Fuzzy Reasoning and Fuzzy Automata in User Adaptive Systems

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Introduction

**Difficulties:** Control partially known complex systems.

**Solution:** Fusing partially valid control strategies in the function of their suitability:

- Behaviour-based control structures

  **An interpolative view:** “The more similar the actual situation to one of the known partial strategy prerequisites, the more similar the strategy used to that strategy must be.”

  **Similarity based strategy reconfiguration**

**The main tasks to solve:**

- **The actual system-state approximation:** The actual system-state – 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* – must be determined.

- **The fusion of the existing partial strategies:** based on the approximated system-state - *in the function of their suitability* – the conclusions (proposed actions) of the known partially valid (component) strategies *must be fused.*

  *For the first task,* the adaptation of *fuzzy automata* is proposed, where the state variables are the corresponding similarities, and the state-transitions are driven by fuzzy reasoning.

  *For the second task,* the application of *interpolative fuzzy reasoning* is suggested.
Adaptive
Behaviour-based Structure

Adaptivity to the

– current situation (common
  behavioural-based applications),
  *(Identifying the situation in the
  manner of the available behaviours)*

– or the controlled system itself (e.g.
  fault tolerant control applications),
  *(Identifying the system in the manner
  of the available controllers)*

– or even the actual user herself/himself
  (user adaptive systems).
  *(Identifying the user in the manner of
  the available user models)*
Adaptive Emotional Model

Fuzzy Automata
- Fuzzy Reasoning
  - State Transition Rulebase
- Actual State
  - Actual Similarities

Similarities to the Existing Emotional Models

Actual User Opinions related to the Edited Object

Similarity Calculations

The Edited Object

Object Database
- Object Descriptor₁
- Object Descriptor₂
- Object Descriptorₖ

Emotional Model₁
- Emotional Descriptor₁
- Emotional Descriptor₂
- Emotional Descriptorₖ

Emotional Model₂
- Emotional Descriptor₁
- Emotional Descriptor₂
- Emotional Descriptorₖ

Emotional Modelᵢ
- Emotional Descriptor₁
- Emotional Descriptor₂
- Emotional Descriptorₖ

Emotional Modelᴺ
- Emotional Descriptor₁
- Emotional Descriptor₂
- Emotional Descriptorₖ

Model Fusion (Weighted Sum)

The selected Actual Object

Object Descriptorₛ
- Emotional Descriptor₁
- Emotional Descriptor₂
- Emotional Descriptorₖ

Actual Emotional Model

Selection Engine

Adaptive Emotional Model

Actual
Similarities
(Weights)
Adaptive Thesaurus

Fuzzy Automata

Fuzzy Reasoning
State Transition Rulebase

Actual State
Actual Similarities

Relevance Evaluation

Relevance of the same document related
to the different query expansions

User Query and Relevance Feedback

Query

Ordered Documents

Relevance Evaluation

Documents

Query Expansion

Query Expansion

Query Expansion

Thesaurus₁

Thesaurus₂

Thesaurusₙ

Thesaurus Fusion
(Weighted Sum)

Actual Similarities
(Weights)
Adaptive Group Identification

User

User Query and Relevance Feedback

Query

Selected Document

Ordered Documents

Document Classification

Relevant Document

Documents Group$_1$

Documents Group$_2$

Documents Group$_N$

Ordered Documents$_1$

Ordered Documents$_2$

Ordered Documents$_N$

Relevance Evaluation (Document Ranking)

Actual Similarities

Relevance of the same document related to the different document groups
User identification related to the existing models ⇒ Fuzzy automata
(Approximating the similarities of the actual user to the existing user models)

**State:** A set of similarity values, the actual approximated similarities of the actual user and the existing user models.

**State-transitions:** Are driven by fuzzy reasoning (Fuzzy state transition rulebase) as a decision based on the previous actual state (approximation) and the similarities of a given user opinion (feedback) to the user models.

State-transitions rulebase for the $i^{th}$ state variable $S_i$ ($R_{Ai}$):

<table>
<thead>
<tr>
<th>Condition</th>
<th>Then</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_i=$One And $SS_i=$One</td>
<td>$S_i=$One</td>
</tr>
<tr>
<td>$S_i=$Zero And $SS_i=$Zero</td>
<td>$S_i=$Zero</td>
</tr>
<tr>
<td>$S_i=$One And $SS_i=$Zero And $SS_k=$Zero</td>
<td>$S_i=$One</td>
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<td>$S_i=$One</td>
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<tr>
<td>$S_i=$Zero And $SS_i=$One And $S_k=$One And $SS_k=$One</td>
<td>$S_i=$Zero</td>
</tr>
</tbody>
</table>

where $SS_i$ is the calculated similarity of a given user opinion to the $i^{th}$ existing user model, $k \in [1, N], k \neq i$. The structure of the rules is similar for all the states. (Incomplete rulebase - interpolative fuzzy reasoning)
Don’t “pick up” a new state (you already have a good one)
Don’t “pick up” a new state (even it seems a little bit better)
Change if the previous is not satisfied and a better one exists.
Change if the previous is not satisfied and a better one exists

States

States

Similarities

Time in step count
But don’t change if the new one is not really better
Even both could be good solution

States

Time in step count

Similarities
Model Fusion

⇒ Interpolative fuzzy reasoning – (flexible)

⇒ Weighted Sum – (Simple)

Interpolative fuzzy reasoning:

\[
\text{If } S_1 = \text{One} \quad \text{And} \quad S_2 = \text{Zero} \quad \text{And} \quad \ldots \quad \text{And} \quad S_N = \text{Zero} \quad \text{Then} \quad y = y_1
\]

\[
\text{If } S_1 = \text{Zero} \quad \text{And} \quad S_2 = \text{One} \quad \text{And} \quad \ldots \quad \text{And} \quad S_N = \text{Zero} \quad \text{Then} \quad y = y_2
\]

\[
\ldots
\]

\[
\text{If } S_1 = \text{Zero} \quad \text{And} \quad S_2 = \text{Zero} \quad \text{And} \quad \ldots \quad \text{And} \quad S_N = \text{One} \quad \text{Then} \quad y = y_N
\]

Weighted Sum:

\[
E_{i,j} = \sum_{k=1}^{K} w_k \cdot E_{i,j,k}
\]

\[
E_{i,j} = \frac{\sum_{k=1}^{K} w_k \cdot E_{i,j,k}}{\sum_{k=1}^{K} w_k} \quad , \quad \forall i \in [1,I], \quad \forall j \in [1,J], \quad w_k = S_k, \quad \forall k \in [1,N],
\]

where \( E_{i,j} \) is the matrix of the actual emotional model, \( w_k = S_k \) is the \( k^{th} \) model weight.
The user adaptive furniture selection

As an example of the proposed Adaptive Emotional Model structure, a furniture selection system was developed:

The goal of the selection system:
- To aid furniture (chair) selection by giving the chance to the user to express his/her requirements through emotional levels.
- The set of handled emotions is fixed to 16 emotional words related to chairs.
- The user is giving the requirements by selecting some of the emotional words and adjusting the corresponding sliders. (On the sliders the “+”, “0”, “-” symbols are appearing only, to inspire the user to give his/her feelings in a scale less manner.)
- As a response of the user intervention, the best fitting chair is appearing in the working window. The same time the system gives all the emotional values (16 in our case) related to the furniture on screen, fetched from the actual emotional model. These values are appearing the same manner, on sliders (side by the user sliders), as the user was giving his/her requirements. This method inspires the user to make modifications in more/less, small/big differences manner – relative to the furniture on screen.
- In the case the user is disagree with the evaluation given by the system, he/she can give his/her opinions by copying the actual furniture to the editing window and adjusting some of the bottom sliders. Pressing the Ready button, the system recalculates the actual similarities.
Screenshot of the user adaptive furniture selection system
The emotional user models

- The existing emotional user models were generated based on questionnaires.
- The inquired persons had to make a partial ordering of a set of pictures of 43 different chairs.
- For each emotional attributes in the questionnaire, the inquired persons were first asked to make a rough order of the pictures into seven groups: very ~, ~, a little bit ~, ?, a little bit not ~, not ~, very not ~ - where ~ is the actual emotional attribute. Then he/she was asked to partially order the pictures of the same groups. (Partially ordering was meant as ordering in the case of the pictures are distinguishable in respect to the emotional attribute, and signing equality, if they are indistinguishable.)
- The answers than translated to real values of the [-1,1] interval, according to equal width of the seven attribute group, and equal distances of the elements of the same group in the manner of partial ordering (equal values for the indistinguishable ones). These values are forming the Emotional descriptors.
Conclusions

Benefits:
– Easy introduction. (Implementing user adaptivity in an existing system)
– Quick convergence (online applications)
  (User identification related to the existing models instead of model identification)
– State identification:
  fuzzy automata (easy to modify, simply “readable”)
– Model fusion:
  Fuzzy reasoning – flexible
  Weighted sum – simple

Drawbacks:
– Difficulties in collecting many models with high diversity.
The basic structure of the state-transitions rulebase for the \(i^{th}\) state \(S_i\) (\(R_{Ai}\)):

- If \(S_i=\text{One}\) and \(S_1-S_i=\text{One}\) then \(S_i=\text{One}\)
- If \(S_i=\text{One}\) and \(S_i-S_k=\text{One}\) then \(S_i=\text{Zero}\)
- If \(S_k=\text{One}\) and \(S_k-S_i=\text{One}\) then \(S_i=\text{One}\)
- If \(S_k=\text{One}\) and \(S_k-S_i=\text{Zero}\) then \(S_i=\text{Zero}\)

where \(S_i-S_j\) is the conclusion of the symptom evaluation about the state-transition from state \(i\) to \(j\).

Strategy fusion rulebase:

- If \(S_1=\text{One}\) and \(S_2=\text{Zero}\) and \(...\) and \(S_N=\text{Zero}\) then \(y=y_1\)
- If \(S_1=\text{Zero}\) and \(S_2=\text{One}\) and \(...\) and \(S_N=\text{Zero}\) then \(y=y_2\)
- \(...\)
- If \(S_1=\text{Zero}\) and \(S_2=\text{Zero}\) and \(...\) and \(S_N=\text{One}\) then \(y=y_1\)
AGV navigation control example

- Path tracking and restricted collision avoidance strategy
- The collision avoidance strategy
- The collision avoidance with left/right tendency strategy
The structure was able to follow the studied operational modes (states) and state-transitions, even in some cases to approximate the unstudied situations, too.