Simulating Crowds with Balance Dynamics

Ori P. Ratner*
Computer Science Department
University of Virginia

David C. Brogan*
Computer Science Department
University of Virginia

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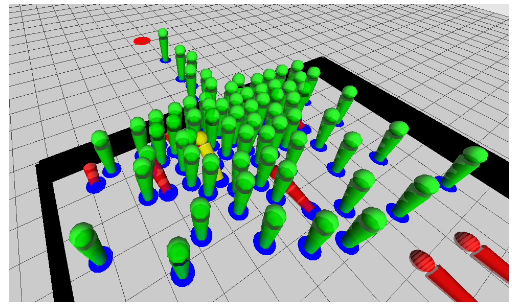

Figure 1: Pedestrians exiting a room during an earthquake. Red pedestrians have fallen and yellow are falling.

1 Introduction

The dynamics of walking dramatically influences the behaviors of pedestrians, yet few details of human biomechanics and walking control are addressed in crowd animations developed for virtual environments and scientific applications. People cannot stop or start instantaneously and their movements reflect an attention to balance as well as other environment-driven goals. This work seeks to fill the void between full-scale, computationally expensive models of articulated human motion and simplified particle/cell models used in many multiagent simulations. Comparison of our pedestrian model results with those published elsewhere reveals that this work preserves phenomena like self-organization, lane formation, and semi-circular crowding at exits [Helbing et al. 2002]. Furthermore, our pedestrian model enables novel behaviors such as tripping, stumbling, and falling which permit animating more extreme scenarios; for example, earthquakes, where translational forces significantly affect pedestrian and crowd dynamics.

2 Pedestrian Model and Crowds

The two-level system that we have constructed to accomplish crowd behaviors is composed of autonomous characters that must perceive the environment and accomplish goals subject to the physical limitations of humans. The high-level crowd control algorithms specify a goal velocity for every pedestrian such that crowd objectives are accomplished. The crowd control algorithm we use is similar to those implemented by Reynolds, Helbing, and others in that the pedestrians exhibit centering, neighbor avoidance, and velocity matching. Our low-level pedestrian model computes a sequence of actions for each pedestrian that seeks to accomplish the goal velocity issued by the crowd control algorithms. The pedestrian model must create character animations that move like a human when navigating through crowded environments and it must respond realistically when external forces are applied.

Because maintaining balance, in particular, is a critical element of human walking and it is dynamic in nature, we base our pedestrian model on a physical simulation of a classic inverted pendulum (cart-pole). The type of inverted pendulum that we create for these crowd behaviors reproduces pedestrian acceleration and deceleration profiles, nominal velocities, and balance maintenance. Specifically, we require a cart-pole simulation that can move forward from a dead stop without first moving backward and must have a large stable region. Unlike the classic inverted pendulum that balances a pole about a fixed point by applying forces to a cart, our cart balances a wide pole, or bottle. When the relative velocity between the cart and bottle is small, the bottle remains stably balanced atop the cart through infinitely strong friction forces. The bottle will tip to the side, however, when the relative velocity is sufficiently large. A physical simulation of an inverted pendulum is used to model the tipping of the bottle. Using two instances of the tipping bottle is sufficient to represent a bottle that tips along any point around its circular base. Turning dynamics are not explicitly modeled. The bottle is balanced using a proportional-derivative servo controller that is tuned to replicate human-like velocity profiles reported in the literature [Helbing et al. 2002; Brogan and Johnson 2003]. Through the application of external forces to the cart, the cart-bottle simulation can model character collisions and environmental disturbances.

Our system exhibits behaviors similar to those reported in previous systems where crowds split around an obstacle, exit a room through a doorway, and pass through a narrowing hallway. To extend these previous systems, our model is capable of predicting and animating the effects of tripping pedestrians. After a few pedestrians have fallen and others trip over them, new crowd dynamics appear through the subsequent blockages they create. Additionally, our model is capable of representing the effect of ground (or building) translations as experienced during earthquakes (figure 1). Pedestrians are observed moving in irregular paths in order to counteract the shifting ground, some able to maintain balance, while others fall and become obstacles for those around them. Sizes of the crowds simulated in our test scenarios range from 100 to 1000 characters at near-realtime speeds. Simulation timesteps on the order of 33 ms give accurate results, with even larger values suitable for non-scientific applications. This work is ongoing, as we continue to investigate locomotion controllers for physically simulated heterogeneous crowds in natural environments.

*e-mail: opr9t@virginia.edu and dbrogan@cs.virginia.edu

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