Adaptive 3D Navigation User Interface Design Based on Rough Sets

CHENG SHI-WEI [1, 2], SUN SHOU-QIAN [2]
[1]College of Computer Science, Zhejiang University of Technology, Hangzhou, 310014, China
[2] College of Computer Science, Zhejiang University, Hangzhou, 310027, China
E-MAIL: swc@zjut.edu.cn

Abstract: An adaptive user interface has been developed to enhance the three-dimensional navigation adaptation in this paper. Rough sets are applied to user modeling including uncertainties, namely, vagueness and incomplete information about users during their navigations in the virtual environments. We propose an approach to generate the user types' decision-making table and identity the types by their interaction behaviors through the core reduction algorithm. Then, to structure the user adaptation templates, system can change the HCI to adapt to users' navigation knowledge, path-finding ways and other interaction attributes. A prototype system is described at the end, and it can improve the user performances in three-dimensional navigation.

Keywords: user modeling; adaptation; user interface; rough sets; three-dimensional navigation

1. Introduction

The adaptive virtual environment can help users to work more efficiently, avoid common problems such as disorientation, over looking an important part of the space, and being lost [1]. The lack of proper 3D navigation support causes the user to suffer from some problems, e.g., navigation in the wrong direction. As a result, users will become rapidly frustrated and abandon the tour in the virtual environment; even miss interesting parts (especially in large scale environment) or with the feeling of not having adequately explored the environment [2]. It is particularly true for novice who should be helped as much as possible by offering them proper navigation aids in the adaptive virtual worlds.

Adaptive navigation strongly depends on the user modeling. A user model usually incorporates various characteristics of users, and the usage data are also represented in the user model at the same time. The intelligence of user interface is exhibited through the automation of its intelligent behaviors, namely, effectiveness in performing tasks to both task conditions and different users. Having a good user model is crucial for the performances of interactive three-dimensional navigation systems. Rough sets theory, introduced by Pawlak [3], is a technique for dealing with uncertainty, and the concepts have been applied to numerous applications to better model the uncertainty and imprecision prevalent in the real world. For user modeling, there is much vagueness from various users, while rough sets can be improved user interaction characteristics discovery and user type's identity.

The goal of this paper is to present an approach to modeling adaptive navigation in virtual environments. We discuss the relevant concepts about rough sets and utilize it to generate the user types' decision-making rules, which can map identified users to adaptation templates. Besides, we introduce a example prototype system, and discuss the benefits that such a system offers in the design and maintenance of adaptive 3D navigation.

2. Related Work

Already many studies have been done for user modeling of adaptive navigation. Study [4] propose an approach based on Unified Modeling Language (UML) to model possible paths through hypertext by state diagrams. However the user interaction states in the virtual environment are very complex and this method will lose its applied value. Stephen Hughes et al provide attentive navigation mechanism for computing idea viewpoint based on a user model including direct guidance, sorting, hiding and annotation [1]. [5] implements a prototype of an adaptive virtual store and aid navigation to the customers, but the adaption rules inferring method is much more simple. Other user models are supported by UHDM [6], WebML[7] and W2000[8] but all independently from navigation. All the methods above can not generate efficient adaptation navigation for users in virtual environments, and especially the adaptive rules are litter mentioned.

Some uncertainty computing methods also are applied to user modeling, such as fuzzy sets and rough sets. For example, [9] provides a human-computer interaction prototype to identify users with fuzzy mathematic, but it requires pre-defining member functions and probability values. Compared to probability theory and fuzzy sets theory, rough sets don't need pre-defined or additional data and can apply it to build an intelligent interaction system.

3. Rough Sets and Decision Rule Algorithm

3.1. Rough Set Introduction

Rough set is a formal approximation of a crisp set (i.e., conventional set) in terms of a pair of sets which give the lower and the upper approximation of the original set. The lower and upper approximation sets themselves are crisp sets in the

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standard version of rough set theory [3].
In this paper, we resort to information system (IS) to describe user features in 3D environment, and the IS is a data set represented as a table, where each row represents a user case, and each column represent an attribute (i.e. property of user interaction behavior features). We can describe it as (U, A), which can be called a decision-making table, $A = C \cup D, C \cap D = \varnothing$, C is called condition attribute sets, D is decision-making attribute sets. Let $\varnothing \subset X \subseteq C, \varnothing \subset Y \subseteq D, U / Y \neq U / \delta = \{U\}$.

3.2. Decision Rule Algorithm

In decision-making table, different attributes may have different significances, and for finding significances of some attributes, we must delete some other attributes in the table. There several methods can be used to rule reduction and core computing, for example, the discernibility matrix [10], but the algorithm complexity will increase rapidly if the sample amount is too much. Here, the method based on significance [11] is emphasized.
If $x \in X$, the significance of x in X (for Y) can be defined as $sig^{Y}_{X-\{x\}}(x)$, and the definition as follow $sig^{Y}_{X-\{x\}}(x) = (|S_X(Y)| - |S_{X-\{x\}}(Y)|)/|U|$ and obviously $0 \le sig^{Y}_{X-\{x\}}(x) \le 1$. x is only significant in X (for Y) U $sig^{Y}_{X-\{x\}}(x) > 0$ .All the significant attributes in set *X* compose to a new set (for *Y*) which called core of *X*, can be denoted $C^{Y}_{X} = \{x \in X \mid sig^{Y}_{X-\{x\}}(x) > 0\}$ .The algorithm computes the core C^{Y}_{X} of X .Let $X = \{x_1, x_2 ... x_{|X|}\}$, $x \in C^{Y}_{X}$. The details of algorithm shown as follows:

Algorithm

Step1: [Initialize] Set 1 $\rightarrow$ i.

Step2: [Is $sig^{Y}_{X-\{x_i\}}(x_i)$ >0?] If $sig^{Y}_{X-\{x_i\}}(x_i)$ >0, go to Step3. If $sig^{Y}_{X-\{x_i\}}(x_i)$ =0, go to Step4.

Step3: [Set $x_i \in C^{Y}_{X}$] Set $x_i \in C^{Y}_{X}$, go to Step4.

Step4: [Is i=|X|?] If i=|X|, then algorithm is completed and C^{Y}_{X} is the core of *X* (for Y).If i<|*X*|, then go to Step5.

Step5: [Increase i] Set i+1 $\rightarrow$ i. Go to Step2.

4. Example

4.1. User Modeling

For adaptive navigation system, users simply divided into novice, intermediate and expert level, but it is not a proper description of user characteristics, while user's familiarities with the system operation, the understanding of interaction tasks, et al, are also very important. Therefore, thinking about the factors as above, the user model of our system includes four types of users: NL, NM, EM and EL shown in Table 1.

Table 1 User Modeling

	Navigation	
User	Landmark-based	Map-based
Novice	**NL**	**NM**
Experience	**EL**	**EM**

4.2. Adaptive Rules

To establish adaptive navigation system, we must devise user type inference rules. Inspired by the similar study of decision making rules generation by Li [10], we resorted to the user study to get related information. First of all, to represent the four types of users shown in Table 2, there were 15 participants involved in user study: 9 male and 6 female, who had the 3D navigation experience ranging from none to 2 years, and the mean age was 25.Through the questionnaire and observation of some navigation trial in virtual environment, we extracted the most influence of 3D navigation behaviors, and collated them into a decision-making table as shown in Table 2.

Table 2 User Model Decision-Making Table

	Condition Attributes (low-0,median-1,high-2)						Decision-making Attributes (false-0，true-1)			
User	C_1	C_2	C_3	C_4	C_5	C_6	NL	EL	NM	EM
u_1	1	0	0	1	2	0	1	0	0	0
u_2	1	0	0	1	2	2	0	1	0	0
u_3	1	1	0	0	2	0	1	0	0	0
u_4	1	2	2	2	0	2	0	0	0	1
u_5	2	1	1	0	2	0	1	0	0	0
u_6	1	2	2	2	0	0	0	1	0	0
u_7	2	1	0	0	2	0	1	0	0	0
u_8	1	2	1	1	2	0	1	0	0	0
u_9	1	2	1	2	0	0	0	1	0	0
u_{10}	2	2	0	0	2	0	1	0	0	0
u_{11}	1	2	1	1	2	2	0	0	1	0
u_{12}	2	2	2	2	0	0	0	1	0	0
u_{13}	2	1	1	0	2	1	0	1	0	0
u_{14}	1	2	1	1	0	2	0	0	0	1
u_{15}	1	0	0	1	2	1	0	0	1	0

C_1=Memory; C_2=Attitude; C_3=System operation frequency; C_4=operation familiarity; C_5=help-using frequency; C_6=navigation familiarity

Let universe U= {u_1, u_2… u_{10}} represent 10 users, and E= {Memory, Attitude, System operation frequency, Operation familiarity, Help-using frequency, Navigation familiarity}, Y= {NL, EL, NM, EM} denotes four types of users. By the algorithms (Algorithm 1) discussed above, it will be:

$sig^Y_{x_2x_3x_4x_5x_6}(x_1) = (|S_X(Y)| - |S_{X-\{x_1\}}|)/|U| = (15-15)/15 = 0$ .For the same, $sig^Y_{x_1x_3x_4x_5x_6}(x_2) = (15-15)/15 = 0$; $sig^Y_{x_1x_2x_4x_5x_6}(x_3) = (15-15)/15 = 0$; $sig^Y_{x_1x_2x_3x_5x_6}(x_4) = (15-15)/15 = 0$; $sig^Y_{x_1x_2x_3x_4x_6}(x_5) = (15-13)/15 = 2/15$; $sig^Y_{x_1x_2x_3x_4x_5}(x_6) = (15-11)/15 = 4/15$; Hence, $C^Y_{\{x_1,x_2,x_3,x_4,x_5,x_6\}} = \{x_5, x_6\}$.

So, for the system， {Help-using frequency} and {Navigation familiarity} are most significant attributes (Core); and {Memory}, {Attitude}, {System operation frequency}, {Operation familiarity} are reduced attributes.

Through the attribute reduction shown in Table 2, we can obtain the adaptation inference rules for user types:

R_{11}: If (Help-using frequency, high) and (Navigation familiarity, low), Then (NL，true);
R_{22}: If (Help-using frequency, low) and (Navigation familiarity, low), Then (EL, true);
R_{33}: If (Help-using frequency, high) and (Navigation familiarity, high), Then (NM, true);
R_{44}: If (Help-using frequency, low) and (Navigation familiarity, high), Then (EM, true).

4.3. Adaptive 3D Navigation Architecture

The users' navigation types in virtual environment are related to their spatial knowledge, and different users have different knowledge about 3D navigation based on their experience in virtual worlds. Therefore, we can find that some people prefer the landmarks for orientation; some people depend on roads to find navigation path; and others resort to map for orientation [13]. If system can judge the types of user by user model, it will give HMI adaptation for user navigation. Based on the insights and patterns identified from the study of Chittaro et al. [14] , we designed the adaptive 3D navigation architecture which is illustrated in Figure 1, and it is composed by the following logic modules:

User Behavior Sensing (UBS): to monitor the user's interaction behaviors in the 3D world.

User Model Database (UMD): to record the user data sent by UBS and classify them for different user types.

Adaptation: composed by two sub-modules, respectively named User Model Update Rules and Navigation Adaptation Rules. The purpose of the first sub-module is to perform inferences needed to update the user model. The second sub-module is to decide the adaptation that should be performed on the basis of the current user model. The Adaptation Module can be automatically run when user operating the system for a given short while.

HMI Creator: to receive adaptation rules and change the 3D navigation user interface through the templates.

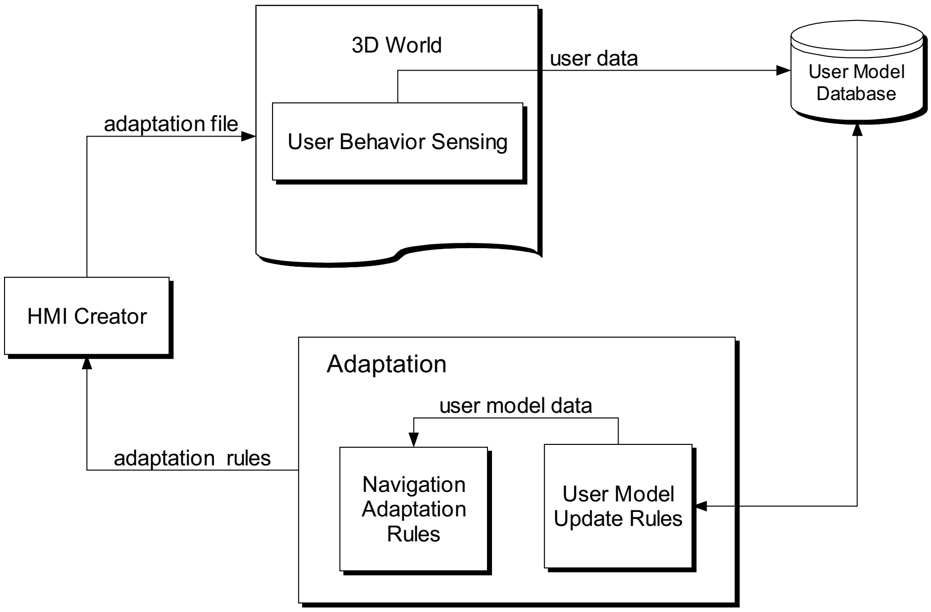

Figure 1.Schema of the architecture for adaptive 3D navigation

5. Application Case

5.1. Adaptation Templates

To adapt to different types of users, we designed a system of four templates corresponding four types of users (defined in Table 1). Table 3 shows the templates with some main attribute differences between them. V denotes the value of the moving speed, the more"+", the more quickly; S denotes the value of the "Field of View" (FOV), the more "+", the bigger.

Table 3 Interface Template for Different User

Attributes	User Type			
	NL	EL	NM	EM
Map	false	false	true	true
Landmark	true	true	false	false
Speed	v	v+	v++	v++
FOV	s++	s++	s+	s

5.2. Prototype System

We developed a VRML (Virtual Reality Modeling Language) based prototype through Cortona SDK [15]that named VEM(Virtual Exhibition Museum), which was a virtual environment to test navigation adaptation The VEM system can adjust user interface to map the different types of users when they navigate in 3D world, and the system profiles are defined with XML. Take the adaptation rule "R_{11}: (Help-using frequency, high) and (Navigation familiarity, low), then (NL, true)" for example (coordinated with "interface template" of table 3):

```
<xsd: rule name=" R11">
  <xsd: userType>
    <xsd: condition attribute name=" help-using frequency" value="high">
    <xsd: condition attribute name=" Navigation familiarity" value="low">
    <xsd: decision attribute name="NL" value="true">
  </xsd: userType>
  <xsd: interfaceTemplate>
    </xsd: interface attribute name="map" value="false">
    </xsd: interface attribute name="landmark" value="true">
    </xsd: interface attribute name="speed" value="v">
```

</xsd: interface attribute name=”FOV” value=”s++”>
</xsd: interactionTemplate>
</xsd: rule>

As shown in Figure 2 (a), it’s the system interface for NL type users, who are novices in the virtual environment and used to landmark centered navigation. The system emphasizes the landmark (e.g. show box and exhibition room) in text label, and the help tip is shown at the up left corner of the screen at the same time.

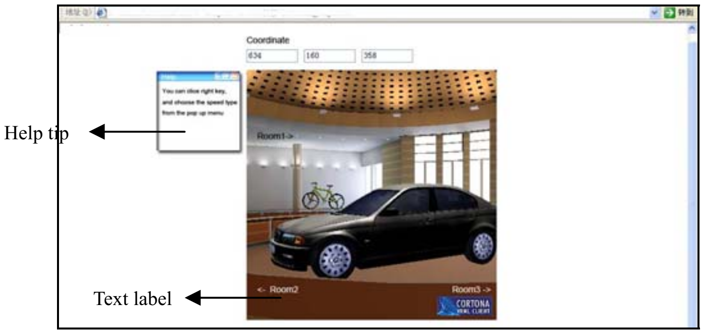

Figure 2(a). User Interface for NL User

On the other hand, for the EM type users who are expert on virtual world and familiar with the map centered navigation, as shown in Figure 2 (b), system will display the map (one dot stand for the user position at present)of whole virtual scene. At the same time, users can moving fast and undertake little FOV during navigation.

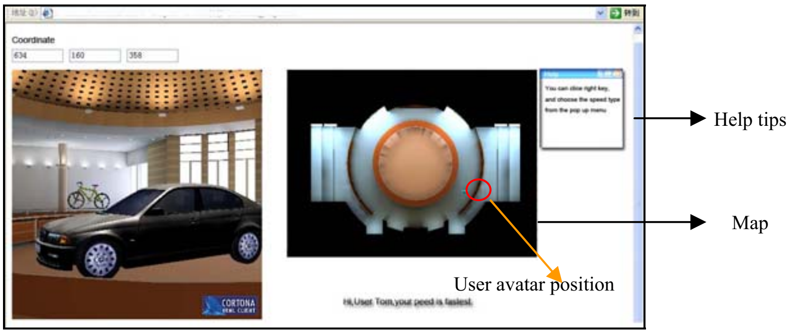

Figure 2(b). User Interface for EM User

5.3. User Study

In the user study, we set up a comparative experiment: 16 participants involved in two navigation systems, one is adaptive for different types of users with our proposed approach and the other one not. Participants were asked to complete exploring, random browsing and object searching tasks, and then gave the points from 1 to 9 though the Questionnaire of User Interface Satisfaction (QUIS) [16].

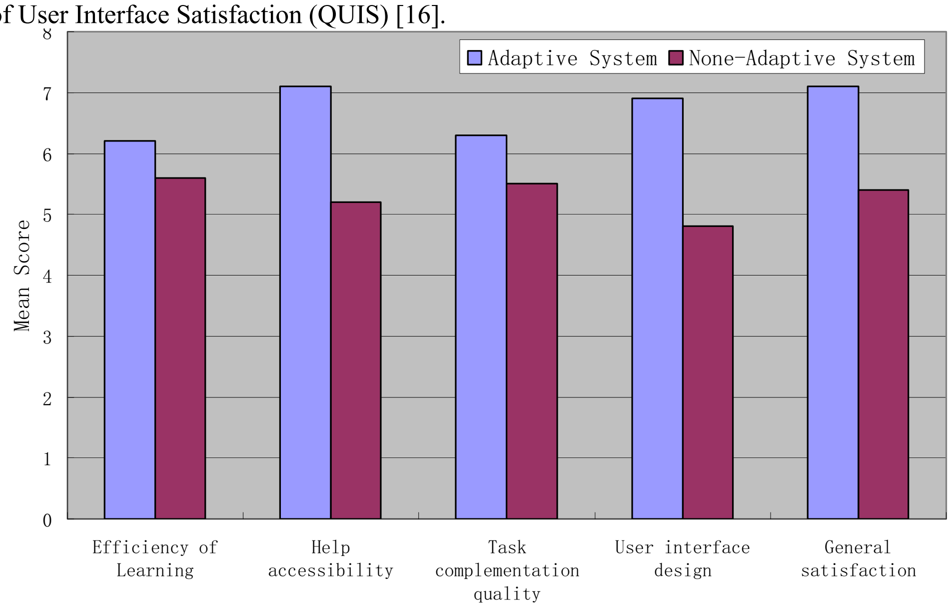

Figure 3.User Study Result

Results shown in Figure 3, the evaluation mean scores for several user performance criteria. We can make conclusion that the proposed adaptive approach here is better than the normal navigation system.

6. Conclusions

In this paper, we have proposed rough sets based user modeling approach for 3D adaptive navigation. The attribute reduction algorithm we can generate the user type decision-making table and identity the user types by their interaction behaviors. Through the user adaptation templates, system can change the HMI to adapt to users' 3D navigation. For the example prototype and its evaluation, the proposed approach indeed can improve the user performance in navigation.

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