Agent Based Modeling of Crowd Behavior in an Evacuation Scenario

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Abstract

My research involved the utilization of Agent Based Modeling (ABM) tools to simulate a quasi-realistic evacuation scenario in a built space. The space took the form of a stadium and the model attempted to take into account psychological aspects like group formation and social comparison to accurately represent crowd behavior. Crowd behavior in built spaces is of interest to a number of types of individuals ie. urban planners, emergency personnel. Similarly, agent based modeling can adapt itself to the simulation of a vast array of scenarios. My model was written to take advantage of flocking behavior to simulate grouping behavior. The model illustrates the ability for ABM to approximate crowd behavior using low level decision making processes and flocking behavior. Additionally various aspects of communication among people can be shown to have an affect on evacuation time.

1 Introduction

Agent based modeling is a tool/system for modeling and simulating anything which can be represented by the interactions of agents in an environment. The building blocks of ABM are agents and patches. Agents are endowed with characterstics and decision making processes. Each agent can be entirely unique and follow a unique set of rules. Patches form a grid that make up the environment or "map". Patches also can have their own characteristics but unlike agents, patches cannot move. Various "breeds" can be created to have different default characteristics but for my model this was not necessary. The program I used was Netlogo which is written and maintained by Uri Willensky. Netlogo is an all in one development environment for ABM that uses the logo programming language for coding and has an attractive GUI for running simulations.

Crowd behavior in built spaces must take into account a few aspects. First is that the built space affects the actions taken by the individuals and crowd. Second, crowds are made up of individuals with their own goals and characteristics. People do not behave like particles, rather they are governed by psychological aspects and behave intelligently. For this reason, abm seems ideal. Individuals

can be endowed with their own decision making processes and localized interactions among them can bring out a global emergent behavior. Crowds form as a result of these localized behaviors.

Flocking aims to represent the flocking of birds or fish and is achieved using three methods: Separation tells an agent to avoid neighbors and "separate from them", Alignment sets the heading of an agent to the average heading of its flockmates or groupmates, and Cohesion brings agents in a flock closer together. These simple processes can bring about interesting behavior. By building in obstacle avoidance and grouping based on certain factors, flocking can be made to be a reasonable representation of group formation and travel. Within a group one agent was designated as a group leader. This "leader" is endowed with more abilities than the general group members. The leader is essentially responsible for the location of the exit and communicating with the rest of the members of the group.

Different parameters controlling communication amongst agents also proved to be important in determining total evacuation time. Agents could learn exit location from a number of sources: other flockmates, other agents, group leaders, and police officers. Once an agent knew the location of the exit, depending on the initial parameters, that information could propagate back to other agents. Similarly the group leader has a "leader volume" that can be changed. This parameter determines the radius in which the leader can share information about exit location. Maximum group size is also configurable, this parameter is present to control typical flock size in the model. There are other parameters which can be changed; this is just a brief overview of the most important aspects.

1.1 Literature Review

There is a good deal of literature on the subject of crowd behavior and evacuation dynamics. Helbing wrote one of the major pieces on the subject and gives an overview of various techniques for modeling crowd behavior, in addition to pointing out many of the emergent behaviors that arise in crowds. [5] Fridman's paper provided an introduction to the notion of social comparison theory and its application to crowd behavior. [3] I did utilize this psychological notion in some ways by allowing each agent to have characteristics and then implementing a "social comparison" function to be used during group formation. Camillen gave an introduction to using a program like netlogo to model crowds and evacuations in closed spaces. This information was useful because the nature of a closed space is different than that of outdoors. [2] Thirion's article conveyed a model of crowd behavior but used advanced path planning techniques to move to exits [6]. This article was interesting but in the end I chose to use a more simplistic model without any intelligent path planning. The paper that recalled accounts of evacuees of the World Trade Center by Galea was quite useful in the formation of my model. This paper turned me on to the idea of group formation and group leadership [4]. From these accounts, my idea to have all agents move at the same speed was also affirmed. From group behavior I came up with the idea of communication, a major aspect of my model. The most useful source

of information came from an Open ABM chapter about Crowd Behavior [1]. While this source mentioned flocking behavior, it did not explicitly talk about applying this behavior to crowds of people. The idea for that was my mentor's and mine. However, the open abm site did provide a netlogo model that expanded on the default flocking model by adding obstacle avoidance. I took this model even further and adapted it to fit within my model and mimic realistic grouping behavior. The nature of my research was that a lot of the progress was made using my own ideas and developing my model further. While this may not be the most "correct" way to research, it seemed to be the best course of action for me.

2 Results

Netlogo is a powerful tool for the simulations of models that can be adapted to use agent based modeling. The program makes it simple to code a model and receive instant feedback in the form of running the simulation. Additionally, no two simulations are ever the same (unless the random seed is set manually) because when accessing the array of agents, Netlogo chooses a random order. This allows for more realism in the model. Netlogo's system of turtles and patches make creating a model relatively simple and once the logo programming language is learned, everything is quite intuitive. There is excellent documentation for every command in netlogo and this proved to be handy. There is also a large community using netlogo so finding support and examples was not difficult.

After initially creating an incredibly simple model, where agents escaped a square room but did not avoid eachother and merely bounced off of walls, I eventually figured out how to import a custom drawn image and began work on the current iteration of my model. I created my model incrementally, adding more sophistication at each step while being sure not to "force" everything and instead have the result be a product of simple interactions by naive agents.

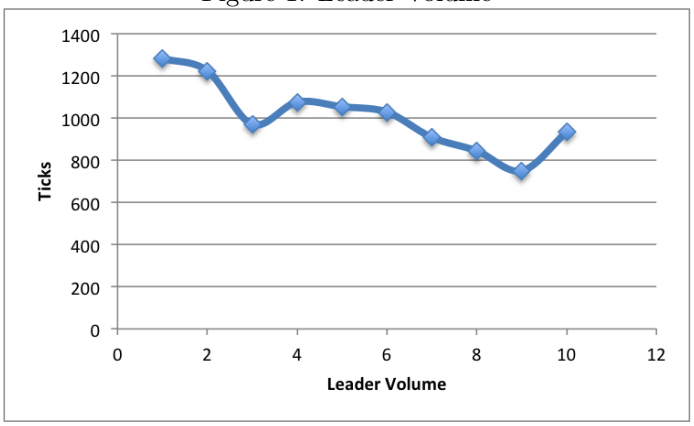
The final model operates in three main steps. Initially all agents are sitting in "seats" and the first step is to locate and move to an aisle, forming a queue if necessary. After the aisle is reached, agents need to move up the aisle and enter the concourse. Finally, in the concourse the goal is to form a group to facilitate location of an exit. Eventually all agents locate and move to an exit, thus completing the evacuation scenario.

With a homogenous crowd in the sense that everybody walks at a constant speed, flocking did appear to be fairly successful at approximating group formation and crowd movement with naive agents. By building in obstacle avoidance and designating walls and other people as "obstacles," the flocking movement was able to navigate the concourse without spinning in circles or bouncing off of walls like my earlier attempts tended to do. The flocks basically pick a heading at random, turn to avoid obstacles and once they know the location of an exit, set their heading to face that exit. With this behavior built in, the crowd seems reasonably intelligent. Additionally, flocks are dynamic and agents can leave a flock. Grouping behavior is supported by accounts from the World Trade

Center evacuation on September 11. From those accounts I learned that groups tended to be small with someone acting as a group leader. Groups were calm and composed as opposed to panicked. For this reason, I allow all agents travel at the same speed.

Different settings can be modified to achieve slightly different results; the aspect of communication did prove to be one of the biggest factors in my model with regards to evacuation time. With small group sizes (as supported by the accounts of the WTC evacuation) leader volume played a significant role in evacuation time [Figure 1]. The louder the leader, the more agents that leader could inform about exit location. This would lead me to believe that anything that would impede communication between group members like an alarm or another loud noise, would be detrimental to an evacuation.

Figure 1: Leader Volume



From this figure we can see that as leader volume increases, total evacuation time (which is measured in model time or ticks) decreases for the most part. The difference is not drastic but the trend seems significant enough to allow me to say that in my model, leader volume tends to have the biggest effect on evacuation time.

I had attempted to implement a number of other things in my model but often agents would get stuck and the simulation would fail to work correct. For that reason, the model has been made as simple as possible; I think that in this case that is a good choice and fits within the agent based modeling paradigm. The agents do not utilize any sort of advanced path planning, rather they walk with a heading (which adapts based on flocking behavior) and react to their surroundings to avoid obstacles and eachother. With this simple behavior, the model never (or hopefully never) breaks down.

For me the success lies in learning a new technique (ABM) and succeeding in modeling a complex situation in a way that appears to be realistic and takes into account some psychological elements like group formation and flocking behavior. ABM is a great tool that will be of use in the future as it can adapt itself to

any number of situations.

2.1 Unique Aspects of this Model

The model I created is unique in a number of ways. Unlike other models I have researched, my model embraces simplicity and rather than rely on complicated algorithms for intelligence and path planning, all of the behavior that arises is due to simple phenomena. Group formation, as far as I can tell is unique to my model and is supported by real world accounts. Bringing in some simple aspects of social comparison theory is also unique and while truthfully this could have been abstracted from my model, its inclusion makes the model more realistic.

3 Conclusion

I am not entirely sure how much more work will get done on this model after my time at DIMACS is over. There are some things that could expand the model but none that seem to be particularly imperative. One thing that I would find interesting to implement would be endowing agents with the knowlege that they must evacuate at different times rather than beginning a global evacuation all at once. This could pose a problem however because due to the nature of my model, if there is an agent in the way while looking for an aisle, a queue will form and so agents who knew of the eavacuation would be unable to move. One way around this would be to inform entire sections at a time, which does seem realistic.

That being said, I do plan on continuing with another DIMACS project while back at school. The project will be done with James Leslie and is an implementation of Gene's fingerprint classification method.

Because a large amount of my research involved using and implementing my own ideas, remaining ethical was not a large problem. I did do some background research and have cited the ideas learned from that research where appropriate. Netlogo also provides a section in the information tab to reference other models used which I used when appropriate.

Maintaining a professional demeanor while at DIMACS was also important. Paying attention to, and getting the most out of, the various speakers and activities was a great experience. Showing up to the office every day and working on my reasearch was also something that was very important. I was also ethical in my correspondence with my mentor. We met weekly and I did my best to convey everything that I have done, in addition to talking about new ideas to implement. The most important thing to being ethical is giving credit where credit is due.

The DIMACS Reu program as a whole was an amazing experience. I truly cannot think of anything major that I would suggest changing. My time here has been invaluable and really has motivated me to pursue a graduate degree after graduating from Colgate. During the summer I have learned many new tools, including Emacs, latex, git, and most importantly, netlogo. I enjoyed nearly all of the seminars and activities. I do very much believe that I have

gotten a great deal out of this summer. Gene, Cliff, and everybody else at DIMACS has made this summer a great one.

References

[1] Crowd behavior (open abm).

[2] Camillen, F. e. a. Multi agent simulation of pedestrian behavior in closed spatial environments.

[3] Fridman, N., and Kaminka, G. Computability and logic.

[4] Galea, E. R. An analysis of human behavior during evacuation.

[5] Helbing, D., and Johansson, A. Pedestrian, crowd and evacuation dynamics.

[6] Thirion, T., and Basu, S. K. Real-time crowd simulation for emergency planning.

Appendices

A Netlogo Algorithm

```
globals [middle rightExit]
turtles-own [

  knowledge
  team
  leaderTurtle
  closestAisle
  reachAisle
  reachConcourse
  leadership
  reachExit
  closestExit
  height
  weight
  age
  sex
  child
  flockmates          ;; agentset of nearby turtles
  nearest-neighbor    ;; closest one of our flockmates
  groupLeader
  expandGroup
```

```
  parkingLot
  family
  ]


patches-own [ptype pheight exit exitNumber]
to setup

  clear-all
  ask patches [set pcolor violet]
  import-pcolors nameMap
  set rightExit 0
  set middle patch (max-pxcor / 2) (max-pycor / 2)
  ifelse teams = false [ask patches with [
      shade-of? pcolor turquoise or shade-of? pcolor cyan
          or shade-of? pcolor sky] [
      set ptype "seat" if (round (distance middle) mod (
         rowDensity) = 0   ) [
        sprout 1 [
          set parkingLot one-of [0 1 2 3] set family
             turtles-here set expandGroup true
          set shape "person" set groupLeader false set
             knowledge 0 getAttributes
          set reachExit false set closestExit Nobody set
             leaderTurtle Nobody
          set reachConcourse false set closestAisle
             Nobody set reachAisle false
          set flockmates turtles-here set size 3 set team
              color] ]]] [
    ask patches with [
      shade-of? pcolor turquoise or shade-of? pcolor cyan
          or shade-of? pcolor sky][
       set ptype "seat" if (round (distance middle) mod (
          rowDensity) = 0
         and pycor > (max-pycor / 2 )) [
         sprout 1 [
           set parkingLot one-of [0 1 2 3] set family
              turtles-here set expandGroup true
           set shape "person" set groupLeader false set
              knowledge 0 getAttributes
           set reachExit false set closestExit Nobody set
               leaderTurtle Nobody
           set reachConcourse false set closestAisle
              Nobody set flockmates turtles-here
           set reachAisle false set size 3 set color
              orange set team color ] ]]
```

```
  ask patches with [
    shade-of? pcolor turquoise or shade-of? pcolor cyan
        or shade-of? pcolor sky][
     set ptype "seat" if (round (distance middle) mod (
        rowDensity) = 0
       and pycor < (max-pycor / 2) ) [
       sprout 1 [
         set parkingLot one-of [0 1 2 3] set family
            turtles-here set expandGroup true
         set shape "person" set groupLeader false set
            knowledge 0 getAttributes
         set reachExit false set closestExit Nobody set
             leaderTurtle Nobody
         set reachConcourse false set closestAisle
            Nobody set flockmates turtles-here
         set reachAisle false set size 3 set color
            black set team color] ]]]
ask patches with [
  shade-of? pcolor yellow] [
  set ptype "aisle" set pheight distance middle]
ask patches with [
  shade-of? pcolor green or shade-of? pcolor lime] [
  set ptype "field" set pheight 0]
ask patches with [
  shade-of? pcolor gray] [
  set ptype "concourse" set pheight 300]
ask patches with [
  shade-of? pcolor red or shade-of? pcolor magenta or
     shade-of? pcolor pink] [
  set ptype "wall"]
ask patches with [
  shade-of? pcolor orange] [
  set ptype "upperLevel"]
ask patches with [
  pcolor = white] [
  set ptype "exit"]
ask patches with [
  pcolor = 0] [
  set ptype "nothing"]
ask patches with [
  pcolor = violet] [
  set ptype "outside"]
while [count patches with [ptype = 0] > 0] [
  ask patches with [ptype = 0] [
    ask one-of patches in-radius 1 [
      let tempType ptype let tempColor pcolor ask
```

```
            myself[
          set ptype tempType set pcolor tempColor]]]]

  if seatDensity != 50 [ask n-of ((count Turtles) /
     seatDensity) turtles [die]]

  ask patches with [ptype = "exit"] [ifelse (pxcor < 36
     and pycor > 36) [set exitNumber 0] [
      ifelse (pxcor > 36 and pycor < 36) [set exitNumber
         1] [
        ifelse (pxcor > 36 and pycor > 280) [
          set exitNumber 2] [set exitNumber 3]]]]
;  if globalNotification = true [
;    ask patches with [ptype = "exit"] [
;      ask turtles in-radius 150 [
;        set closestExit myself]]]

  if globalNotification = true [
    ask turtles [set closestExit ([one-of patches
       in-radius 5] of
        min-one-of patches with [ptype = "exit"] [
           distance myself]) ]]

  if police = true [
    ask n-of policeCount (patches with [ptype = "
       concourse"
        and not any? patches in-radius 2 with [ptype != "
           concourse"] ]) [
        ask patches in-radius 1 with [ptype = "concourse"
           ] [set ptype "police"
          set pcolor blue set exit (min-one-of patches
             with [ptype = "exit"] [
              distance myself]) ]]]

  ask turtles [let famSize random 5 if count turtles
     in-radius 5 >= famsize [
      set family n-of  famSize turtles in-radius 6 ask
         family [
        set family [family] of myself set parkingLot [
           parkingLot] of myself ]]]
  ask turtles [set family (turtle-set turtles-here family
     ) set flockmates family]
end

to getAttributes
  ;0 is male, 1 is female
```

```
  set sex random 2
  ;assumes roughly two adults to every child at the
     stadium
  set child (random 3 < 2)
  ifelse child = false [
    set age 2 + abs round random-normal 40 15
    ifelse sex = 0 [
      set height 2 + abs round random-normal 69.5 3] [
      set height 2 + abs round random-normal 64 3 ]][
      set age 2 + abs round random-normal 10 5
      ifelse sex = 0 [
        set height 2 + abs round random-normal 50 4][
        set height 2 + abs round random-normal 47 4]]
  millerFormula
end

to penOn
  ask turtles[pen-down]
end

to penOff
  ask turtles[pen-up]
end

;replace with classification tree: leader, peer, no
    relation
to-report socialComparison [agent1 agent2]
  let numericalComparison 0
  if [color] of agent1 != [color] of agent2 [set
     numericalComparison (numericalComparison - 30)]
  if [child] of agent1 = [child] of agent2 [set
     numericalComparison (numericalComparison + 30)]
  if [sex] of agent1 = [sex] of agent2 [set
     numericalComparison (numericalComparison + 30)]
  set numericalComparison (numericalComparison + (20 -
     abs (.25 * ([height] of agent1 - [height]
          of agent2))))
  set numericalComparison (numericalComparison + (20 -
     abs (.25 * ([weight] of agent1 - [weight]
          of agent2))))
  set numericalComparison (numericalComparison + (20 -
     abs (.5 * ([age] of agent1 - [age]
          of agent2))))
  report numericalComparison
end
```

```
to go
  ;if ticks = 250 [set preferExit false]
  if count turtles = 0 [stop]
  tick
  if (ticks mod upperLevelRate) = 0 [
    ask n-of upperLevelQuantity patches with [
      ptype = "upperLevel" and count turtles-here = 0] [
      sprout 1 [
        set parkingLot one-of [0 1 2 3] set family
            turtles-here set expandGroup true
        set shape "person" getAttributes set flockmates
            turtles-here set groupLeader false
        set reachExit false set closestExit Nobody set
            leaderTurtle Nobody
        set reachConcourse true set closestAisle Nobody
            set reachAisle true
        set size 3 set color (one-of list orange black)
            set team color]]]
  ask turtles [ ifelse reachAisle = false [
          if closestAisle = Nobody and leaderTurtle =
             Nobody[
           locateAisle] moveToAisle] [
           ifelse reachConcourse = false [
             moveToConcourse] [
             escapeBuilding ]]]


end

to millerFormula
  ;Miller formula for adult weight
  ;Luscombe weight formula for estimating children's
     weight
  ifelse child = false or age > 13[
    let tempHeight height ifelse sex = 0 [
      ifelse height >= 60 [
        set weight (weight + 124)
        set tempHeight (tempHeight - 60)
        set weight (tempHeight * 3)][set weight 124]][
      ifelse height >= 60 [
        set weight (weight + 117) set tempHeight (
            tempHeight - 60) set weight (tempHeight * 3)][
        set weight 117]]][let weightkg ((3 * age) + 7)
            set weight (weightkg * 2.2)]
```

```
end
; making it so that height must be positive allows me to
    "disable" an aisle by setting height to 0 or negative
to locateAisle
  let aisle (min-one-of patches in-radius 10 with [ptype
     = "aisle" and pheight > 0] [
      distance myself])
  ifelse aisle = Nobody [
    set leaderTurtle one-of turtles with [distance myself
        < 10 and closestAisle != Nobody]
    if leaderTurtle != Nobody [
      let a Nobody ask leaderTurtle [
        set a closestAisle]
      set closestAisle a
      set leaderTurtle Nobody]] [set closestAisle aisle
         set leaderTurtle Nobody ]

end

to moveToAisle
  ifelse closestAisle = Nobody [ set heading (random 360)
      locateAisle
      jump 1] [face closestAisle jump 1]
  if collisions = true [
    if count turtles-here > 1 [jump -1 locateAisle]]
  let dest one-of patches in-radius 2 with [ptype = "
     aisle" and count turtles-here = 0]
  if dest != nobody [move-to dest]
  if ptype = "aisle" [set reachAisle true]
end

to moveToConcourse
  ;field is included to take into account a fiew patches
     that wind up being shades of green unintentionally
  let nextStep max-one-of patches in-radius 3 with [ptype
      = "aisle"
    or ptype = "concourse" or ptype = "field"] [pheight]
  if nextStep != Nobody [
  face nextStep ]
  jump 1
  if collisions = true [
    if count turtles-here > 1 [jump -1 set heading (
       heading + random 45)] ]
  let dest one-of patches in-radius 2 with [ptype = "
     concourse" and count turtles-here = 0]
  if dest != nobody [move-to dest]
```

```
  if ptype = "concourse" [set reachConcourse true]
end

to locateExit
; 70 is typical human cone of vision

  set closestExit (one-of patches in-cone 50 70 with [
      ptype = "exit" and (preferExit = false or
         exitNumber = [parkingLot] of myself)])
  if closestExit = nobody and any? patches in-cone 10 70
     with [ptype = "police"] [
    ifelse preferExit = false [set closestExit [exit] of
       one-of patches in-cone 10 70 with [
        ptype = "police"]][
      if any? patches in-cone 10 70 with [ptype = "police
         " and exitNumber = [
          parkingLot] of myself] [set closestExit [exit]
             of one-of patches in-cone 10 70 with [
          ptype = "police" and exitNumber = [parkingLot]
             of myself]]]]

  if closestExit != Nobody [let temp nobody
      ask closestExit  [set temp one-of patches in-radius
          8 with [ptype = "exit"]]
      set closestExit temp
      face closestExit]

end

to learnExit
  if learningType = "local" [
  if any? turtles in-radius leaderVolume with [
     closestExit != nobody and (preferExit = false
      or parkingLot = [parkingLot] of myself)][
      ifelse preferExit = false [ set closestExit [
         closestExit]
        of one-of turtles in-radius leaderVolume with [
           closestExit != nobody]] [
        set closestExit [closestExit] of (one-of turtles
           in-radius leaderVolume
          with [closestExit != nobody and parkingLot = [
             parkingLot] of myself])]
  let temp nobody
  ask closestExit  [set temp one-of patches in-radius 5
     with [ptype = "exit"]]
  set closestExit temp
```

```
  ]]

  if learningType = "flockmates" [
  if any? flockmates with [groupLeader = true] [if
      distance one-of flockmates with [
       groupLeader = true] < leaderVolume [
  set closestExit [closestExit] of one-of flockmates with
       [groupLeader = true]] ]
  ; nobody in group knows, find out from people in small
      area
  if groupLeader = true [if closestExit = nobody [
    ifelse preferExit = false [if any? turtles in-radius
        leaderVolume with [closestExit != nobody][
       set closestExit [closestExit] of (one-of turtles
          in-radius leaderVolume with [
           closestExit != nobody])]] [if
       any? turtles in-radius leaderVolume with [
          closestExit != nobody and parkingLot = [
           parkingLot] of myself][
       set closestExit [closestExit] of (one-of turtles
          in-radius leaderVolume with [
         closestExit != nobody and parkingLot = [
            parkingLot] of myself])]]
       ]]
  ]
  if closestExit = nobody and any? patches in-cone 10 70
      with [ptype = "police"] [
    ifelse preferExit = false [set closestExit [exit] of
        one-of patches in-cone 10 70 with [
         ptype = "police"]][
       if any? patches in-cone 10 70 with [ptype = "police
          " and exitNumber = [
           parkingLot] of myself] [set closestExit [exit]
              of one-of patches in-cone 10 70 with [
           ptype = "police" and exitNumber = [parkingLot]
              of myself]]]]

  if closestExit != Nobody [let temp nobody
      ask closestExit  [set temp one-of patches in-radius
          8 with [ptype = "exit"]]
      set closestExit temp
      face closestExit]

end
```

```
to escapeBuilding

;if count flockmates = 0 [set flockmates turtles-here]

;if not any? flockmates [set heading (heading + random
    (60) - random 120)]
if closestExit = nobody and flockCommunication = true and
     any? flockmates with [
  groupLeader = true and closestExit != nobody] [set
      closestExit [closestExit]
  of one-of flockmates with [groupLeader = true and
      closestExit != nobody]]
if closestExit = nobody and learningType != "none" [
    learnExit]
if closestExit = Nobody and groupLeader = true [
    locateExit]
;if closestExit != Nobody [ face (closestExit)
 ; if distance closestExit <= 15 [set heading ( heading +
      random 50 - random 100)]
  ;ask other flockmates [set heading [heading] of myself
      + random 50 - random 100]]

flock
let safe avoid_obstacles
ifelse safe = true [fd 1][ifelse closestExit != nobody [
    face closestExit
      set heading (heading + random 30 - random 40)] [
      set heading (heading + random 30 - random 40)]
  if any? patches in-cone 2 150 with [count turtles-here
      = 0
    and (ptype = "concourse" or (preferExit = false and
        ptype = "exit"
          or (ptype = "exit" and exitNumber = [parkingLot]
              of myself))) ] [
    move-to one-of patches in-cone 2 150 with [count
        turtles-here = 0
      and (ptype = "concourse" or (preferExit = false and
          ptype = "exit"
          or (ptype = "exit" and exitNumber = [parkingLot
              ] of myself))) ]]]
;fd 1
if any? patches in-radius 3 with [ptype = "exit"] [if [
    exitNumber]
  of one-of patches in-radius 3 with [ptype = "exit"] =
      parkingLot
```

```
  and preferExit = true [set rightExit (rightExit + 1)]
      set reachExit true die]

end

to flock  ;; turtle procedure

  ;flockmates too far away, find new flockmates

  ;if expandGroup = true [if random 10 < 2 [ask
     flockmates [set expandGroup false]]]
  if count flockmates > maxGroupSize [ask flockmates [set
      expandGroup false]]
  if count flockmates < maxGroupSize and expandGroup =
     true [find-flockmates]


  if not any? flockmates with [groupLeader = true] [
     locateExit]

  if any? other flockmates
    [ find-nearest-neighbor
      ifelse distance nearest-neighbor <= 1
        [ separate ]
        [ align
          cohere ] ]

  if leadershipFunction > 70 [makeLeader]

end
to makeLeader
  set groupLeader false
  ask flockmates [set groupLeader false]
  ask max-one-of flockmates [leadershipFunction][set
     groupLeader true]
end

to-report leadershipFunction
  let leaderValue 0
  if child = false [set leaderValue (leaderValue + 50)]
  set leaderValue (leaderValue + .5 * age)
  set leaderValue (leaderValue + .5 * weight)
  if count flockmates = 1 [set leaderValue 0]
  report leaderValue
end
```

```
to find-flockmates  ;; turtle procedure

 set flockmates turtles in-radius (maxGroupSize)  with [
   ;socialComparison self myself > 20 and
   reachConcourse = true and expandGroup = true and (
       preferExit = false or parkingLot = [
        parkingLot] of myself)]
 ask flockmates [set flockmates [flockmates] of myself]
 if count flockmates with [groupLeader = true] > 1 [ask
    flockmates [set groupLeader false]]
end

to find-nearest-neighbor ;; turtle procedure
  set nearest-neighbor min-one-of flockmates [distance
     myself]
end

;;; SEPARATE

to separate  ;; turtle procedure
  turn-away ([heading] of nearest-neighbor) 4.5
end

;;; ALIGN

to align  ;; turtle procedure
  turn-towards average-flockmate-heading  1
end

to-report average-flockmate-heading  ;; turtle procedure
  ;; We can't just average the heading variables here.
  ;; For example, the average of 1 and 359 should be 0,
  ;; not 180.  So we have to use trigonometry.
  let x-component sum [sin heading] of flockmates
  let y-component sum [cos heading] of flockmates
  ifelse x-component = 0 and y-component = 0
    [ report heading ]
    [ report atan x-component y-component ]
end

;;; COHERE

to cohere  ;; turtle procedure
  turn-towards average-heading-towards-flockmates 1
end
```

```
to-report average-heading-towards-flockmates  ;; turtle
    procedure
  ;; "towards myself" gives us the heading from the other
      turtle
  ;; to me, but we want the heading from me to the other
      turtle,
  ;; so we add 180
  let x-component mean [sin (towards myself + 180)] of
      flockmates
  let y-component mean [cos (towards myself + 180)] of
      flockmates
  ifelse x-component = 0 and y-component = 0
    [ report heading ]
    [ report atan x-component y-component ]
end

;;; HELPER PROCEDURES

to turn-towards [new-heading max-turn]  ;; turtle
    procedure
  turn-at-most (subtract-headings new-heading heading)
      max-turn
end

to turn-away [new-heading max-turn]  ;; turtle procedure
  turn-at-most (subtract-headings heading new-heading)
      max-turn
end

;; turn right by "turn" degrees (or left if "turn" is
    negative),
;; but never turn more than "max-turn" degrees
to turn-at-most [turn max-turn]  ;; turtle procedure
  ifelse abs turn > max-turn
    [ ifelse turn > 0
        [ rt max-turn ]
        [ lt max-turn ] ]
    [ rt turn ]
end

to-report avoid_obstacles
    let i 0
    while [([ptype] of patch-ahead i = "concourse" or ([
        ptype]
          of patch-ahead i = "exit" and (preferExit =
              false or [exitNumber]
```

```
          of patch-ahead i = parkingLot )) and i <= 10)
              ]
  [set i (i + 1) ]
  if ([ptype] of patch-ahead i != "concourse" and ([
     ptype] of patch-ahead i != "exit"
       or (preferExit = true and [ptype] of patch-ahead
           i = "exit" and [exitNumber]
         of patch-ahead i != parkingLot)))
  [
      if [ptype] of patch-at-heading-and-distance (
         heading - 5) (i + 1) != "concourse"
      and ([ptype] of patch-at-heading-and-distance (
         heading - 5) (i + 1) != "exit"
        or (preferExit = true and [ptype]
          of patch-at-heading-and-distance (heading -
             5) (i + 1) = "exit"
          and [exitNumber] of
             patch-at-heading-and-distance (heading -
             5) (i + 1) != parkingLot))
      [
          ifelse [ptype] of
             patch-at-heading-and-distance (heading +
             5) (i + 1) != "concourse"
          and ([ptype] of patch-at-heading-and-distance
              (heading + 5) (i + 1) != "exit"
            or (preferExit = true and [ptype]
              of patch-at-heading-and-distance (heading
                  + 5) (i + 1) = "exit"
              and [exitNumber] of
                 patch-at-heading-and-distance (heading
                  + 5) (i + 1)
              != parkingLot))
          [
              ifelse random 1 = 0
              [ set i 0 rt 40 ]
              [ set i 0 lt 40 ]
          ]
          [ifelse heading <= 180 and [ptype]
            of patch-at-heading-and-distance (heading -
                5 ) ( i + 1 ) = "wall" [
              set i 0 rt 60 ][set i 0 lt 60]]
      ]
  ]
 ifelse count [other turtles-here] of patch-ahead 1 = 0
 and ([ptype] of patch-ahead 1 = "concourse" or (
    preferExit = true and [ptype]
```

```
        of patch-ahead 1 = "exit" and [exitNumber] of
            patch-ahead 1 = parkingLot)) [
        report true] [report false]
end
```