   Then S_i=One   ∀k∈[1,N],k≠i (1.4)
If S_i=Zero And SS_i=One  And S_k=One      And SS_k=One    Then S_i=Zero  ∃k∈[1,N],k≠i (1.5)
```

where $SS_i$ is the calculated similarity of the actual user opinion to the $i^{th}$ existing emotional model, N is the number of models (or state variables). The structure of the state-transition rules is similar for all the state variables. `Zero` and `One` are linguistic labels of fuzzy sets (linguistic terms) representing high and low similarity. The interpretations of the `Zero` and `One` fuzzy sets can be different in each $S_i$, $SS_i$ universes. The structure of the state-transition rules is similar for all the state variables. The reason for the interpolative manner of fuzzy reasoning is the incompleteness of state-transition rulebase [8].
The goals of the rules are straightforward: (1.1) simply keeps the previously chosen state values (emotional models) in the case if the user opinions agree. The rule (1.2) has the opposite meaning if the state values were not chosen, and moreover the user opinions that are very different from these state values (models) should be suppressed. The rule (1.3) keeps the already selected state values (previous approximation), even if the user disagrees, if there is no better fitting model.

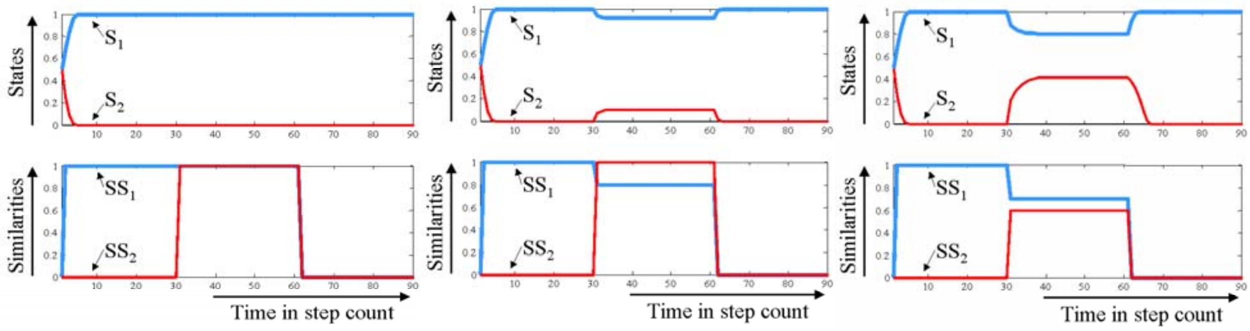


**Fig. 2. Do not "pick up" a new state if the previous approximation is still adequate.**

Rules (1.4) and (1.5) have the task of ensuring the relatively quick convergence of the system to the sometimes unstable (changeable) user opinions, as new models (state variables) which seem to be fit, can be chosen in one step, if there are no previously chosen model, which is still fitting to the user opinions (1.4). (Rule (1.5) has the task to suppress this selection in the case of existence of well fitting models already chosen.)

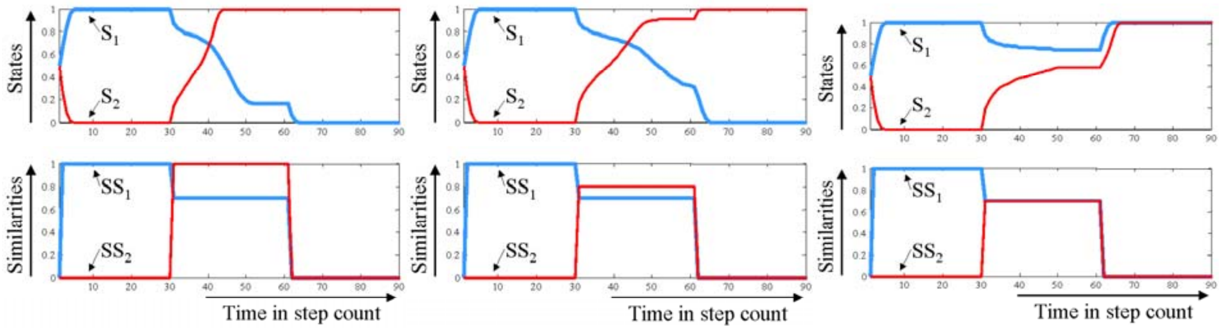


**Fig. 3. But "pick it up" if it seems better, or at least as good as the previous was.**

The main benefit of the previously introduced rulebase (1) is the relatively quick convergence of the system to fit the user opinions even if these opinions could be changeable during the iterative approximation.
This quick convergence to changeable opinions forms the main benefit of the fuzzy automata based iterative classification compared to some gradient descent like step-by-step approximation.

***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:

**If** $S_1$=One **And** $S_2$=Zero **And** ... **And** $S_N$=Zero **Then** $\boldsymbol{y}=y_1$ (2)
**If** $S_1$=Zero **And** $S_2$=One **And** ... **And** $S_N$=Zero **Then** $\boldsymbol{y}=y_2$
...
**If** $S_1$=Zero **And** $S_2$=Zero **And** ... **And** $S_N$=One **Then** $\boldsymbol{y}=y_N$

where $S_i$ is the $i^{th}$ state variable, $y_i$ is the conclusion of the $i^{th}$ behaviour, or one element of the $i^{th}$ 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).

## 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.

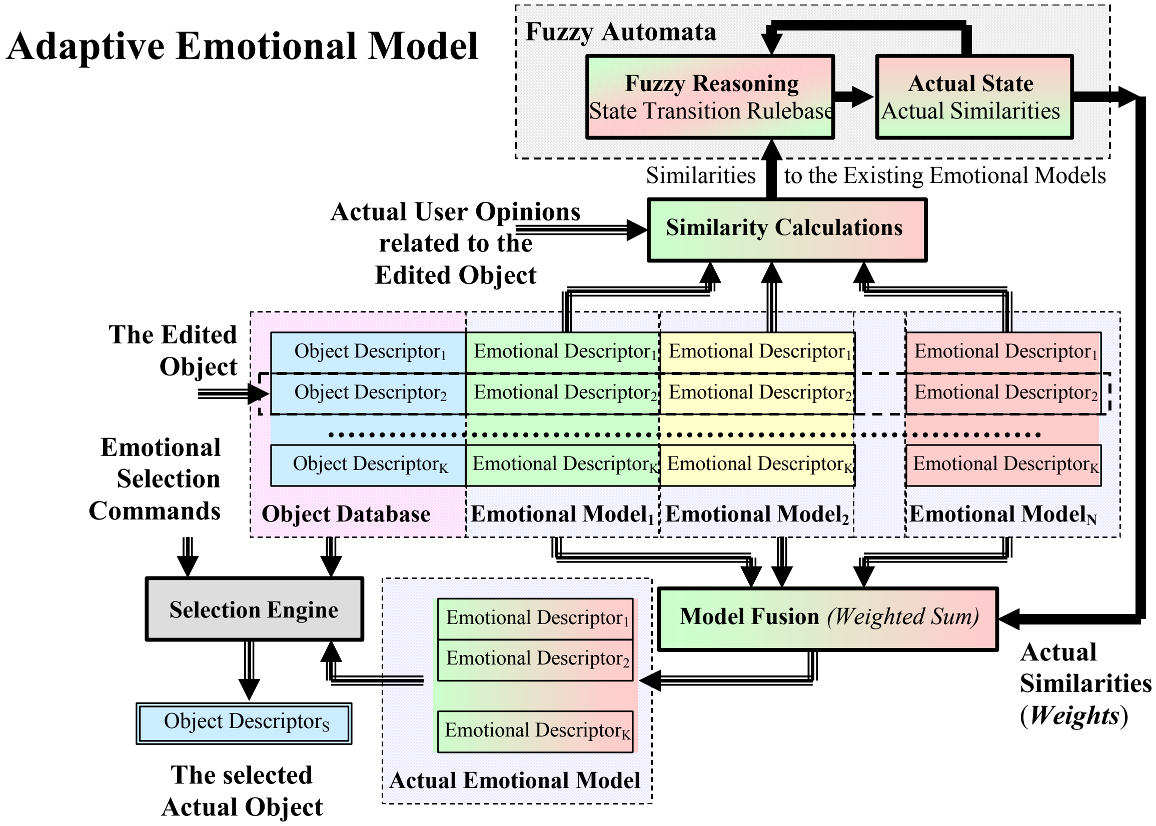


**Fig. 4: Structure of the proposed adaptive emotional model generation.**

The suggested behaviour-based control structure (see fig.1.) implementation is introduced on fig.4. The main differences (compare fig.1.-fig.4.) are the substitution of the known strategy controllers ($FLC_i$) by existing user models (Object 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.4.) 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.4.) 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 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 was implemented.

## ADAPTIVE INFORMATION RETRIEVAL SYSTEM EXAMPLES

The next two application examples are related to user adaptive information retrieval system structures.

In case of the adaptive thesaurus generation the proposed structure is handling user adaptivity, as a combination of existing (off-line built) Related Term Fuzzy thesauruses (see e.g. on fig.5.). 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 [15]. (The relevant document is presented by the user during the relevance feedback procedure.)

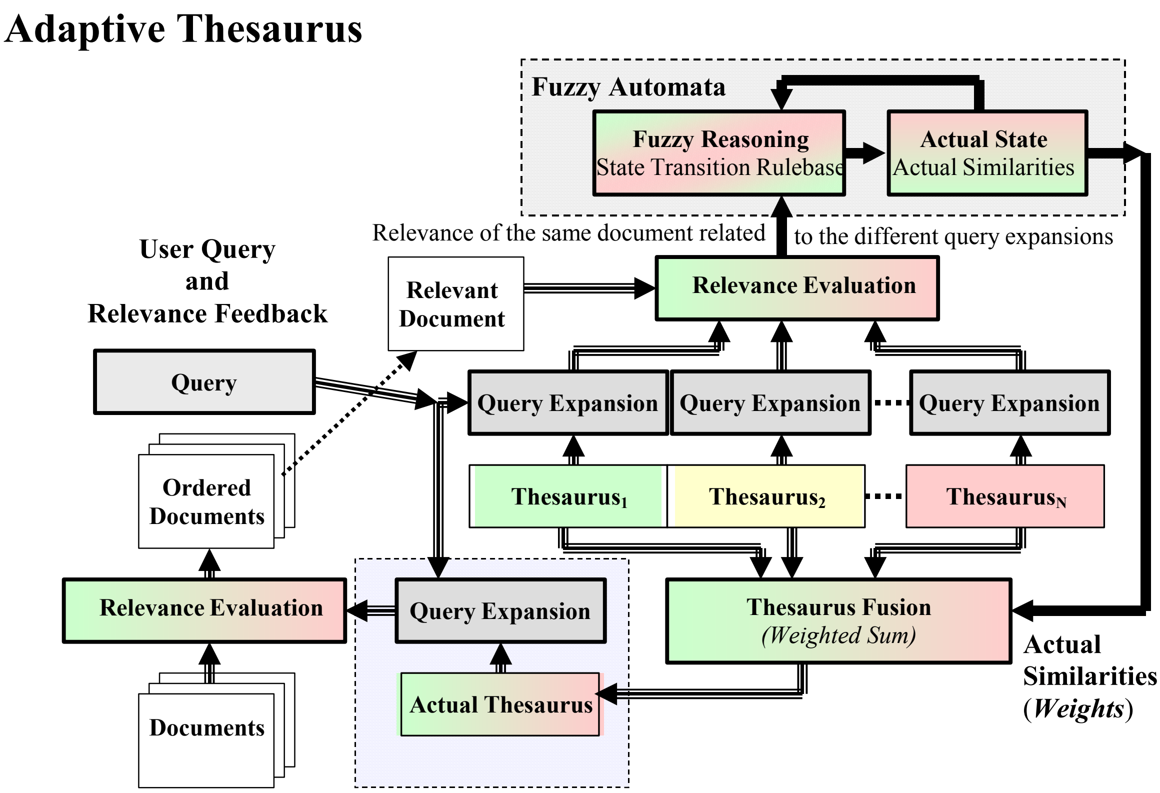


**Fig. 5: Structure of the proposed adaptive thesaurus generation.**

The suggested behaviour-based control structure for adaptive thesaurus generation is introduced on fig.5. The structure itself is very similar to the previous example. The main difference (compare fig.4.-fig.5.) 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 adaptive thesaurus generation 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.

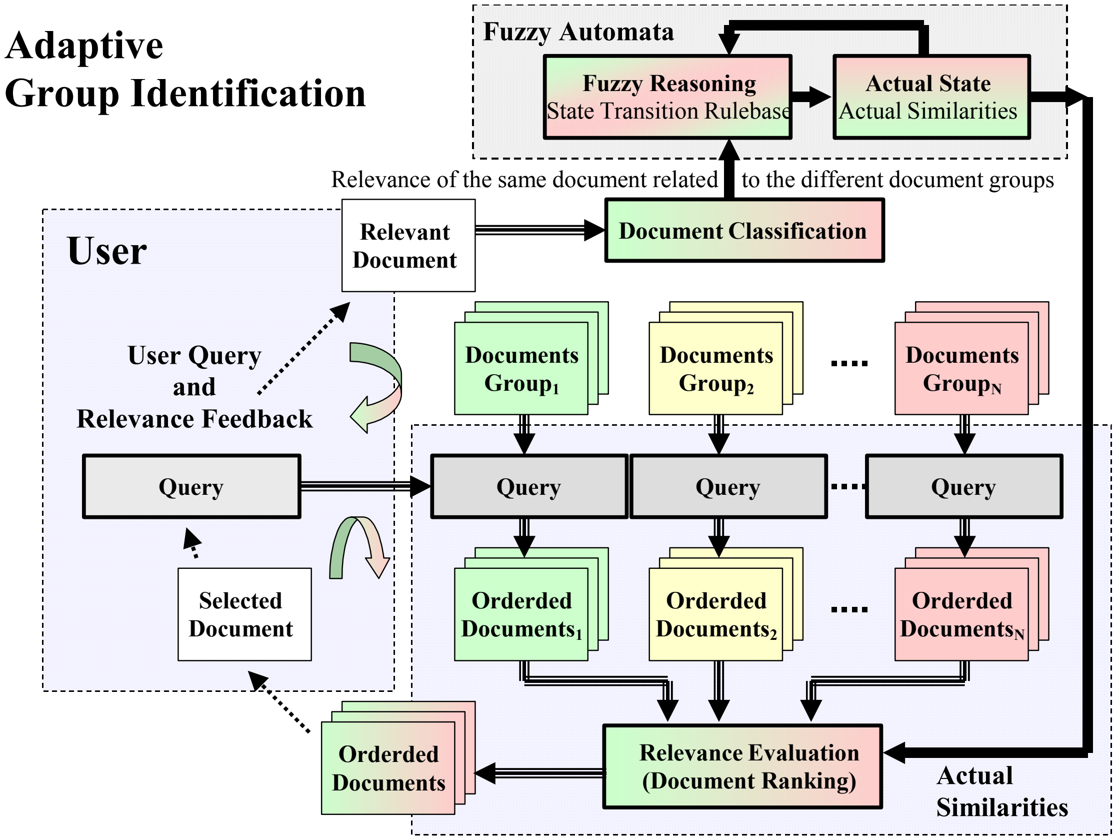


**Fig. 6: Structure of the proposed adaptive document group identification system.**

The second adaptive information retrieval system structures example is an adaptive (news)group identification system (see e.g. on fig.6.). In case of information retrieval of documents ordered to different groups – based on their content, e.g. Usenet Newsgroups – the structure tries to identify the actual user interest in the manner of document groups. The main difference of this structure compared to the previous examples is the inexistence of the "user model". This case the model space, where the user interest is classified, is formed from the document groups themselves – in other words, the document groups are forming the user models. (As the document groups are formed from documents related to the interest of a group of people.) Similarly to the previous example the user feedback is given through a relevant document (see e.g. on fig. 6.). For the similarity levels needed for the state-transition calculation, the relevant document is reclassified in the manner of content similarity to the document groups (see e.g. on fig. 6.).
Using the adaptive (news)group identification system, similarly to the adaptive thesaurus generation 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 the RSVs of the separate group queries and the group relevancies). Then the user can select a document to be a relevant one based on his (her) opinion. Having this document, the system reclassifies it to determine its similarities to the document groups and based on these similarities and the previous document group relevancies (see actual state on fig. 6.) it recalculates its new state (the new group relevancies). Then based on the new group relevancies, the documents are re-ranked (the document relevancies weighted by the group relevancies are recalculated).

## 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.
The main benefit of the application of behaviour-based control structures in interactive emotion-based systems is the easy introduction of user adaptivity in already existing interactive systems. As the user adaptation itself is handled as a kind of adaptive fusion of existing (collected off-line) human opinions (emotional models) in the approximated best fitting way to the actual user taste. Creating more user models and elaborating the way of user feedback, the user adaptivity can be relatively simply introduced to the already existing interactive systems.
In case of online applications this adaptive structure also has the benefit of relatively quick iterative adaptation as the system tries to identifies the actual user in the space of the existing models, based on a series of user interactions (feedback), not the – usually much more complicated – actual model itself.
On the other hand collecting numerous models with high diversity, needed for the proposed structure, can also lead to serious difficulties, save the situation, where the models are automatically generated or already exist (e.g. the last example – where the existing document groups are forming the model themselves).

## ACKNOWLEDGEMENT

This research was partly supported by the Japan Gifu Prefectural Research Institute of Manufacturing Information Technology, the Australian Research Council, the Murdoch University, the Intelligent Integrated Systems Japanese Hungarian Laboratory and the Hungarian National Scientific Research Fund grant no: F 029904. Szilveszter Kovács is supported by the György Békésy Postdoctoral Scholarship.

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