GEORGIA INSTITUTE OF TECHNOLOGY

CSE 6730 Project #1: Cellular Automata (CA) Simulation of Pedestrian Traffic Leaving Stadium

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1. INTRODUCTION

In this project a model and simulation is developed to study the egress of pedestrians from the area around Georgia Tech's Bobby Dodd Stadium after an event. More specifically, the project will model the egress from one exit of the stadium and simulate dispersion of people from that exit. The simulation models pedestrians only (does not include vehicles) and is based on the concept of Cellular Automata (CA). The report is structured as follows: section 1 gives background on CA and what is found in the literature for CA models of pedestrians, section 2 will detail the development of a conceptual model for this project, section 3 and 4 describe simulation software development, and finally section 5 will present simulation results.

1.1. CELLULAR AUTOMATA (CA)

Cellular Automata (CA) are set of machines which are capable of changing state based on inputs (automata) arranged in a grid (each to a cell)[1]. The states of the cells are updated in discrete time steps using a state transition function that defines the rules of interaction between a cell and its neighbors. This method can be used to model large complex systems and effectively model group relationships [1].

A basic time stepping CA simulation is described in [1]. The framework of the time stepping simulation is shown in Algorithm 1 below. First the system states are initialized and then observed (e.g., visual graph of pedestrians on a map); then the system states are updated for one discrete time step and again visualized. The update processes is then stepped for discrete time steps. this time stepping model is implemented in the simulation described in this report.

Algorithm 1: Basic CA time stepping code from [1]

```
initialize();
observe();
foreach step in TimeSteps do
    update();
    observe();
end
```

Due to the fact that time, space, and model states are all discrete, only a finite number of possible states and transitions exist. However, an exhaustive search to evaluate all possible states requires exponential running time, which is impractical in most cases. Nevertheless, the discrete nature of the simulations allow CA to model complex and nonlinear systems such as pedestrian traffic flow.

1.2. Pedestrian CA Models in the Literature

The paper *Cellular automata microsimulation for modeling bidirectional pedestrian traffic flow* [2] presents a model for the general case of bidirectional pedestrian flow. This paper built off of its authors' previous work on unidirectional flow which would have been more applicable to this particular project (I was unable to obtain a copy of that report for review). However, the authors summarized much of the unidirectional model in order to describe their additions for bidirectional flow. The new rule set defines rules for avoiding collisions with other pedestrians moving in the the opposite direction. They also define rules that cause the pedestrians to create flow lanes (like humans do naturally). A time step of 1 second and a cell size of $0.21m^2$ ($0.457m$ sides) was used and the speed of pedestrians was varied. The speed of pedestrians was distributed as 5% fast (5 cells/sec), 90% normal (3 cells/sec), and 5% slow (2 cells/sec).

In *Simulation of Evacuation Characteristics Using a 2-Dimensional Cellular Automata Model for Pedestrian Dynamics* [3] the authors use CA to model high density pedestrian evacuations. Their model uses a 1/3 m x 1/3 m cell with one pedestrian allowed per cell. This is somewhat smaller than that in other literature since it is modeling higher density situations. A "floor field" is implemented in order to "attract" pedestrians to the exits. Additionally, a "friction coefficient" is utilized when pedestrians are compacted closely with other pedestrians in order to model the decrease of walking speed with the increase of pedestrian density. Further, an attractive force (desire for travel in the direction) and a repulsive force (to avoid collision with another pedestrian) are both calculated in order to determine a pedestrian's next movement. When multiple pedestrians want to move to the same cell, one is selected randomly and the others remain unchanged. This model is used to simulate several evacuation scenarios including a small stadium.

An in depth discussion of modeling pedestrian flow with CA is presented in *Simulation of pedestrian dynamics using a two-dimensional cellular automaton* [4]. In this model, pedestrians have a strong repulsive force at close distances in order to prevent multiple pedestrians from occupying the same cell. At larger distances there is an attractive force (lanes, groups, curiosity, etc.). Additionally, pedestrian speed is limited to one cell per time step in order to more easily prevent collisions. Cells are 40 cm x 40 cm which is the average space occupied by a pedestrian. The average pedestrian speed is 1.3 m/s, which at a rate of one cell move per time step (0.4 m) correlates to time steps of 0.3 sec (a reference is provided in the paper for the given empirical data). Each pedestrian is given a 3x3 movement matrix that calculates the probabilities of moving to the next cell given the pedestrian's preferred direction of travel. These will overlap with other pedestrians and the resulting conflicts are resolved using the probabilities. The pedestrian model presented is intentionally kept simple, the complex interactions are implemented through a "floor field". This field is analogous to an electric force field which effects the flow of electrons. This field governs pedestrian interactions from a distance by storing historical information (i.e., lanes are created based on previous traffic).

In *Simulation of competitive egress behavior: comparison with aircraft evacuation data* [5] the authors model evacuations using a very similar setup to that in [4]. They use a "floor field" model to determine pedestrian movement probability. The difference here is the floor field is not dynamic but rather static and used to draw the simple particles (pedestrians) to the evacuation exits. They use a binary factor in their movement calculations to ensure a probability of zero for movement to forbidden cells. They use a friction parameter to describe conflicts. This is very important in their model since evacuation involves tight cramming of pedestrians.

A simulation of pedestrians evacuating a room is presented in *Cellular automaton model for evacuation process with obstacles* [6]. Again a static floor field is used to draw the pedestrians to the exits. The movement decisions are determined based on the static floor field and interactions with other pedestrians. The situation modeled in this paper is not unlike modeling pedestrian egress from a stadium (basically a more complicated version of the same thing). The concepts in this paper helped me to understand the "floor field" concept and greatly influenced the development of the model presented in this report.

The authors of *Pedestrain cellular automata and industrial process simulation* [7] utilize pedestrian cellular automata simulation techniques to model the dynamical system of a manufacturing floor. Their model uses a combination of both static and dynamic floor fields. An interesting aspect of this model is that each individual pedestrian stores their own version of the dynamic field. This allows individuals to adapt to the simulation environment on the fly and change course (take a different route, go where help is most needed, etc.). Each pedestrian does not necessarily follow their predecessor like other "lane forming" CA models using dynamic floor fields.

2. CONCEPTUAL MODEL DEVELOPMENT

The conceptual model is a representation of the System Under Investigation (SUI) using some type of formalism. It is an abstraction of a real world system and it is essential to the successful development of a simulation program representing the SUI [8]. The role of the conceptual model is shown below in Figure 2.1.

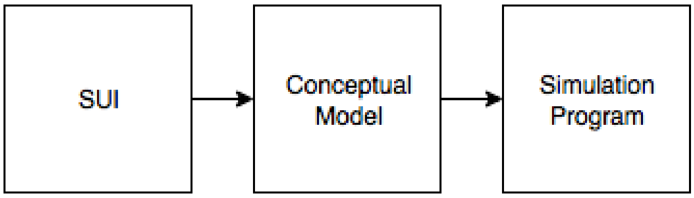


Figure 2.1: The role of the conceptual model

2.1. OBJECTIVE

For this project, the objective is to model the egress of pedestrians from a stadium (Georgia Tech's Bobby Dodd Stadium). The conceptual model must be generated to represent the SUI which is the pedestrian movements.

2.2. INPUT

Model inputs includes pedestrian and map information. The number of pedestrians and their characteristics: travel speed and destination. The simulation environment (walkways, destinations, etc.) must be input as map information. The map information should be input as a grid (for the CA implementation). It must contain definitions of walkways, destinations, stadium exits, and street crossings (crossings can be turned on and off).

2.3. OUTPUT

The model output is the simulated egress of the pedestrians (given in the input) through the modeled environment (map information given as an input).

2.4. CONTENT

The model does not include activities inside the stadium; however, the stadium exits do provided inputs to the simulation. Therefore, the stadium and activities within are regarded as exogenous entities for this model. The stadium (Bobby Dodd Stadium) can hold 55,000 spectators [9] which provides an upper limit on the number of spectators to include in the simulation.

The endogenous entities in this model are pedestrians and map objects (walkways, streets, etc.). A queuing model is for the pedestrian entities. They are then placed into the model as space opens up at exit locations (previous pedestrians walk away). Pedestrian entities contain properties for waking speed and selected destination. The walking speed distribution is obtained from research in [10] and is similar to that used in [4]. The walking speeds for each pedestrian are drawn form the normal distribution shown in Table 2.1.

Table 2.1: Pedestrian Walking Speed Distribution [10]

	ft/sec	m/sec
Mean	4.40	1.340
Std. Dev.	0.87	0.265

Map information is represented as a grid of cells that measure $0.21m^2$ ($0.457m$ sides) [2]. Each cell is given a type that represents information relevant to this simulation. More specifically, the cells are identified as walkways, crosswalks, streets, or prohibited.

2.5. Assumptions and Simplifications

Pedestrian entities are assumed to always travel toward their predetermined destination (they do not change destinations during the simulation) and to stay on the allowed paths. The pedestrian model does not include personal attributes, although some attributes may correlate with pedestrian walking speed, this is taken into account through the walking speed distribution. Additionally, directional travel is not modeled. Only movements directly to cells that share a side with the current cell are allowed (North, South, East, and West).

The map information is simplified to a 2-D grid (for use with CA). Terrain attributes (incline, material, etc.) are not included.

3. Simulation Development

Pedestrian movement is a dynamical system and for this project, pedestrian egress from a stadium, it will be modeled as a discrete time dynamical system using CA. The simulation grid is made up of cells that are either “allowed” or “prohibited” for pedestrian traffic. A “floor field” [6] is calculated for each destination and used to influence the movement decisions of the pedestrians. The pedestrians enter the simulation at the cells designated for the stadium exit(s). A simple time stepping loop (see Algorithm 1) is then used to move the pedestrians to their respective destinations. A high level representation of the simulation algorithm is presented below (Algorithm 2).

3.1. Pedestrian Objects

The simulation defines a pedestrian object with the following attributes:

1. Coordinates (location on the grid)

Algorithm 2: High Level Simulation Algorithm

```
Data: Map information, number of pedestrians
Define distribution of pedestrian speeds
Define distribution of pedestrian destinations
Create a queue of pedestrian objects
Create map object
Create separate static fields for each destination
for number of time steps do
    pop pedestrinas off queue and place at stadium exit
    update pedestrian positions
    visualize map
end
```

2. Destination ID

Currently the pedestrian objects do not incorporate a speed parameter. All pedestrians are assumed to have a speed of one cell per time step. This is to simplify the initial development of the simulation. Eventually each pedestrian will be given a speed that is drawn from some distribution.

3.2. Simulation Grid

A simulation grid is created to represent the desired map divided into cells. Each cell has an attribute that indicates its type. A cell can have any of the types listed below.

1. Prohibited
2. Walkway
3. Crossing
4. Entry point (also allowed walkway)
5. Exit point (also allowed walkway)

Using these attributes the simulation will be able to make decisions. If a cell is marked as prohibited, pedestrians will not be allowed to move to those locations. Walkways and crossings will be allowed. Crossing cells are identified separately so that the simulation can periodically open and close the crossing to simulate real life traffic scenarios. The simulation will insert and remove pedestrians at entry and exit point cells respectively.

A “floor field” [6] is calculated for each destination by assigning a value of 1 to the destination cells and then incrementing the value of neighboring cells for each step they are away from the destination. This “field” is used to “force” pedestrians through the grid to their desired destination. The calculation of this field is similar to a breadth-first search in graph theory and runs in $O(m+n)$ time (where n is the number of gird rows and m is the number of grid columns).

Each cell also has attributes for the pedestrian currently occupying the cell. This provides information to the movement calculations.

3.3. Pedestrian Movements (State Transitions)

Currently the pedestrian movements are very simple and are only influenced by the "floor field". Next steps will involve varying speeds and collision avoidance. I don't model two way traffic (since the simulation models egress only). Therefore the simulation does not include "lane formation" logic. No lanes are assumed and all pedestrians move in the same direction. I need to define the function that calculates the state of a cell based on neighbors.

4. Description of Simulation Software

4.1. Architecture

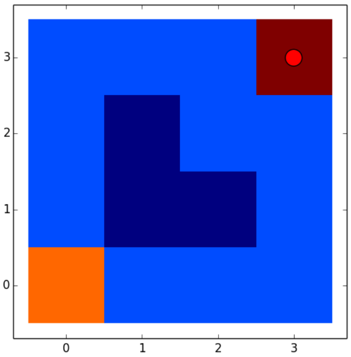
Python...

4.2. Interfaces

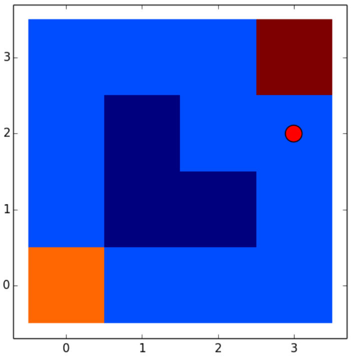
See map input data in the appendix

5. Simulation Results

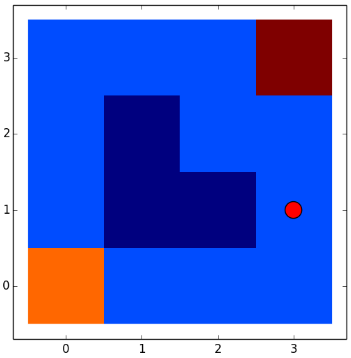
The figures below show the movement of a single pedestrian along the map toward his destination. Walkways are light blue and prohibited areas are dark blue. Need to show that the pedestrian walking speeds are normally distributed. Show statistics on total evacuation time...



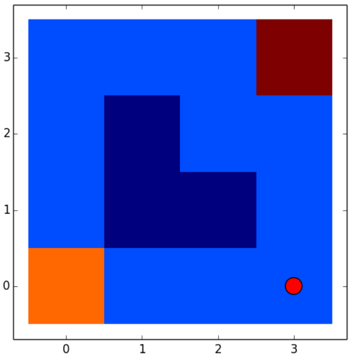
(a) Step 1



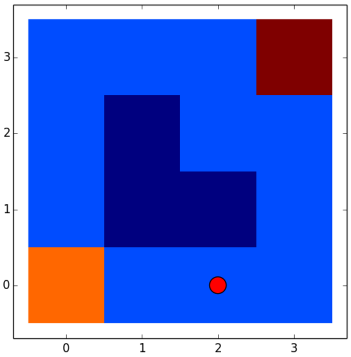
(b) Step 2



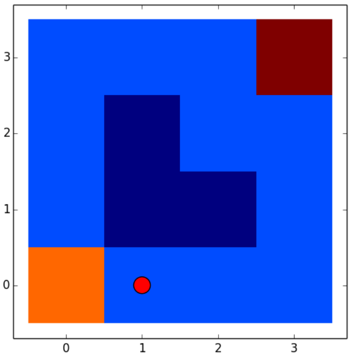
(c) Step 3



(d) Step 4



(e) Step 5



(f) Step 6

6. Summary

TODO

Appendix A Map File Format

A custom map file format was developed for getting map information into the simulation. The format defines a grid on the first row and then allows blocks of cells to be given a type attribute. The simulation assumes any cells not specified to be prohibited. An example map file and its corresponding map (from the simulation) are shown below.

```
# Test Map File
#
# Grid size (row,col) and size of cell area (arbitrary area unit)
100 100 1
# Define a block (start_row,start_col) to (stop_row,stop_col) of type t
# Cell types:
# 0       = Prohibited (default)
# 1       = Walkway
# 2       = Street
# 4       = Crossing (can also be defined by overlapping 1 and 2)
# 3 to 99 = Arbitrary (for specific use by simulator if needed)
# 1XX     = Destination (can be multiple destinations)
# 2XX     = Starting location (can be multiple starting points)
45 00 50 99 1
00 00 99 05 1
00 48 45 50 1
00 00 02 50 1
00 09 99 19 2
00 60 99 70 2
00 00 00 05 100
00 00 05 00 100
99 00 99 05 101
45 98 50 99 200
```

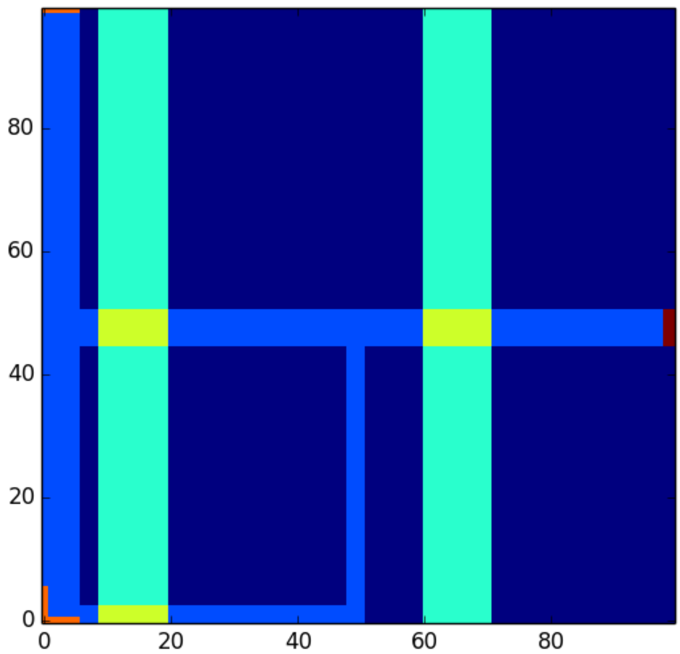


Figure A.1: Example map read from data file

References

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