Crowd Simulation: Queue-up Behavior

MS Project Report

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Understanding complicated crowd behaviors is essential to urban designers and architects. However, grouping a large amount of people to do experiment is dangerous and unrealistic. In order to do experiments, researchers are requires to design and create an application which could correctly represent crowd behavior. This project report describes an implementation called *Queue-up Crowd Simulation* that aim at creating realistic, unique and dynamic crowds by taking agents' data as input and outputting the results in animation form.

1 Introduction

The increasing proportion of people living in urban areas brings new challenges to urban planning and architecture. Crowd simulation plays an important role in addressing these challenges. With the help of crowd simulation techniques, urban designers and architects could determine the evacuation time of a massive crowd, predict the behavior of a crowd flow inside of a building or prevent overcrowding during certain events. In order to create realistic and trustworthy crowd simulation results, I will design a sophisticated crowd simulation algorithm that allows agents to achieve complex features. The features I will implement will be obtained from data collections and direct observations from video records in real-life events.

A crowd forms when a large amount of people gathers in a limited space. Simulating the whole people as a single unit might help understand the flow movement of the moving crowd. However, each person in a crowd is independent. In order to achieve this feature, we will divide the crowd into groups that contains 2 people or individuals so the behavior of the crowd can be more realistic. In a group, people that know each other might walk together. Previous researcher Reynolds [1] proposed a steering approach known as Leader Following (LF). This approach also involves pair agents where the "follower" agent follows the leader and stays to its side. The disadvantage of this approach is that the leader agent does not wait for its follower agent if the distance between these two agents is too large, which is not realistic.

More recent simulations of crowds of people use more complicated calculations. For example, previous approach [2] designs agent as ellipses that have a sense of the environment and plan their own path ahead of time to avoid agent collisions. Unfortunately, the output of this kind of simulation lacks realism and flexibility. Since it does not involve complex behaviors such as allowing agents to move in and out of different group or queues based on agent's desire, agents who have planned a path ahead of time might end up a situation such as an unnatural long waiting line in the scene where several shorter lines exist. However, in reality, people do not just stay in waiting line once they choose it; they might need to change lines if there is a better option.

2 Related Work

Many simulations have achieved complicated behaviors. Julio Godoy [6] provided a dynamic agent base approach that allowed agents in a scene to have distinct goals and plan their own movements and collision avoidance ability. Interactions among each agent are "polite" and natural after agents learned optimal strategy in the given simulated environment. Carmine [3] extended state-of-art predictive approaches with social awareness, prediction and social collision avoidance to achieve the prediction in social path following behavior. Social awareness is signaling agents that are approaching each other, then agents adjust their behavior and direction for future social interaction to improve the realism. In the simulation, simply allowing the agents to have interaction, repulsive forces and given priority are not

enough. In order to simulate social interactions among agents in the crowd, Walk Along Steering [4] developed the Walk Along Steering algorithm that allows agents in small groups to have six social steering behaviors that makes agents' movement and reaction smoothly and naturally. Based on a three-layer architecture controlling motion of IVAs designed by Reynolds [1], agents could achieve patterns like following, avoidance, waiting and approaching. To allow the crowd to have more dynamic social behaviors, Sai-Keung's [5] approach presents a crowd simulation that involves behaviors agents that are more interactive. In the simulation, two or more agents are required to perform actions simultaneously to finish certain tasks, agents are divided into two categories: workers and pedestrians. Tasks can be assigned to worker agents; workers will cooperate with each other and create complicated behaviors by decomposing a complex task into numbers of simple task.

3 Report Outline

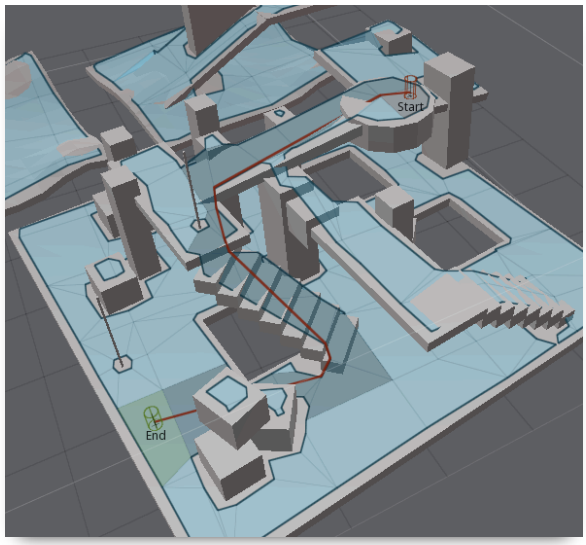
In this section, this report presents important components of this application which use the open source library Recast & Detour. Then we discuss observations and collections of real-life video records that are essential to understand the output produced by QueueBehaviorApp. Also, we present details about the scene initialization and agent initialization. Then we talk about the scenario that we want the crowd to reproduce and strategies we implement to achieve the goals. We present the strategy of simulation results evaluation. Finally, we conclude with future work discussion.

4 Resources

This application uses an open source library Java Port of Recast & Detour navigation mesh toolset [7].

Recast
Recast is a state-of-the-art navigation mesh construction toolset for games. Recast is an open source library that could automatically provide you a mesh at any level geometry quickly; Recast could also be customized to achieve user's specific purpose.

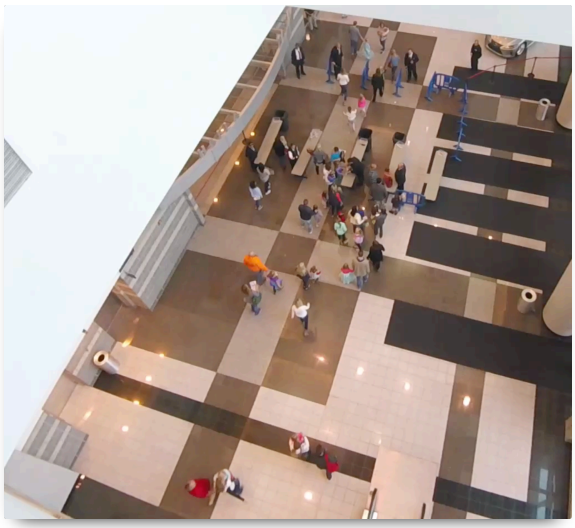
Detour
Detour is a spatial reasoning toolkit which accompanies with Recast to offer a simple static navigation mesh. DetourCrowd is a crowd management module offers features for agents handling and behavior customization. Detour allows a user to create lots of agents and move agents in a navigation mesh. Detour also allows user to create customized behaviors that determines agent's how to move and react at a low level.

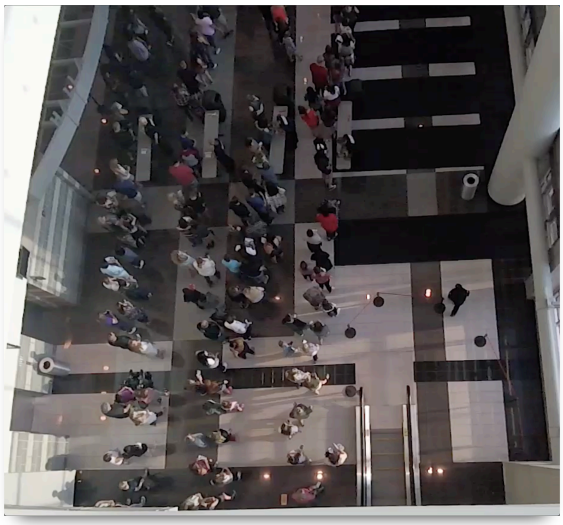


5 Observations from Video Records:

Previously, in order to understand how a crowd moved, we recorded crowd videos at CenturyLink on different entrances during events such as concerts and a Disney on Ice Event to study and analyze how people gather, walk, form waiting lines and passing security processes. We collected and gather common behavior features that crowds might have and implemented those features into every aspect of our application:

- Pair walking, pair line up.
- Queue up behavior.
- Form waiting lines.
- People switch from a long line to shorter one.





5.1 Pair Walking

Normally, people attend events with their friends or family, thus people in the crowd are divided into numbers of small groups. Because people know each other and have conversations while they are walking, people in a small group are more likely to stay side by side. If one of the people in the group is left behind, people in front will stop somewhere and wait until his/her partner catches up, or if people realize themselves are left behind their partner, they will speed up to catch up is partner. Based on the videos, this behavior happens a lot. For example, people who finished the security check will stand at somewhere in front and wait for his/her partner.

5.2 Queue up Behavior

When a waiting line is formed, people simply queue up and slowly move forward in the line. Because people might walk with their friends, they might form waiting line that each row could have one or two people. Based on videos, waiting lines could have different length, and we found out people in the long waiting line will change to the shorter line or people will directly change direction and walk to the new gate if they find out there has a new empty gate. However, for some people, they might be less interested in moving to the shorter line and just stay at their original line.

5.3 Security Checking Behavior

For people who reach the security gates, they have two security processes to finish before entering the building. For the first process, security faculties will check the ticket and bag (if someone carries bag to the event). For people just bringing the ticket, people show the ticket to the checker, then they could quickly pass through the first gate. For people who carry bags, security faculty need to take a few seconds to check people's bag. Thus, people who carry bag will stay more time on the first gate. For the second process, security faculty will use handheld body scanner to scan people one by one. Because everyone

takes almost the same process, the time difference among people need to finish the second process is more consistent than the first process.

Based on the video, the scene contains two lines of security gates. If the number of people pass the first gate line is large enough, the room between lines is easy to get full. When the room is full, even people finish the first checking process, they will still need to wait until there have space to let them move forward.

6 Foundation architecture and Scenario

In this project, I will develop a crowd simulation application which aims at creating realistic, dynamic and accurate crowd. To achieve this goal, I will use an open source state of art navigation mesh construction toolset called Recastnavigation to achieve static avoidance and shortest path calculation. I will also utilize a path-finding and spatial reasoning toolkit Detour to achieve dynamic avoidance among agents in the path and to completed calculation of each frame of the simulation [3]. Using these open source platforms, I will build the lower level of my approach – QueueBehaviorApp.

Scenario: Single agents or pair agents are randomly generated from the virtual entrance; each agent is initialized with a default start position and end position, and they will walk from start to end position. However, before agents reaching their destination, every agent has to finish two security checks first. (People did ticket checking and security check during the concert event). Thus, every agent needs to stop near the security gate to simulate the security process. Since the new agents are generating and security process takes time, the number of agents in the scene increase dramatically and a crowd form. However, instead of generating a massive chaotic crowd, agents in the crowd will orderly queue up and form several waiting lines, and each agent in line will do the security check one by one. After finishing the security check, agents will move to their default end position and depart.

7 Environment Implementation and Setup

7.1 Input Data Initialization

Input file allows us to determine the basic scene information such as agent id, agent start time, start position, end position and behavior mode. Instead of directly applying data from the real-life video, we need to manually generate agent data based on features we observed from the video. For example, we will define agents in pair relationship by letting agents have the same enter time, start position and end position.

In order to achieve more crowd features, we will design input data base on the following patterns:

Agent id, enter time, start position, end position, behaved mode

- Each agent has its unique id number.
- Agent's enter time determines when agent will walk into the scene.
- Start position determines where agent will appear. End position determines where agent will exit, it also determines agent's walking direction.
- Enter time, start position and end position determine agent's relationship.
- Agent's behavior mode demonstrates agent's behavior
    - Queue - means agent will queue up to form line.
    - Flee - means agent will choose the shortest path to walk out of the scene.
    - None - means agent will simply walk from start position to end position.

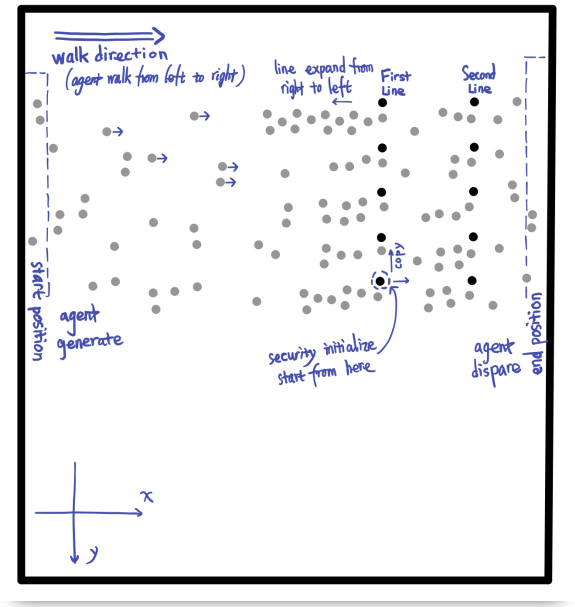
Below is the data input sample:

30,3656,-60.255486,0.31802097,-5.320471,44.077248,0.318020731,1.1289825,queue
31,3661,-59.755486,0.31802097,-4.820471,44.577248,0.318020731,1.6289825,queue
32,4734,-61.710487,0.31802097,11.044155,44.371113,0.318020731,6.9663258,queue

Blue is agent id; each agent has its unique id; green is agent's enter time; *3656* means agent enters the scene at 3656 million second; orange is the start position (x coordinate, z coordinate, y coordinate); red is the end position (x coordinate, z coordinate, y coordinate); purple is agent's behavior mode.

In the simulation, agents who stand next to their corresponding gate are representing security faculty in the real-life video. Since our video are mostly recorded on a hall that only allows crowd walking from one place to another place, we decide to define agents' start position and end position within this limited range to simulate the hall environment. What's more, agent's walking direction determines the expand direction of waiting line. For example, agent walking from left to right, when it reaches the tail of waiting line, it lines up at the tail, then the waiting line grow from right to left.

Here is a demo to help us better understand how to determine range of start position, end position and security gate lines.



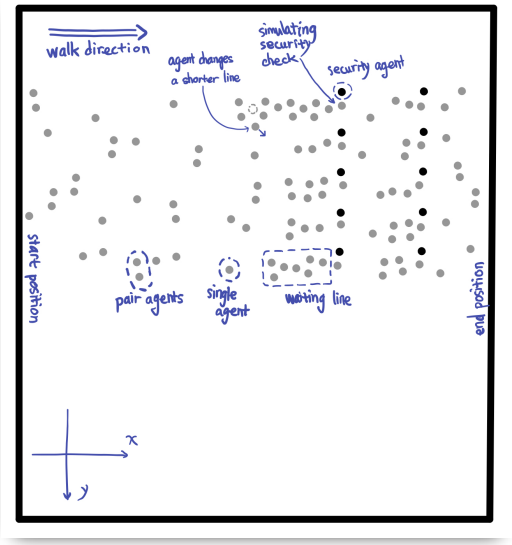
Each circle represents an agent, agents in black are security faculty, agents in grey are normal agents. Faculty agent are specifically initialized, and they will stay at the same position during the simulation. Agents walk in from the rectangle on the left called start position and walk out of scene on rectangle on the right called end position. Without security gates, all normal agents simply walk from start position to the end position. However, in this case, agents will do security check and queue up.

7.2 Environment Initialization

Before achieving the complicated crowd behavior features such as pair walking, queuing up and form single/pair waiting lines, we need to initialize environment initialization so that agents could perform security check. Before reaching the end position, every agent is required to pass two positions to simulate security checks. Based on the real-life video samples we recorded during events, people have two checking process to finish before they enter the event, one is the ticket and

bag checking, another one is body detector scanning. Having the input data is not enough, to make agent move naturally, we need more factors both in environment and agent itself.

At the beginning of the simulation, we will first initialize environment based on the input data that we mentioned above. The image on the below is the mockup demo to demonstrate simulation result.



The code below are always runs at the beginning of the simulation.

```
initGates();
initAgentCheckTime();
initAgentGateOption();
initFriendRelationship();
initAgentsAnxiety();
```

Methods above cover all the initializations required in the simulation. Descriptions below will talk more about details of the initialization:

- ***initGates*** – In this scene, we will create 10 checking gates and divided these gates into two lines to represent two checking processes. Then we initialize 10 faculty agents represent security faculties standing next to the gates. All security faculties will stand next to its own checking spot during the simulation.

- ***initAgentCheckTime*** – As we mentioned above, each people have two processes to finish before entering the building, one is ticket and bag checking, another one is body checking. For people who might carry bag, their checking time at first gate is longer than people who just bring the ticket. Thus, in the simulation, each agent is randomly assigned two values that represent times they need to stop to finish the ticket and bag check and body scanner check. For the value that represents ticket/bag checking time, because the people carry bag are randomly appear and the number of them is relatively smaller than the number of people who don't, the initialization of agents' first gate checking time will follow the corresponding pattern. However, for the value that represents the second gate checking time. Since everyone has the same checking process, the values among each agent will be more consistent.

- ***initAgentGateOption*** – In this simulation, agents will be randomly generated on the one side of the scene. Then, based on each agent's current position, they will choose the closest gate

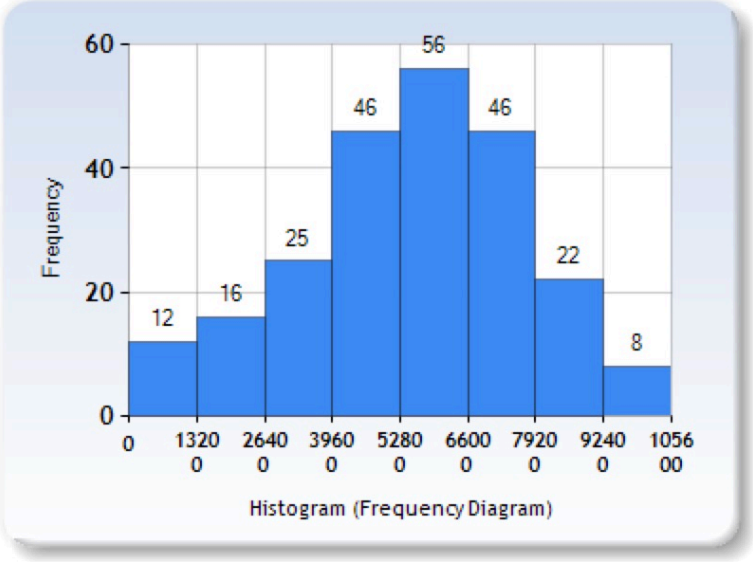
to go and move forward.

- ***initFrienddRelationship*** – Every agent is whether in individual status or pair status. Based on the input data, we will pair up two agents that have the close enter time, start position and end position. Each agent in pair relationship plays different role, one is leader, another one is follower. For individual agent, they are neither leader nor follower.

- ***initAgentsAnxiety*** – In real life, people at tail of a waiting line might not be satisfied with the length of their own line and then they will seek opportunity to switch to the other shorter line. To achieve this behavior feature, we allow each agent to have anxiety. The agent's anxiety degree updates based on the its current position in waiting line. Agents are more likely to change waiting line when they have higher degree of anxiety.

7.3 Appearance Feature of Upcoming Agents

In the simulation, in order to create a realistic crowd, we intensively control the flow of crowd and let it follows certain pattern. At the beginning of the simulation, the number of agents is relatively small, but when the simulation continues, the number of agents appear in the scene will start to increase and then reaches the maximum. After that, the number of upcoming agents will slowly decrease.



Charts above roughly illustrate the number of new agents appear every 1320 million seconds. The bar table shows the change of number of new coming agents during the simulation. During time range from 5280 to 6600 million seconds, the number of new coming agents reaches the maximum.

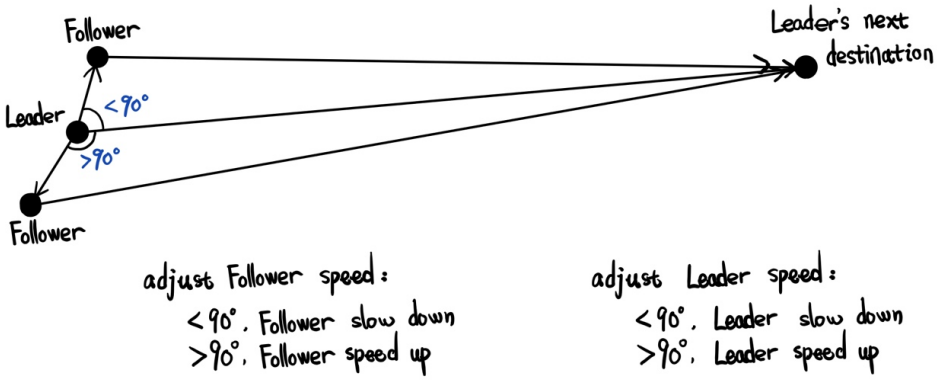
8 Agent Behavior Implementation

8.1 Pair Walk Behavior

In the real-life video, people in group are talking to each other while they are walking. To maintain this status, they need to stay side by side and sometimes they need to slightly adjust their speed to stay in pair. In order to achieve the natural pair walking pattern, we let agents in pairs to be followers or leaders. Leaders will be the one leading them to their shared destination; followers will always adjust its speed to catch up its leader. However, we not only change the speed of the follower, we also allow the leader to adjust its speed to wait or catch its follower. For example, in

the simulation, if the leader finished security the check first, instead of directly moving to the next destination, the leader will stop somewhere in front and wait until its follower finish the check.

How to Achieve Pair Walking?
In order to adjust follower's moving speed, we need to keep track of angle of two vectors: one is from leader's current position to leader's current destination. Another one is from leader's current position to its follower's current position. By utilizing the law of cosines and these two vectors, we could get angle between those vectors.



Bases on the value of angle, we allow agent's speed to have three states:

1. When the degree is 90: the follower is exactly left or right side of the its leader. The follower agent doesn't need to change it's moving speed.
2. When the degree is less than 90, it means the follower is in front of its leader, the follower starts to slow down.
3. When the degree is larger than 90, it means the follower is left behind by its leader, the follower starts to speed up.

However, knowing the angle between two vectors is not enough to create the natural speed adjustment. Because agents have to queue up or pass through the security checking process, the current destination of the leader's agent might change. The modification of the current destination might affect the value of angle we mentioned above. Thus, in order to maintain the correct current destination, we will allow the leader agent update and set the next destination after agent has reach the current destination.

8.2 Queue up Behavior

In order to enter the event, people need to do security check, they will stop at the security gate for a few seconds. However, the upcoming people continue moving to security gates, and people who wait behind will form waiting lines. To simulate this queue up behavior, we allow each agent to have the following states:

- isWalking – agent is walking.
- isWaiting – agent lined up.
- isChecked – agent finished security check.

These 3 states help determine behavior of the agents. When agent is in *isWalking* state, agent is either walking to the gate/line or walking to the end position. Once agent lines up or a specific agent who could directly reach the empty gate, that agent is immediately set to *isWaiting* state. If the agent is the leader, then the state of its follower is automatically set to *isWaiting*. For an agent who

is in *isWaiting* state, they are either in the waiting line and stand behind certain agent or doing security check. In order to maintain all agents in waiting line, we will design a queue maintained function to handle each agent in the queue.

Inside the queue maintenance function, in order to let agents stay in the queue, we will let each agent in the waiting line temporally set the back position of agent in front as its current destination. For each agent who is at the head of the waiting line, it will start count the internal checking time. Once the value of checking time is 0, this agent finishes the security checking and continue moving forward to the next destination. Since each agent's value of time checking is different, we will see different agent take different time to finish security check. Then agent behind it will replace the head position and start its checking process.

When an agent is finished checking, its state will change *isChecked*. For agents finished check, they are either walking to the next checking gate or their final destinations. For agents walking to the second checking gate, they will repeat the same process they do in the first checking gate. One difference is that the value of time agent needs to do the second checking process among each agent will be evener. Thus, we will see the time different agents spend in second line of gates are more consistent.

Because agents in pair relationship will walk in pairs, they still stay side by side even after queuing up. Thus, inside the waiting line, conditions between agents could have the following statuses:

- **. .** – individual agent queues up behind another individual agent.
- **. :** – individual agent queues up behind pair agents.
- **: .** – pair agents queue up behind individual agent.
- **: :** – pair agents queue up behind another pair agents.

As we mentioned above, follower agent is set to stay next to its leader agent. Thus, in the waiting line, unlike the other agents that their current destination is set as back position of agent in front, the follower agents' current destination will be set as left/right side of its leader. Then when individual agent queues up behind pair agents, it will set its current destination to middle back position of the pair agents.

However, space between gate lines is limited. Each agent takes different time to finish the first security check. In the simulation, there are more agents who do not carry bag, it could lead to certain situation: because the majority of agents don't take too much time on the first checking gate; the checking time of the second checking gates is longer; the space between first gate line and second gate line will be quickly full. Once the room between gate lines is full, agents will wait until there has room to move forward.

8.3 Re-consider Behavior

Once agents enter the scene, each agent is assigned a value to represents its anxiety level. From real-life video we recorded, we found out some of people will switch to other waiting line if they have a better option. However, instead of switching to the other shorter line, they are more willing to stay in their own line. Thus, in order to simulate this interesting condition, we will let agents have anxiety. The anxiety degree determines agent's line switch decision.

Assigning anxiety level to agents are not enough to simulate the reconsidered behavior—we also have an anxiety monitor to adjust the anxiety degree based on the waiting lines conditions. Agents in higher anxiety are more likely to change line, agents in low anxiety are more willing to stay at its original line. In the simulation, each agent will have certain levels of anxiety degree.

Anxiety degree updates in certain internal conditions: (1) the agent queues up in waiting line. (2) the agent checks the length waiting line of left and right side of current line. (3) based on the difference between the current line and other line, anxiety degree is correspondingly updated. (4) if the agent is satisfied with its length of waiting line, the agent's anxiety degree will decrease or remain still. If the agent is not satisfied with the length of its waiting line, agent will increase the anxiety degree.

Once the agent's anxiety degree reaches the maximum value and have a shorter line on left or right side. Agent will leave its current waiting line and move to the new line. For an individual agent, it will move by itself. For pair agents, both agents will leave and move together. After queuing up in the new line, all agents' anxiety will set the lowest degree.

9 Evaluation

9.1 Input Data Evaluation

We will evaluate the input data generated by QueueBehaviorApp based on the requirement of the simulation. For agents in pair relationship, agents' information should share the something in common. However, based on the limitation of the pair relationship in the simulation, we only allow at most two agents in pair.

9.2 Behavior Evaluation

Here are features the crowd should have in the simulation animation result:

- Agents appearance follows certain pattern.
- Individual agent and pair agents.
- Agents in pair relationship do pair walking.
- Agents adjust their speed to stay side by side.
- Agents do security checks before walking to their final destinations.
- Agents queue up and form waiting line.
- Waiting lines have one or two agents in each row.
- Agents stop if no room between gate lines.
- Agents leave and move to a shorter waiting line.

10 Future Work

In terms of future work, the application could only allow two agents walk in pair. However, in reality, we could always see group contains more than 3 people could also maintain the side by side walking. In this project, we present an approach allows agents do the complex queue up behavior such as forming waiting line, switching between lines and passing through certain gates. However, the waiting line is a straight line. Further, we will look for a way to allow waiting line to adjust its shape bases on the specific obstacle such as fence.

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