A Framework Combining Cellular Automata and Multi-Agents in a Unified Simulation System for Crowd Control

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Keywords: Complex Systems, Cellular Automata, Agents

ABSTRACT

Controlling crowds in airports, train terminals, sporting events, etc., is a complex problem. This particular problem has a great deal of interaction between the entities themselves (i.e. among the individual members of the crowd) and the crowd (or individuals) with the environment in which the crowd is placed. This complexity of this system can be described in the much researched area of artificial life. By combining Cellular Automata (CA) with agents, we can construct a system to capture and control the ebb and flow of a crowd, including the particular characteristics of the individuals in the crowd. To this end, we have developed a prototype crowd control simulation system as a test case for this kind of problem. The imbedded CA provides a framework for flow of people, much like traffic models (Nagel, K., and Rasmussen, S. 1994) and (Blue, V. J. and Adler, J.L, 2000a), while the agent reproduces the behavior of a crowd, including subgroup behaviors, interactions, stochastic decisions of single units etc. This work is an extension of the web-based model in (Bruzzone, A. and Signorile 1999).

CELLULAR AUTOMATA SIMULATIONS AND TRAFFIC SIMULATIONS

Cellular automata (CA) are simple spatial processing models with their origins in the early architecture of digital computers designed in the 1940 and 1950s. CA has close associations with complexity theory and has been employed in the exploration of a diverse range of urban phenomena, generally to investigate ideas about how real urban systems operate, but from a controlled experimental environment within computer software. Urban applications of CA range from traffic simulation and regional-scale urbanization to land-use dynamics, historical urbanization, and urban development (Center for Advanced Spatial Analysis website). Therefore, CA is particularly useful in simulating complex adaptive systems such as people movement.

There has been a great deal of interest in studying traffic flow with Cellular Automata models. CA models are conceptually simple, thus we can use a set of simple CA rules to produce complex behavior. Using CAs we can capture the complexity of interacting traffic pattern behavior. The basic one-dimensional Cellular Automata model for highway traffic flow is described in (Nagel, K., and Rasmussen, S. 1994). The model describes a one-lane traffic road with sequence of grid points, and each grid point is a square representing one vehicle. There are many variations on the basic model (Blue, V.J. and Adler, J.L. 2000b) that consider the effects of acceleration and delay of vehicles with high speed. The actual speed of the car at each time step depends on the "lambda" value that can be adjusted accordingly. This model captures the realistic traffic situations where the car accelerates and decelerates.

The rules in (Blue, V.J. and Adler, J.L. 2000b) model are very simple, but we get complex behavior out of a population of these rules. This complexity is defined by methods in statistical physics. Such models lead us away from the view of multi-agent traffic models as fundamentally linear where units are treated in isolation, thus motivating us to look into combining agents and CA.

Proceedings 16th European Simulation Symposium
György Lipovszki, István Molnár © SCS Press, 2004
ISBN 1-56555-286-5(book) / ISBN 1-84233-106-x(CD)

CELLULAR PEDESTRIAN TRAFFIC SIMULATIONS

The one dimensional car traffic models motivates us to develop more complex models of movement. The area of pedestrian movement has been used as possible application field for the use of cellular automata (Blue, V. J. and Adler, J.L, 2000a) and (Blue, V.J. and Adler, J.L. 2000b)

These models contain cellular entities that have a forward direction of movement and the idea is to optimize the speed of the agent in a given direction, under a maximum walk speed constraint. Each agent will account for the position of other agents and their direction of forward movement. In the simplest case we could have an environment where each agent is moving in the same direction as every other agent. The next increase in complexity involves flow where two types of agents in the population move in opposing directions. To further increase, complexity, consider moves that cover all possible local moves (Blue, V.J. and Adler, J.L. 2000b). In (Dijkstra, J., A.J. Jessurun, and H.J.P. Timmermans. 2001), using agents as an extension of CA was initially discussed, However, these agents are just extension of the movement rules in the CA, and do not have personable attributes we consider important in crowd behavior.

Most of these models are primarily based on CAs to understand emerging behavior of pedestrian's movement. We are interested in more than just movement models, but also pedestrian behavior models. For example, in a museum setting, each agent/pedestrian makes decisions on moving both on the CA rules defined in (Bruzzone, A. and Signorile 1999) as well as other internal rules. These internal rules could include the, again for the museum example, the desire to linger at a particular exhibit. This individual pedestrian behavior affects the total crowd behavior in interesting ways.

As modeling of spatial systems improve and develop, systems can be modeled at finer and finer granularity, or scale. This means that activity can be represented in the model at various levels, (for example, at the individual entity in the systems). Understanding complex systems naturally mean injecting individual behavior into the gross systems. Therefore, individual mobility, and state are inevitably woven into the fabric of the complex system. Therefore, we look at developing models of complex systems that combine cellular automat at the aggregate spatial level and add entity motion to the cells as agents. In this way, we can model gross movement rules (the CS grid rules) and particular individual/group rules (the agents).

THE PROBLEM OF MODELING CROWD CONTROL

Crowd control can be applied to many different areas, such as police operations (Varner D., Scott D.R. Micheletti J., Aicella G. (1998)), shopping center design, public park re-organization (Bruzzone A.G., Rivarolo D. 1997)),rail station re-engineering (Bouvier E., Cohen E. 1995) and epidemic diffusion. In additions, there has been a significant advancement in studying pedestrian traffic patterns in various environments. In (Bierlaire, M., Antonini, G. and Weber,M. 2003), a system based on multiple agents (MAS) was used. The desire of the author was to create a highly flexible system composed of actors that can be modeled individually. In (Helbing, D., and Molnar, Peter, 1998) pedestrian flow is discussed with some features observered. In (Still, K, 2000), the author presents several phenomena about crowd behavior, the most significant being:

- Edge effects
- Finger Effects
- Density Effects
- Shockwave Effects

In (I. Farkas, D. Helbing, T. Vicsek, 2002) the authors developed a model to investigate the Mexican Wave phenomena in a stadium.

To achieve some of the modeling desired by (Bierlaire, M., Antonini, G. and Weber,M. 2003) and the flexibility and simplicity by desired by In (Still, K, 2000), we combined CA and MAS into one system.

To facilitate the pedestrian motion rules for the CA, we combine the following from the discipline of physics:

- Fluid dynamics: This represents a continuous modeling of the crowd by using specific crowd characteristics (i.e. density, speed, etc.) distributed on a grid corresponding to environment in which the crowd is actively moving.

- Particle dynamics: In this approach, each entity in the crowd is represented as a single particle interacting with the other particles by some predetermined attraction/reaction and collisions (Langton C. , 1997) rules.

- Particle queuing: This approach operates in similar way to particle dynamics but doesn't consider attraction/reaction rules and instead stacks the people on queues taking care not to overlap the entities.

We model the individuals as a collection of agents. We also model the agents so that they interact among themselves to maintain consistent groups (i.e. a family or a specified group of people) when applicable. We capture Pedestrian decision making for the agent based on individuality or group membership. These attributes lead to certain decision making on the part of the agent. Decisions are based on Internal Forces (This is related to goal of each entity) and External Forces (This force is related to other entities, layout objects or external force fields and is composed of three parts: (I) collision avoidance, (II) group attraction and (III) external forces).

A relational schema of the above forces is depicted below. For the spatial aspect, consider the need to avoid obstacles (either walls or other individuals) and the need for maintaining the group structure where appropriate.

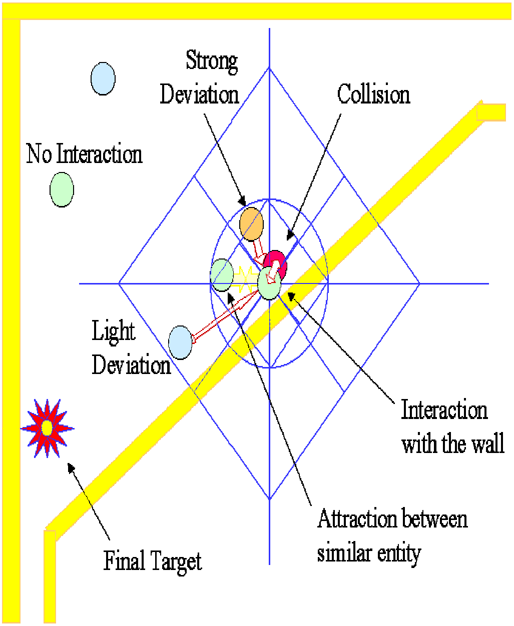

Figure 1: Spatial Relationship of Forces

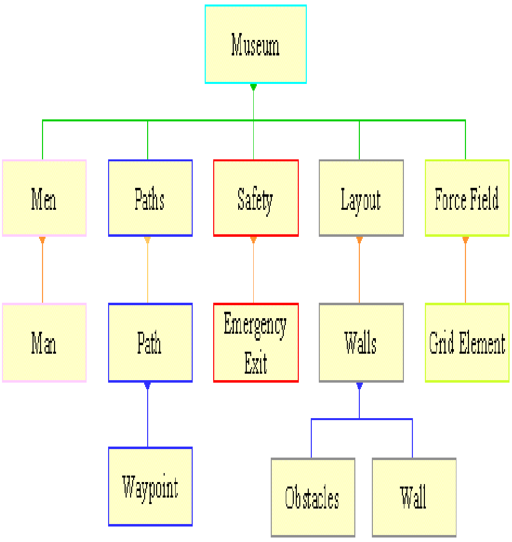

Figure 2. General architecture for objects in the model.

The general architecture of the entities is proposed in Figure 2 above. The figure demonstrates the hierarchical nature of our design. For example, we have an object that is the group of men subject to some specific methods (init, drawing, and alarm for a group of men, changing the behavior of the men instead of the walls or of the attractions).

In Figure 3 below, we see the layout in the application. As you can see, the goal of the individuals, or groups, is to visit the objects in the exhibition. The individuals travel along the two floors (one lower and one upper). There are also emergency exits. We focused, in this paper, primarily on the movement of the individuals/groups among the objects in the exhibit only, and not on the emergency exits. Monitoring agent behavior during emergency exiting will be will be added to our next version of the system. After viewing the exhibit, the individuals/groups leave.

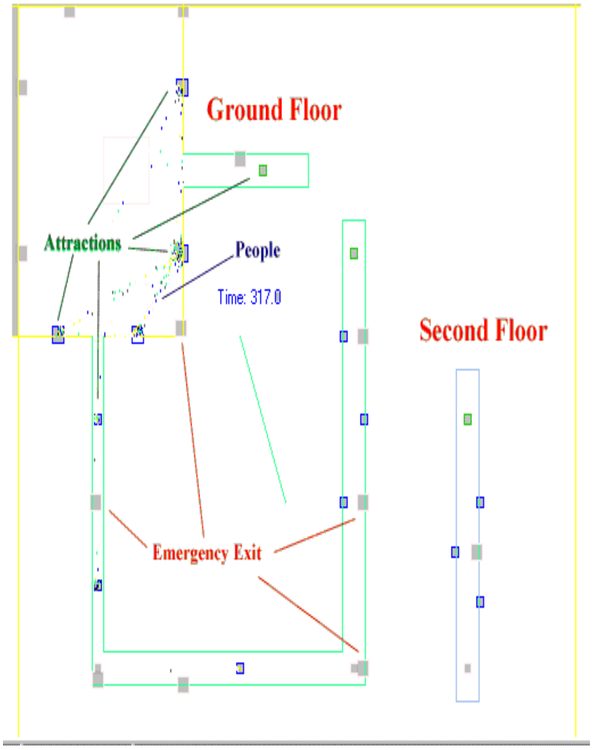

Figure 3: Layout of the environment for the CA and MAS crowd control system.

SIMULATIONS AND RESULTS

Complex Systems is a field of science studying how parts of a system give rise to the collective behaviors of the system, and how the system interacts with its environment. The field of complex systems cuts across all traditional disciplines of science. It focuses on certain questions about parts, wholes and relationships. The study of complex systems is about understanding indirect effects and observing emergent behavior from these systems. Pushing on a complex system "here" often has effects "over there" because the parts are interdependent. (New England Complex Systems Institute website)

Based on some prior work (Bruzzone, A. and Signorile 1999) with the addition of CA and MAS, we ran simulations to observe the behavior of the agents in a museum. Our agents are modeled (randomly) as individuals, family groups (small group of individuals) and tourist groups (larger groups of individuals). The individual agents have the simple goal of moving through the exhibition, viewing the objects on display and leaving the exhibition. The other two types of agents have the added goal of maintaining “neighborhood” contact with their group.

We have situations where individuals/groups of agents linger over some specific popular exhibit, where agents move from one room to another then back again, and where there are areas for agents to rest/contemplate exhibits. Some emergent behavior from our simulations where:

- Reverse Edge effects are observed (especially on the edge closest to the exhibit). Thus, this suggests that ample viewing space along the sides is more important than tunnels for the center of the crowd. This is even more prevalent when the percentage of the agents is groups.

- Finger effects (bi-directional crowds moving amongst themselves) are less evident in this environment. However, when individuals are present, and bottlenecks occur, we observed the “wandering” effect for the individuals to be very prevalent.

- Back pressure (especially when the density of groups is large) is observed. As groups approach an obvious stopping point (descriptions on the wall or a particularly popular object), the back pressure increases precipitously. When we moved such stopping points, to either larger viewing areas or areas with more egresses, the back pressure dropped. In addition, the local Density effect was reduced

- Placement of resting areas can adversely affect density in the crowd. If placed too near a popular stopping point, a clustering effect takes control of the crowd, causing sever back pressure.

CONCLUSIONS AND FUTURE WORK

The study demonstrates the effectiveness of modeling public facilities using both Cellular automata (more basic/complex moving rules) and agents (for behavior attributes) to improve services in a museum setting. Clearly this framework is extendable to modeling many events, such as sporting events, shopping malls, rail stations, airports, etc.

Additionally, we feel that this approach is applicable to other complex systems such as network reliability, supply chain management, and management logistics. Mostly due to the nature of this theory: massive similar entities, internal and external forces to motivate these entities, non-linear interactions between entities and emergent behavior from the system.

We plan to investigate using this theory in the above and other domains.

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BIOGRAPHY

Robert Signorile is an Associate Professor in the Computer Science Department of Boston College. His research interests include multimodal simulation, simulation in business, networks and distributed computing. He has published regularly in applied simulation, simulation methodology, distributed systems and networks.