Conceptual Model

The model is based upon the cellular automata model shown in the paper [1]. It's different in that it doesn't implement the panic mechanism where there is a percent chance that a person won't take an action.

Formal Specification

CD = <X, Y, I, S, θ, N, d, δint, δext, τ, λ, D>

X = Ø

Y = Ø

I = Ø

S = {float exitProximity, int type, int nextDestination, int directionIncoming, double sigma}

Empty: type=0

Person: type=1

Obstacle: type=2

nextDestination = {1, 2, 3,

4, 5,

6, 7, 8}

directionIncoming = {1, 2, 3,

4, 5,

6, 7, 8}

Sigma = output delay

N = {(-1,-1), (0, -1), (1, -1), (-1, 0), (1, 0), (-1, 1), (0,1), (1,1)}

d = 100 ms

τ = N -> S

The local computation rules in cadmium v2 are difficult to express as simple CD++ rules so I have included them as pseudo code.

Rule 1

```
If (s.type < 2) and (s.exitProximity == 0) then
    For (neighbor in neighbors) :
        If (neighbor is diagonal to cell) then
            Append neighbor.exitProximity + 1.5 to list
```

```
            Else if (neighbor is vertical or horizontal to cell) then
                Append neighbor.exitProximity + 1 to list
        s.exitProximity = minimum of list
endif
```

Rule 2

```
if (s.type == 1) and (s.nextDestination == 0) then
        for (neighbor in neighbors) :
            if (neighbor.type == 0) then
                if (neighbor.exitProximity != 0) then
                    Append neighbor.exitProximity and nextDestination direction to list
                Else then
                    Clear the list
                    Exit the loop
        Find smallest exitProximity in list
        If (smallest exitProximity < s.exitProximity) then
            Find neighbors that have the smallest exitProximity
            If more than 1 neighbor has smallest exitProximity then
                Randomly choose between them
            s.nextDestination = direction to chosen neighbor
            s.sigma = 1
        else
            s.nextDestination = 0
            s.sigma = 1
endif
```

Rule 3

```
If (s.type == 1) and (s.nextDestination != 0) then
        For (neighbor in neighbors) :
            If s.nextDestination points to neighbor's relative position then
                If (s.nextDestination + neighbor.directionIncoming == 9) then
```

```
                    s.type = 0
                    s.sigma = 1
                    s.nextDestination = 0
                else if (neighbor.directionIncoming == 0) then
                    s.type = 1
                    s.sigma = 1
                else if (s.nextDestination + neighbor.directionIncoming != 9) then
                    s.type = 1
                    s.sigma = 1
                    s.nextDestination = 0
endif
```

Rule 4

```
If (s.type == 0) and (s.directionIncoming == 0) then
    For (neighbor in neighbors) :
        If (neighbor.type == 1) and (neighbor.exitProximity > s.exitProximity) then
            If (neighbor.nextDestination != 0) then
                If (neighbor.nextDestination points to this empty cell) then
                    Append direction to neighbor to list
            Else if (neighbor.nextDestination == 0) then
                Clear list
                Exit the loop
    If more than 1 neighbor.nextDestination points to this empty cell then
        Randomly select a neighbor from the list
    s.directionIncoming = direction to chosen neighbor
    s.sigma = 0
endif
```

Rule 5

```
If (s.type == 0) and (s.directionIncoming != 0) then
    s.directionIncoming = 0
```

s.type = 1

s.sigma = 1

endif

Rule 6

If (s.exitProximity == 1) and (s.type == 1) then

s.type = 0

s.sigma = 1

endif

Testing

To test the model, I first ran it with a very simple scenario and verified the behaviour of the model. In this scenario it is a 5 by 5 grid with the border cells as obstacles to represent the walls of a room. Only the cell at (4, 2) is open and assigned to the be the door with an exit proximity of 1. Two people are placed in the room with one at cell (2, 2) and the other at cell (3, 2). At time 0 the exit proximity values of each cell are set as they increase the further they are from the exit.

500	500	500	500	500
500	4.5	4	4.5	500
500	3.5	3	3.5	500
500	2.5	2	2.5	500
500	500	1	500	500

Figure 1: Exit Proximity values of each cell for scenario 1

At time 0 the people select what direction they are going to travel in. This is represented by numbers from 1 to 8 as can be seen in figure 2.

1	2	3
4		5
6	7	8

Figure 2: Directions around a cell represented by integers

Figure 3 shows where the people are with a “P” and a number to indicate the direction they have chosen. The walls with exit proximity values of 500 are represented by black cells. The exit is represented by a green cell. It can be seen that the person in cell (2,2) has chosen to go to cell (3,3) as the person in cell (3,2) is blocking the most direct route to the exit. The person in cell (3,2) however is right next to the exit so they are heading down towards the exit at cell (4,2).

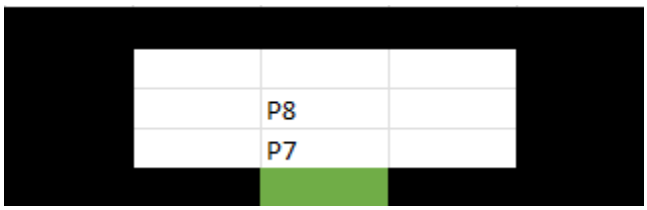


Figure 3: Positions of people at time 0 for scenario 1

Figure 4 shows the people's new positions at time 1.

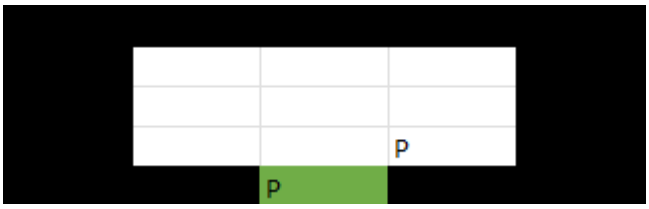


Figure 4: Positions of people at time 1 for scenario 1

At time 2 the person who is at the exit doesn't need to select a direction as they have made it out of the room, but the person at cell (3,3) does need to select a direction. As the person is still in the exit and blocking it, they select cell (3,2). The person at the exit simply leaves the room. This can all be seen in figure 5.

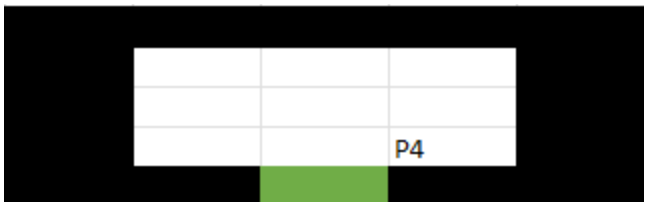


Figure 5: Positions of people at time 2 for scenario 1

In figure 6 you can see at time 3 the person moves to cell (3, 2)

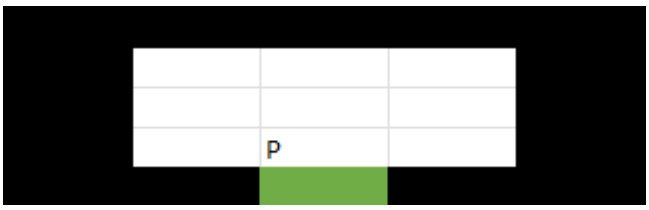


Figure 6: Positions of people at time 3 for scenario 1

In figure 7 you can see at time 4 the person chooses to move to the exit at cell (4,2).

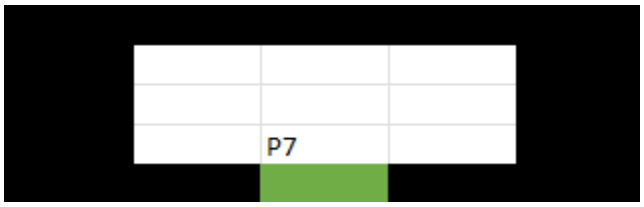


Figure 7: Positions of people at time 4 for scenario 1

In figure 8 you can see at time 5 the person moves to the exit.

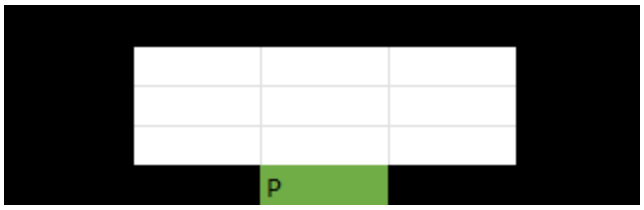


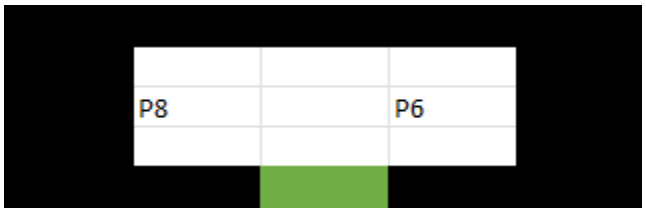
Figure 8: Positions of people at time 5 for scenario 1

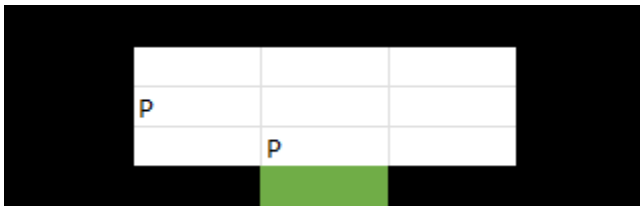
And lastly, in figure 9 the room is empty as the final person has left the room and simulation ends.

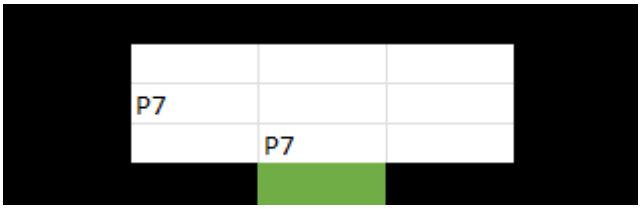
Figure 9: Positions of people at time 6 for scenario 1

From running this scenario a few times I can see how people correctly select the best cell to move to, and how they randomly choose between their destinations if they are an equal distance to the exit.

To view the behaviour of two people who wish to enter the same cell I have run a slightly different scenario where the only difference is that the 2 people are placed in cells (2,1) and (2,3). This ensures that they will both want to reach the same cell at (3,2) to get to the exit faster. For the sake of brevity, I will show the grids with just their associated time steps.







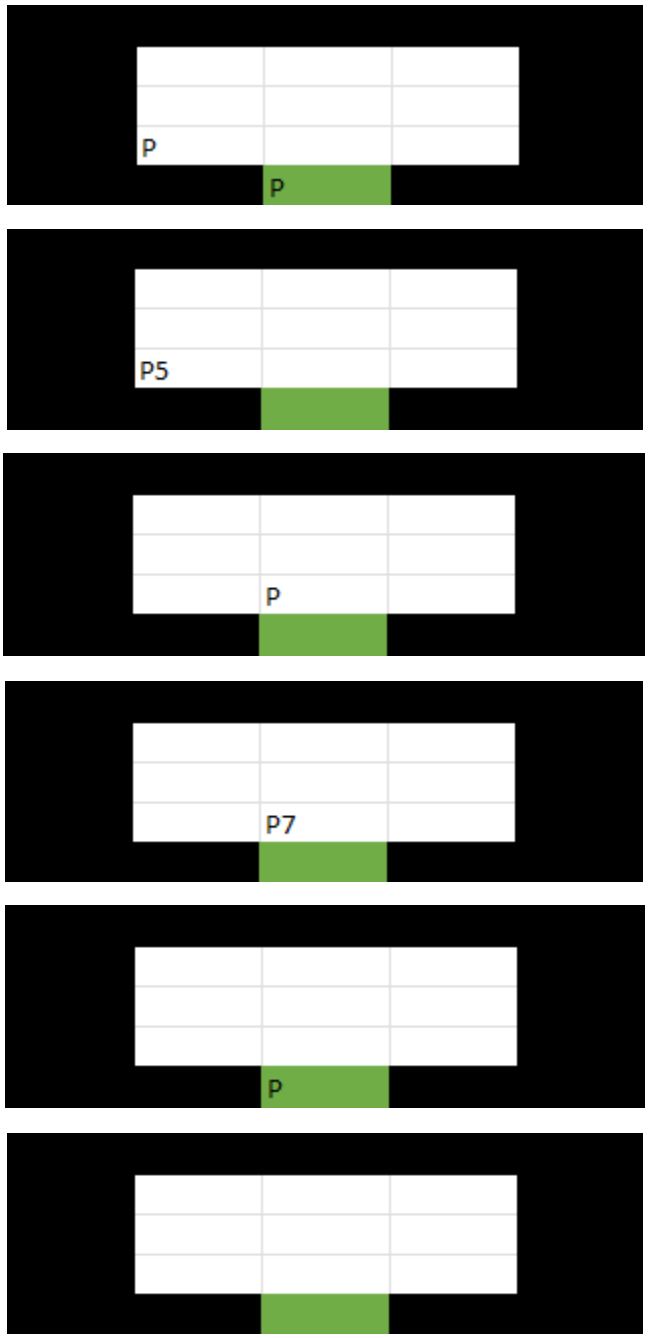
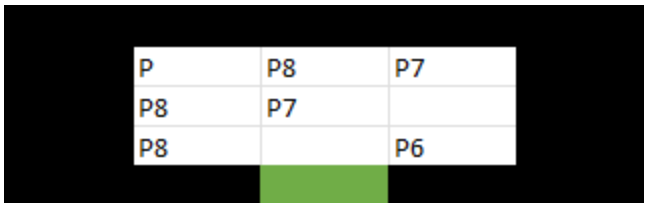


Figure 10: Positions of people from time step 0 to 8 for scenario 2

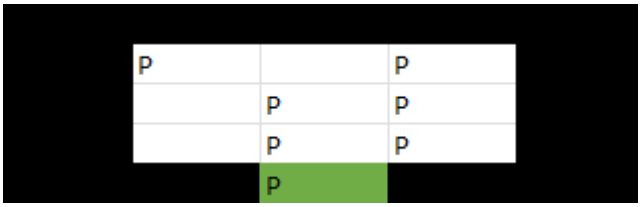
In figure 10 from the start the two people wanted to enter the same cell as it was closest to the exit. However, the person in cell (2,3) won the random selection and blocked the person in cell (2,1) from entering cell (3,2). This concludes testing as all the behaviours are functioning correctly.

Simulations

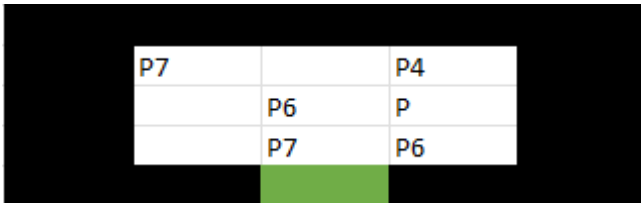
Now to run a more interesting simulation I will keep the 5 by 5 grid as it's easy to interpret and display, but I will add 7 people to the room in positions (3,1), (3,3), (2,2), (2,1), (1,1), (1,2), and (1,3). The results of the simulation at each time step starting from 0 can be seen in figure 11.



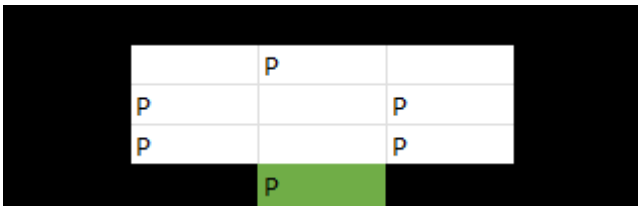
Time Step: 0



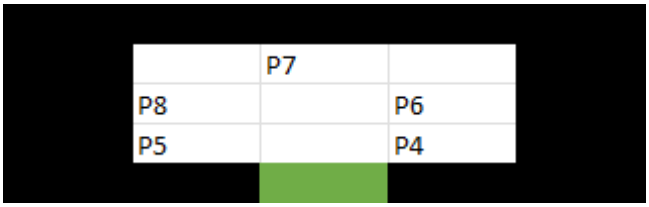
Time Step: 1



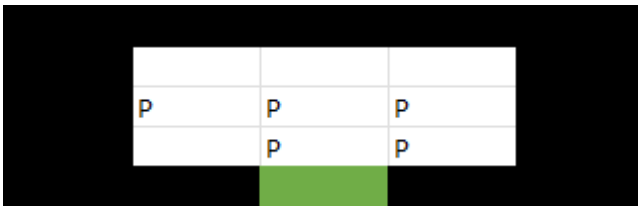
Time Step: 2



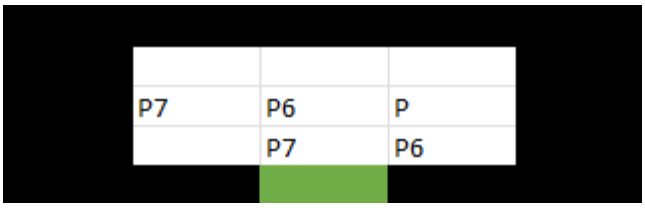
Time Step: 3



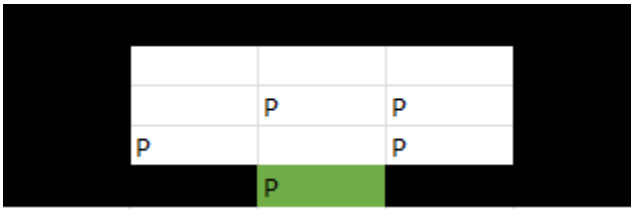
Time Step: 4



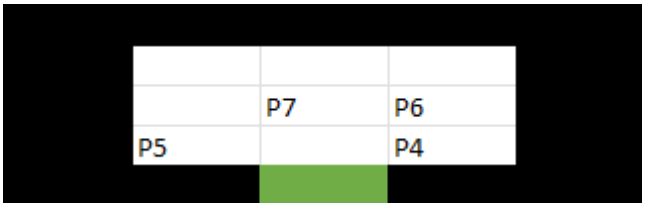
Time Step: 5



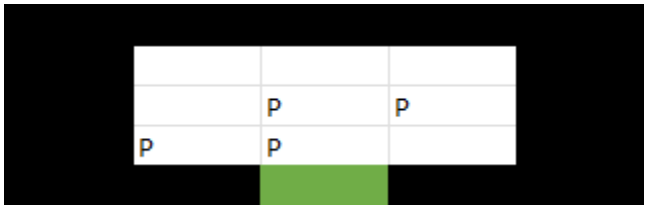
Time Step: 6



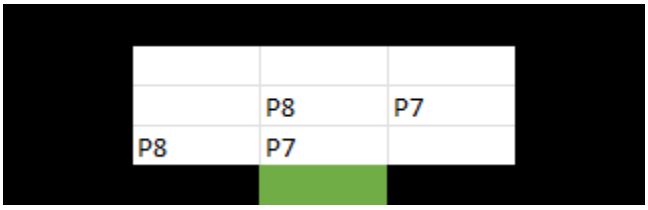
Time Step: 7



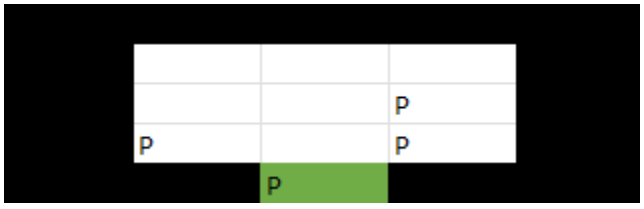
Time Step: 8



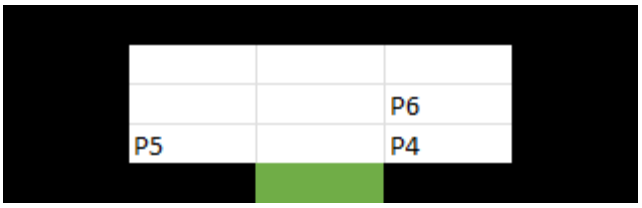
Time Step: 9



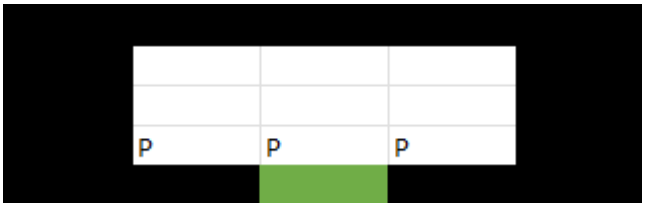
Time Step: 10



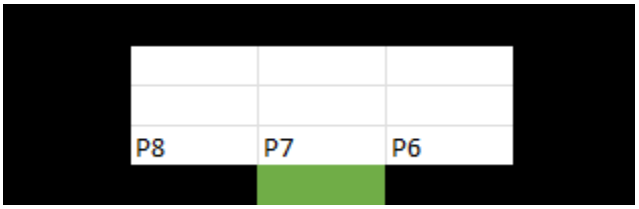
Time Step: 11



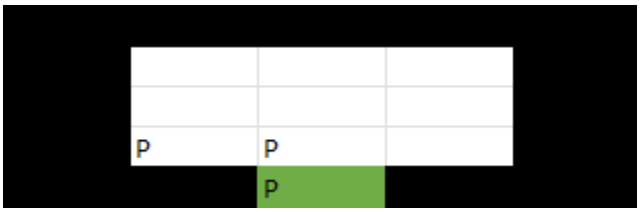
Time Step: 12



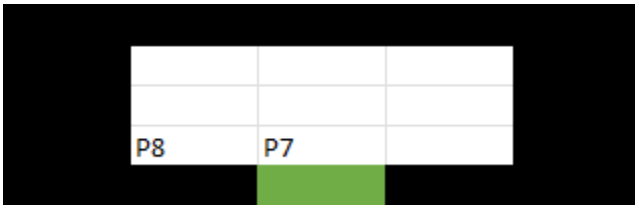
Time Step: 13



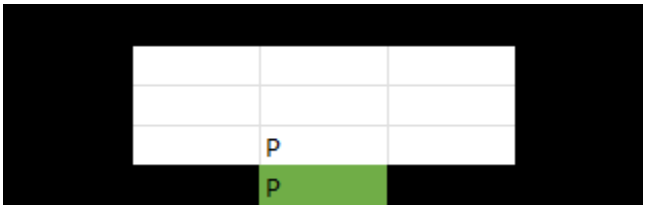
Time Step: 14



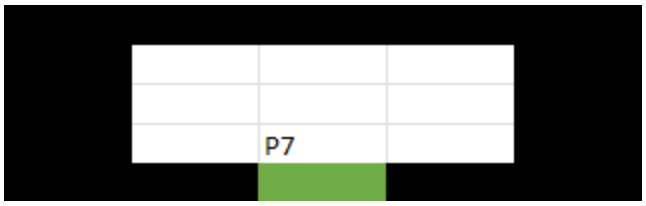
Time Step: 15



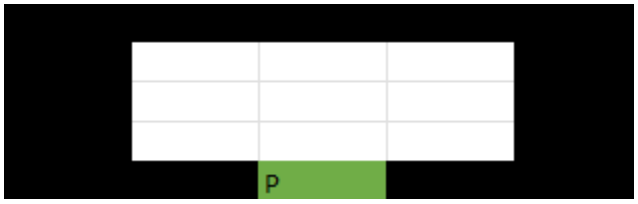
Time Step: 16



Time Step: 17



Time Step: 18



Time Step: 19

Time Step: 20

Figure 11: Positions of people at each time step for scenario 3

The larger number of people interacting in this scenario has shown some interesting behavior. In time steps 18, 16, 14, 10, 6, and 2 the people closest to the exit already recognize that no one is blocking them, so they attempt to enter the exit at cell (4,2). However, in time steps 12, 8, and 4 they don't seem to recognize this and try to enter the next closest cell at (3,2). This is likely because there isn't an order to what cell will fire it's local computation function next, so in the first case the exit cell fired first, but in the second case the exit cell fired last. In the future I would aim to fix this so that the behavior is consistent.

References

1. A. Varas, M.D. Cornejo, D. Mainemer, B. Toledo, J. Rogan, V. Muñoz, J.A. Valdivia, "*Cellular automaton model for evacuation process with obstacles,*" Physica A: Statistical Mechanics and its Applications, Volume 382, Issue 2, 2007, Pages 631-642, ISSN 0378-4371, https://doi.org/10.1016/j.physa.2007.04.006.