Towards a Spatio-Temporal Agent-Based Recommender System
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ABSTRACT
Agent-based recommender systems have been widely employed in the last years to provide informative suggestions to users, showing the advantage of exploiting components like beliefs, goals and trust in the recommendation computation. However, many real-world recommendation scenarios, like the traffic or the health ones, require to represent and reason about spatial and temporal knowledge, considering also their inner incomplete and vague connotation. This paper tackles this challenge, and introduces STARS, an agent-based recommender system based on the Belief-Desire-Intention (BDI) architecture. Our approach extends the BDI model with spatial and temporal reasoning to represent and reason about fuzzy beliefs and desires dynamics.

Keywords
Fuzzy spatio-temporal reasoning, RCC, Allen’s intervals

1. INTRODUCTION
Agent-based recommender systems [9, 4, 5, 6, 7, 2, 12] have been proposed in the last years in different scenarios, e.g., the tourism, health-care and traffic ones, to provide suggestions to support users in the achievement of their goals. The advantage of such a kind of recommender systems is that of encoding in the system users’ beliefs and goals to return a recommendation as close as possible to their needs, with the possibility to take in also additional information like the confidence in the source. These application scenarios require in addition to formalize the knowledge about the time and the location in which the action is taking place. This information often needs to be processed at the same time, as in the case of the traffic scenario where a traffic jam is identified by its location and the time it is occurring during the day, and requires to encode a certain degree of vagueness. In this paper, we answer the following research question: how to represent and reason about fuzzy spatial-temporal knowledge to provide useful recommendations? To answer this question, we introduce STARS, a Spatio-temporal Cognitive Agent-based Recommender System. Based on the extension principle of fuzzy set theory [18], we define fuzzy Allen’s intervals [1] to model temporal knowledge, while fuzzy topological relations are defined in terms of region connection calculus [13], where regions are represented as fuzzy sets. These two components, namely spatial and temporal information, are combined together based on the assumption that the degree to which a spatio-temporal belief is true is the minimum between the confidence degrees of the spatial belief and temporal one, respectively. Spatio-temporal knowledge is then exploited by agents to update their beliefs following the other agents’ recommendations, with the aim to reach their goals. Up to our knowledge, STARS is the first agent-based recommender system taking into account at the same time spatial and temporal knowledge, and the vagueness and incompleteness typical of these components. Related work, e.g., [8], considers either spatial or temporal knowledge, and does not consider the fuzzy connotation of spatio-temporal knowledge, e.g., [16, 3].

2. SPATIO-TEMPORAL BELIEF REPRESENTATION AND REASONING
This work is an extension of the recommender system based on the BDI model we presented in [12, 11], where a spatio-temporal representation of beliefs and desires is proposed. A spatio-temporal belief is an event defined as a spatial relation holding in a temporal interval. A spatio-temporal belief consists then of a sequence of snapshots of an entity taken at specific time points: $b_1$ at $t_1$, $b_2$ at $t_2$, ..., $b_n$ at $t_n$ where $t_1, t_2, ..., t_n \in T$ and $b_1, b_2, ..., b_n$ are spatio-temporal beliefs concerning a moving spatial object (e.g., a car, a moving person, ...).

2.1 Fuzzy Allen’s intervals
The 12 relations defined by Allen for simple time intervals [1] are generalized for modeling fuzzy time relations. Each basic relation can be defined in terms of endpoint relations as in [10]. Using the extension principle, a fuzzy temporal relation is defined. For example, the fuzzy rela-
ation $d_f$ is introduced for the temporal relation $d$ (during), and it is defined as follows:

$$X d_f Y \iff (X^- >_f Y^-) \land (X^+ <_f Y^+)$$

The corresponding degree of confidence, using the extension principle, can be expressed as:

$$\mu_{X d_f Y} = \min(\mu_{X^- >_f Y^-}, \mu_{X^+ <_f Y^+})$$

All the $X$ and $Y$ values can be generalized to fuzzy values and represented by fuzzy triangular numbers. Based on the extension principle, we define first the confidence degrees of the fuzzy relations $\geq_f$ and $\leq_f$ in order to deduce respectively those of $>_f$, $<_f$ and $=_f$. Suppose we have two fuzzy intervals $A$ and $B$ defined by triangular fuzzy functions as follows: $A = (a_1, a_2, a_3)$ and $B = (b_1, b_2, b_3)$. By applying the extension principle, we obtain the following fuzzy relations:

$$\mu_{A \leq_f B} = \begin{cases} 
0 & \text{if } a_1 > b_3 \\
\frac{b_3-a_1}{b_3-a_1 + a_2-b_2} & \text{if } a_1 \leq b_1, b_2 < a_2 \\
1 & \text{if } a_2 \leq b_2 
\end{cases} \quad (1)$$

$$\mu_{A \geq_f B} = \begin{cases} 
0 & \text{if } b_1 > a_3 \\
\frac{a_3-b_1}{a_3-b_1 + b_2-a_2} & \text{if } b_1 \leq a_3, b_2 > a_2 \\
1 & \text{if } b_2 \leq a_2 
\end{cases} \quad (2)$$

From Equations 1 and 2, we obtain the confidence degree of relations $>_f$, $<_f$ and $=_f$ as follows:

$$A <_f B = A \leq_f B \land \neg(A =_f B),$$
$$A >_f B = A \geq_f B \land \neg(A =_f B),$$
$$A =_f B = A \leq_f B \land A \geq_f B.$$
Several open challenges have to be tackled as future research. For instance, further qualitative relations about directions should be introduced concerning spatial reasoning to allow the representation of a more realistic model.

REFERENCES


