Behavior Authoring for Crowd Simulations

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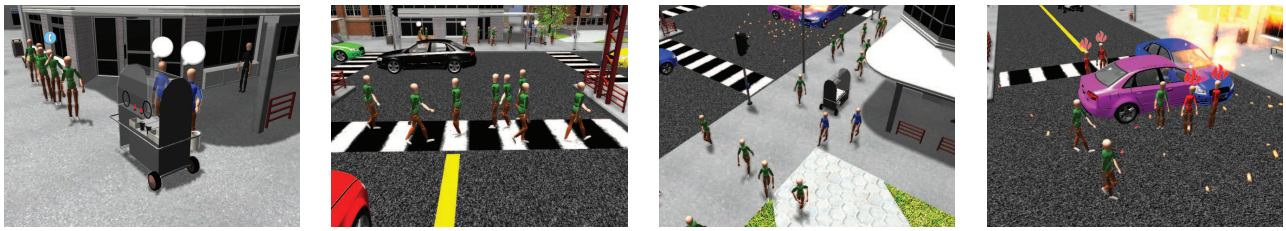

(a) (b) (c) (d)

Figure 1: *Snapshots of the city simulation authored using our framework: (a) Actors queue up at a hot dog stand while the vendors talk to one another. In the meantime, the thief lies in the shadows waiting for an opportunity to steal the money from the stand. (b) Cars giving right of way to pedestrians. (c) Cautious actors run to a place of safety in the event of an accident. (e) Firefighters extinguish the fire while daring actors look on.*

1 Introduction

There has been growing academic and industry interest in the behavioral animation of autonomous actors in virtual worlds. However, it remains a considerable challenge to automatically generate complicated interactions between multiple actors in a customizable way with minimal user specification.

In this paper, we propose a behavior authoring framework which provides the user with complete control over the domain of the system: the state space, action space and cost of executing actions. Actors are specialized using *effect* and *cost* modifiers – which modify existing action definitions, and *constraints* which prune action choices in a state-dependent manner. *Behaviors* are used to define goals and objective functions for an actor. Actors having common or conflicting goals are grouped together to form a *composite domain*, and a heuristic search technique is used to generate complicated multi-actor behaviors. Using our method, users can work at any level of abstraction – from specifying scripted sequences of actions, goals, constraints on trajectories of one or more agents, to specifying high-level motivations for an entire scene. We demonstrate the effectiveness of our framework by authoring and generating a city simulation involving multiple pedestrians and vehicles that interact with one another to produce complex multi-actor behaviors.

2 Our Approach

There are two components to authoring behaviors: (1) behavior specification, and (2) behavior generation. A behavior is specified as a scripted sequence of actions, desired goal state, finite state machines or using complex cognitive models. Then, a behavior generation module computes an action trajectory for all actors corresponding to the desired behavior(s).

There exists a trade-off between manual specification and automation of behavior generation. A simple generation module requires detailed specification of behaviors (e.g. scripted sequences of actions), while abstract specifications (e.g. high-level motivations for actors) require more complexity and automation in behavior generation.

Scripted behaviors are dependent on the current configuration of the actors and the environment and do not generalize easily to different scenarios. Authoring complicated interactions between multiple actors becomes intractable in current approaches. For example, describing the collaboration of two actors to pick-pocket a victim could vary drastically based on the properties of the environment, the victim, or presence of other actors such as a police officer. Also, there is no clear way of directing the trajectory of the story without defining behaviors for every participating actor.

Our approach is to combine the expressive nature of actions, action specializations, constraints and behaviors (specification atoms) along with the automation of a heuristic search planner that works in the composite space of interacting actors. The intended audience for this framework is two-fold: domain specialists can define metrics and actions for a given scenario (state and action space), while end-users can specialize existing action definitions to add variation and purpose to their own simulation. The planner allows complex behaviors for multiple interacting actors to be generated with minimal user specification. Our method has the following benefits:

- **Modular and Natural Specification:** Domain specialists define the state and action space for different scenarios while end-users can specialize and constrain existing definitions to add variation and purpose to their simulation. Specializations and constraints can focus on any levels of abstraction and can be as general or specific as necessary. Behaviors are specified as goals and objectives for actors that are triggered based on their current state.
- **Cooperative and Competitive Planning:** Complicated interactions between multiple actors can be authored by simply specifying common or contradicting goals for actors in the scenario. Our method automatically clusters actors that have cooperative or conflicting goals to define a *composite* state and action space. This avoids the complexity of modeling communication between actors or the need for explicit scripting of cooperation schemes in agents. Collaborative behaviors arise as a solution found by the planner which minimizes the combined cost of actions of all agents in the composite space.
- **High-Level Story Specification:** Constraints can be used to enforce requirements at various points in the simulation without explicitly scripting preceeding and succeeding events. This allows users to make incremental changes in the specification in an isolated manner.

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