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Simultaneous Tracking and Activity Recognition (STAR) using Advanced Agent-Based Behavioral Simulations

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Abstract. Tracking and understanding moving pedestrian behaviors is of major concern for a growing number of applications. Classical approaches either consider both problems separately or treat them simultaneously on the basis of limited contextual graphical models. In this paper, we consider tackling both problems jointly based on richer contextual information issued from agent-based behavioral simulators designed for realistically reproducing human behaviors within complex environments. We focus on the single target case and experimentally show that the proposed approach keeps good performances even in case of long periods of occlusion.

1 Introduction

Let us consider a complex environment, e.g. a subway station, in which pedestrians may evolve and perform several types of actions. The environment is equipped with objects with which a user may interact in order to fulfill his goal. For example, in a subway station, there are ticket machines, ticket barriers, ATMs, and escalators. Also, let us assume that a sensor network has been installed within the environment and that it has been configured to partially cover the environment. The sensors provide noisy location data about pedestrians when they are detected within covered areas. We are interested in inferring the pedestrians' behaviors (high-level activities) on the sole basis of the data perceived by the different sensors regarding their trajectories.

Understanding a pedestrian behavior is intimately coupled with tracking its location as moving people are usually driven by an inner motivation in relation with the activity they are performing in the environment. Therefore, location and motivation are contextually dependent, and the knowledge of one may help estimate the other.

In [7], the authors introduce the "Simultaneous Tracking and Activity Recognition" (STAR) problem with the aim of taking advantage of the contextual dependency between location and motivation for better estimation results. They use dynamic Bayesian networks (DBNs) for representing the scene context and causal influences in the environment and rely on particle filtering for inference purposes. In [4], Manfredotti et al. go one step further and investigate the use of relational DBNs for capturing the relationships among interacting targets in the STAR problem. We follow the idea of taking advantage of the scene information by performing both operations simultaneously. However, graphical models are limited as it is hard, and sometimes impossible, to capture relevant contextual information such as interactions with objects in the environment which may require several time steps to be performed.

In this paper, instead of using graphical models, we propose to use advanced behavioral simulators of autonomous agents which allow leveraging richer contextual information [3]. Such simulators, issued from the field of situated artificial intelligence, rely on process-oriented behavioral models. These models are not only characterized by physical attributes (e.g., position, velocity), but integrate, within themselves, action selection mechanisms responsible for selecting, given an agent, an action to perform in the environment according to its internal state and its current knowledge (including the perceptions) of the environment. Our solution consists in integrating such a simulator, as a predictive block, within a particle filter for estimating and analyzing people behavior.

The remainder of this paper is structured as follows. Section 2 briefly describes how such behavioral simulators work and emphasizes on their utility for solving a STAR problem. Section 3 presents initial results obtained while focusing on a single-target case within the virtual subway station example introduced above, while Section 4 identifies some important research lines induced by the described work.

2 Advanced Agent-Based Behavioral Simulators

The use of advanced agent-based behavioral simulators to generate context-based realistic human behaviors for autonomous characters has become very popular [5]. In these simulators, virtual humans live their own life autonomously in a persistent virtual world, usually a very complex environment. In order to achieve such level of realism, such a simulator mostly relies on three main features.

The first feature is the ability to model the services that are available for the virtual characters within the virtual world. This is usually done via the concept of *Smart Objects* [3], which allows defining generic interactions between virtual human agents and objects in the virtual world. In such an approach, an object includes within its description not only intrinsic properties, but useful information about how to interact with it. Therefore, a virtual human does not need to maintain within its knowledge information regarding usage of objects but it has to retrieve such data from an object offering the service it is interested in.

The second feature is the ability for a virtual agent to express its desire, in a coherent and effective way, for a given service within the environment so as to work towards the satisfaction of its current goal. This is usually done by equipping each virtual agent with an individual motivational mechanism responsible for decison making at each moment in time based on the agent's internal states and perceptions. The role of such a mechanism is to *transform* the agent internal

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[3] By contextual information, we refer to environmental information perceived by a pedestrian that may affect his behavior.

states into actions (corresponding to services offered in the environment) while taking into account environmental information (via the sensorimotor loop) obtained via the agent's perception system. In order to obtain a high degree of autonomy and real-time efficiency, this mechanism needs to be reactive and proactive. Tyrell [6] suggests the use of free flow hierarchies as the architecture of motivational mechanisms for increasing their reactivity and their flexibility. For an example of how environmental information are taken into account in such arcitectures, please refer to [1].

The third feature is the ability to guide the virtual agent toward the object offering the service it is interested in while avoiding obstacles. This is done by relying on a path planner responsible for computing the path the agent will follow to satisfy its objectives.

In summary, given a virtual agent, from its internal state, the motivatonal mechanism provides a motivation which is linked with a service offered by the environment through a smart object from which the path planner deduces a trajectory. Therefore, integrating such a simulator within a particle filter for dealing with a STAR problem presents a major asset as it is possible to build an explanatory diagram from the trajectories observed in terms of motivations (actions to perform) of the agent.

3 Experimental Evaluation

The simulator used is SE-Star, a Thales proprietary engine for modeling motivational and autonomous agents via a free flow hierarchy mechanism and capable of handling interactions with objects. We consider the example of the subway station introduced in Section 1. Figure 1 represents the corresponding environment. The station's objects such as the ATM (in light green), the ticket machine (yellow), a beverage dispenser (brown), ticket barriers (white), and exit barriers (red), have been modeled using the Smart Object approach, therefore providing within the description of the objects information about how an agent can use them. The sensor network is set to not cover areas occupied by the ATM, the ticket machine and the beverage dispenser (see Figure 1).

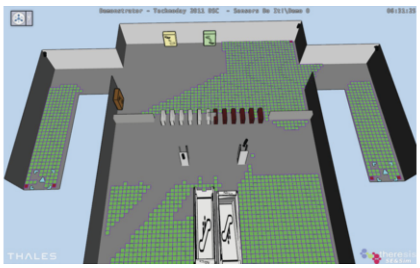

Figure 1: Virtual Subway Station. Green squares represent areas covered by sensors.

Also, we assume that a passenger within the environment can be motivated by three main goals: taking the train (go to work), buying a drink or leaving the station. Also, he may initially own a certain amount of money and/or a valid ticket. We model within SE-Star a motivational mechanism based on three numerical attributes (describing the agent's internal state) taking values in $[0, 2]$ and representing respectively the willingness to work, the thirst level and the stress level of the agent. Further, we have attributes representing the amount of money and the number of tickets owned.

We consider a single target and we integrate the simulator within a particle filter process for the behavior analysis purposes. The sensors' noise standard deviation is set to 0.8, 0.8 and $0.05m$ for the x, y and z coordinates respectively. Initially, a passenger has 30% chances to own a number of tickets (an amount of money) chosen uniformly in $\{1, 2, 3\}$ ($\{1, \ldots, 5\}$) and nothing otherwise. For other attributes, we assume a Gaussian distribution $\mathcal{N}(0.75; 0.5)$. Figure 2 illustrates an example of result obtained from our approach. As demonstrated, our approach is robust in identifying the passenger behavior even in case of long periods of occlusion. For statistical results regarding the proposed approach, please refer to [2].

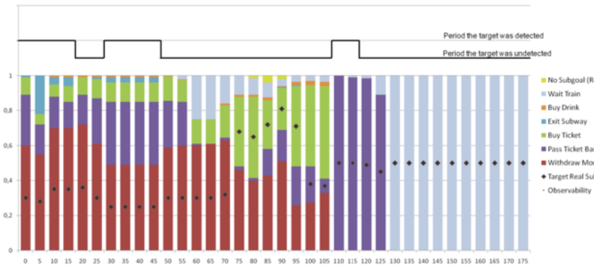

Figure 2: Estimation of the passenger's behavior over a discretized time slot: each bar represents the belief over the behavior (modeled as slices of the bar) by the filter. The black point on each bar represents the actual behavior of the tracked target. The line on top of the bars represents time frames during which the target were either observed or not.

4 Conclusion

In this paper, we address the STAR problem by taking advantage of richer contextual information from advanced agent-based behavioral simulators designed to generate realistic human behaviors for autonomous agents. The proposed approach is therefore adequate for easily handling dynamic changes in the environment. The experimental evaluation shows good performances in inferring the target behavior from noisy trajectory information in the case of a single target. We are currently working on extending the approach for the case of multiple targets. This is raising new challenges as several agents may either concurrently interact with the same object or proceed in queue for its usage, factors that may impact the design of efficient filtering approches for handling multi-target cases.

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