Modeling Spatiotemporal Uncertainty in Dynamic Virtual Environments

S. Vosinakis[1], G. Anastassakis[2], T. Panayiotopoulos[2]

[1]University of the Aegean, Department of Product and Systems Design Engineering
Hermoupolis, Syros, Greece
spyrosv@syros.aegean.gr
[2]University of Piraeus, Department of Informatics
Piraeus, Greece
{ganast, themisp}@unipi.gr

Current virtual agent [1] control architectures involve representations of the environment that must be adequate for effective deliberative behaviour rather than simple encoding of the environment's state. Hence, they must take into account the element of uncertainty that is inherent to perceptual processes, in the form of predicting the future state of perceivable parts of the environment or the current state of non-perceivable parts. A number of approaches have been proposed to deal with uncertainty. A large proportion introducing uncertainty as a means towards increased perceptual believability [2]. A different group attempts to deal with inherent uncertainty in a variety of ways [3,4]. Although substantial benefits are gained in both cases, prediction over time is rarely addressed, while potential knowledge on targets' intentions remains largely unexploited.

In this paper we propose a model of spatiotemporal uncertainty as an enhancement to current virtual agent control architectures. Our model is based on a fuzzy set representation and has been designed to participate in a generic VA control architecture focusing on the real-time nature of the target domain. Based on a distilment of the great variety of VA architectures available today, the architecture contains, among other components, Sensors that are the VA's means to perceive the virtual environment. These provide environment knowledge to a Control component which, in co-operation with a Knowledge Base, generates autonomous behaviours executed consequently by Effectors.

A question arises as to where within such a VA architecture the mechanisms to handle spatiotemporal uncertainty should fit. Sensors seem to be a suitable choice, for a number of reasons. Firstly, predicted knowledge is seamlessly and transparently available to other components just as solid, explicitly-sensed knowledge is. Secondly, a real-world metaphor is introduced, that clarifies and de-centralizes design. Humans, for instance, do not exercise conscious thinking to predict the trajectory of a ball thrown to them or the course of a moving car. Technical benefits are gained, too.

The proposed model uses three dimensional fuzzy sets to represent the uncertainty about the motion of animated entities in the environment. This representation is constructed based on the agent's perceptual information and on its beliefs about the other entities' intentions. The basic element of the proposed representation is the *Fuzzy Position*, which stands for the position of an entity in the environment. It is a 3D Fuzzy Set which represents the plausibility of an entity e to be positioned in (x, y) at time t. The membership function $\mu_{Pe}(x, y, t) \rightarrow [0,1]$ takes into consideration the agent's knowledge of the geometry of all static entities observed, its beliefs about the motion abilities of the entity *e* and its estimation about the possible intention(s) -if any- of *e*.

Concerning the motion abilities of an entity, the proposed model requires from the agent to know its maximum velocity v_{max}, its maximum acceleration a_{max} and its maximum angular velocity ω_{max}. These values could be a priori knowledge of the agent or they could be learned from observation. Also, based on its high-level knowledge and reasoning, the agent might have an estimation of the intentions of the observed entity. There might be places or elements it might want to approach or avoid, e.g. in a game environment a player might approach a gun and avoid an enemy. We call these positions *attractors* and *distractors* respectively and they could be static or animated. Each entity can have an arbitrary number of attractors and distractors associated to it.

The Fuzzy Position of an entity can be used to estimate its location at time *t*, given that the uncertainty increases as the interval $(t - t_0)$ increases, t_0 being the time of the last sensed position. Furthermore, the time at which an entity is expected to reach a certain position or area can be estimated. These estimations can take place using a defuzzification method, such as centroid or average of maxima. This analysis can lead to higher level knowledge, such as possible future positions of entities or actual positions of non visible entities. Even more important is the fact that the agent can extract knowledge about locations where an entity can certainly not be after time *t*, provided that the motion abilities of that entity are known. This is especially useful if fuzzy spatial knowledge is to be used by a planner as part of a behavior-generation procedure, for action precondition evaluation, etc.

The authors have set up an experimental evaluation in order to assess the efficiency of the proposed representation to predict future positions of animated entities in non-deterministic environments. A 3D space representing a virtual museum has been constructed and a number of 20 participants have been asked to move freely around and observe the contents. The evaluation results indicate that the estimations of future locations of animated entities can be precise enough, given that an agent's beliefs about possible attractors and distractors and about motion capabilities of the entities are correct.

References

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