G54SOD (Spring 2018)

Lecture 04

Agent-Based Modelling and Simulation

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The University of Nottingham

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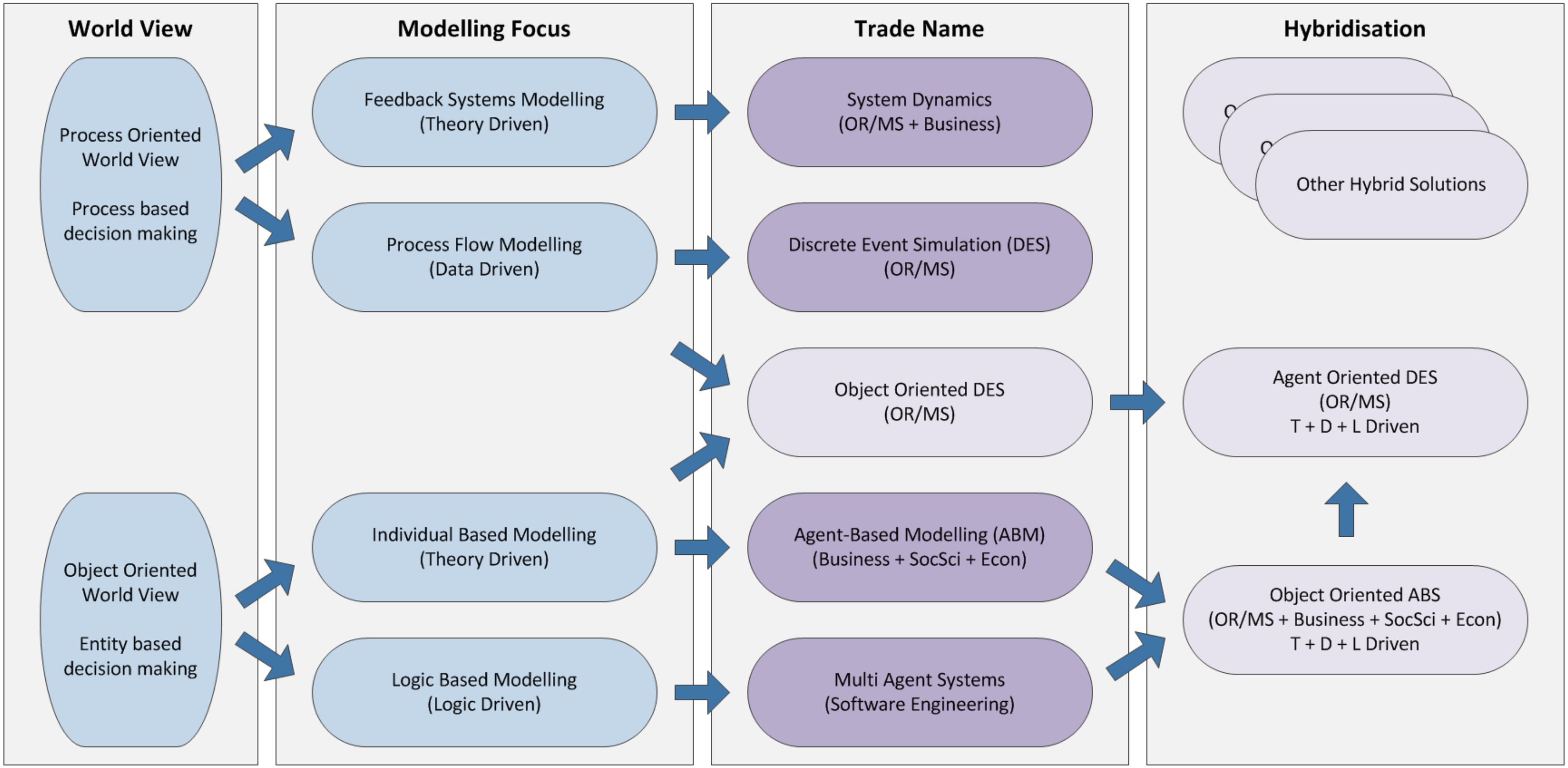
Motivation

- Introduce the concepts of
  - Agents
  - Agent-Based Modelling (ABM)
  - Agent-Based Simulation (ABS)
- Provide some insight into how ABS works internally
- Provide some ideas for defining ABMs
- Provide some insight into the application opportunities of agent-based simulation

Simulation Modelling Framework



Theory Driven: Theories for model formulation; data for model validation
Data Driven: Data for model formulation (can be quantitative and qualitative); data for model validation
Logic Driven: Logic for model formulation; data for model validation

Agent-Based Modelling and Simulation

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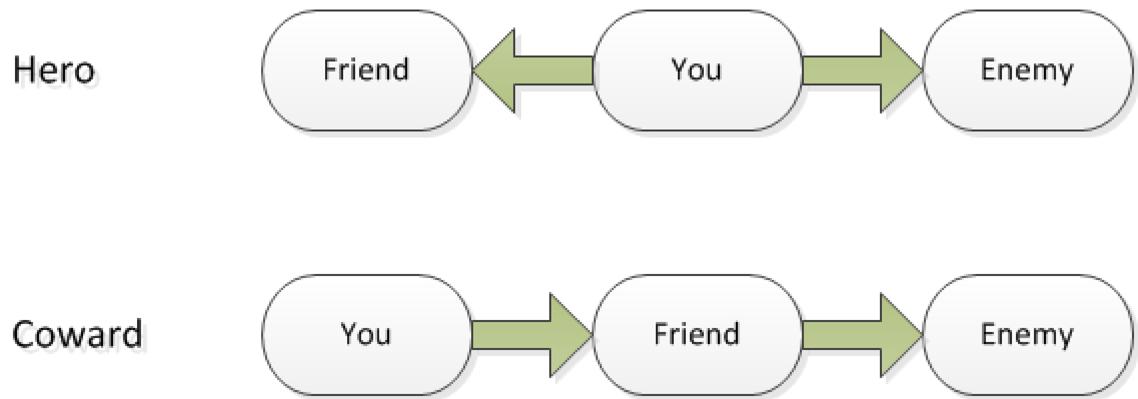
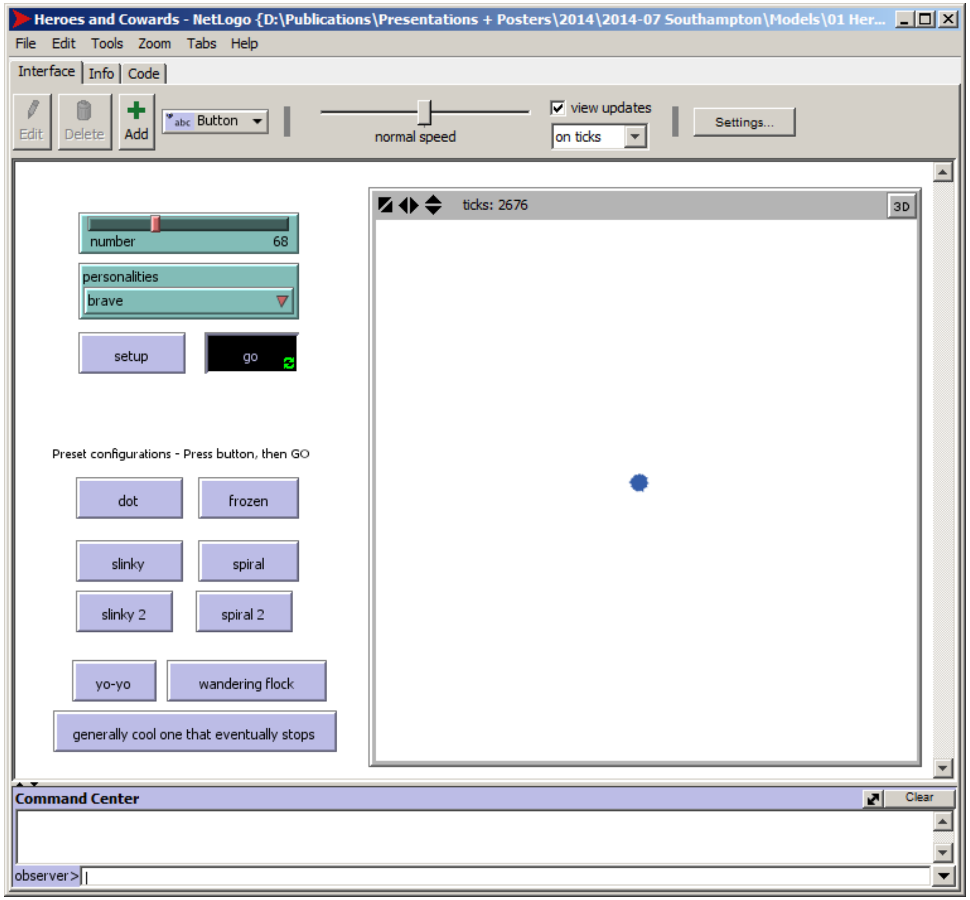
Agent-Based Modelling

- Heroes and Cowards Game [Wilensky and Rand 2013]



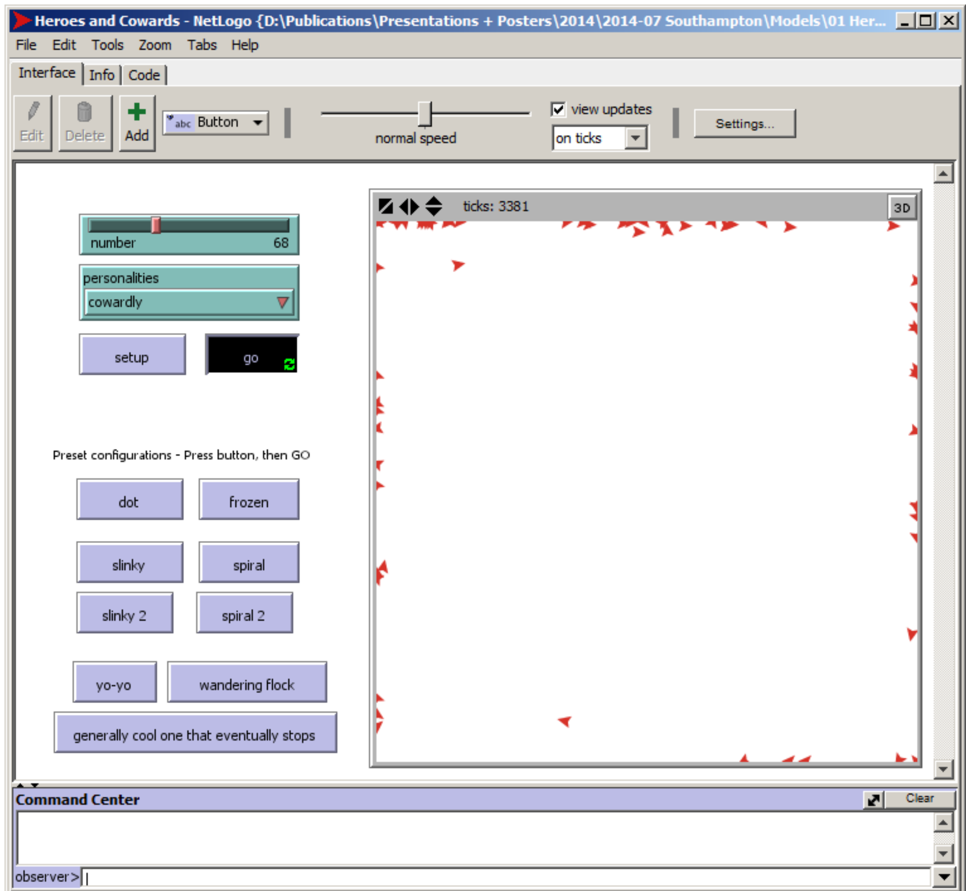
Agent-Based Modelling

- Heroes and Cowards Game : All heroes



Agent-Based Modelling

- Heroes and Cowards Game: All cowards



Agent-Based Modelling

- Heroes and Cowards Game: Source Code

Heroes and Cowards - NetLogo {D:\Teaching\Short Courses\ESM2013-Tutorial}

File Edit Tools Zoom Tabs Help

Interface | Info | Code

Find... Check Procedures ▾ ☑ Indent automatically

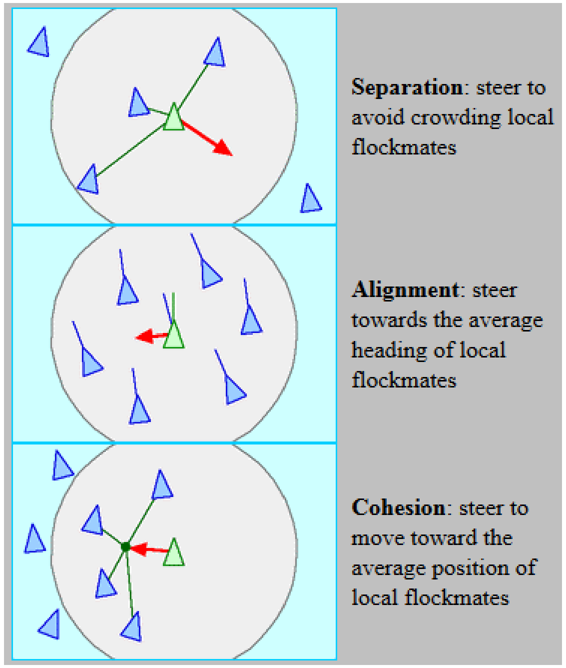
```
to setup
  clear-all


  ask patches [ set pcolor white ]  ;; create a blank background
  create-turtles number [
    setxy random-xcor random-ycor

    ;; set the turtle personalities based on chooser
    if (personalities = "brave")     [ set color blue ]
    if (personalities = "cowardly")  [ set color red ]
    if (personalities = "mixed")     [ set color one-of [ red blue ] ]

    ;; choose friend and enemy targets
    set friend one-of other turtles
    set enemy one-of other turtles
  ]
  reset-ticks
end

to go
  ask turtles [
    if (color = blue)  [ act-bravely ]
    if (color = red)   [ act-cowardly ]
  ]
  tick
end

to act-bravely
  ;; move toward the midpoint of your friend and enemy
  facexy ([xcor] of friend + [xcor] of enemy) / 2
         ([ycor] of friend + [ycor] of enemy) / 2
  fd 0.1
end

to act-cowardly
  ;; put your friend between you and your enemy
  facexy [xcor] of friend + ([xcor] of friend - [xcor] of enemy) / 2
         [ycor] of friend + ([ycor] of friend - [ycor] of enemy) / 2
  fd 0.1
end

; Copyright 2010 Uri Wilensky.
; See Info tab for full copyright and license.
```

Agent-Based Modelling

- Flocking behaviour

Agent-Based Modelling

- Flocking behaviour modelling by Craig Reynolds [url]



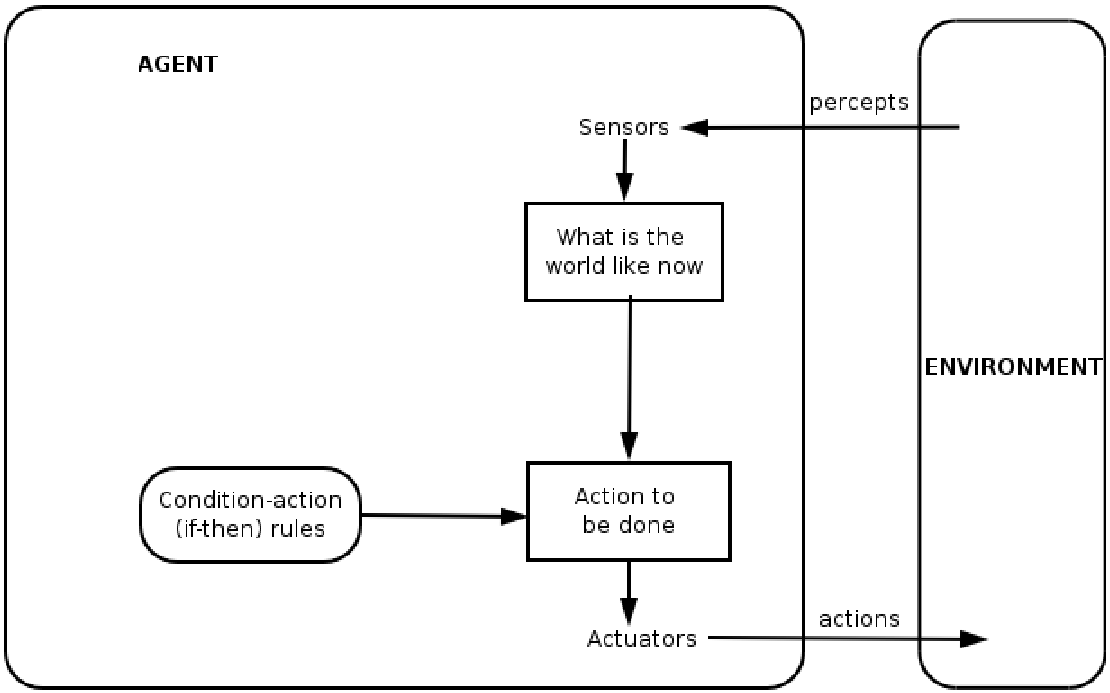
http://ayearincode.tumblr.com/post/107414487116/this-morning-i-added-some-new-rules-to

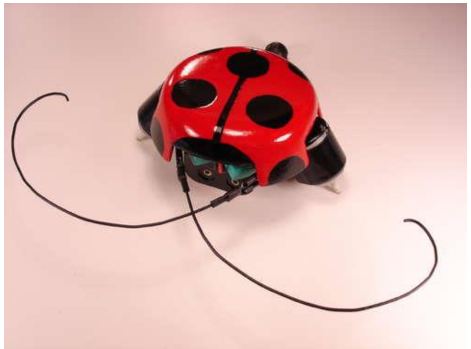
Agent-Based Modelling

- In Agent-Based Modelling (ABM), a system is modelled as a collection of **autonomous decision-making entities** called agents. Each agent individually assesses its situation and makes decisions on the basis of a **set of rules**.
- ABM is **a mindset more than a technology**. The ABM mindset consists of describing a system from the perspective of its constituent units. [Bonabeau 2002]
- ABM is **well suited to modelling** systems with heterogeneous, autonomous and proactive actors, such as **human-centred systems**.

Agent-Based Modelling

- Borrowing from Artificial Intelligence: From simple to complex
  - Simple reflex agent

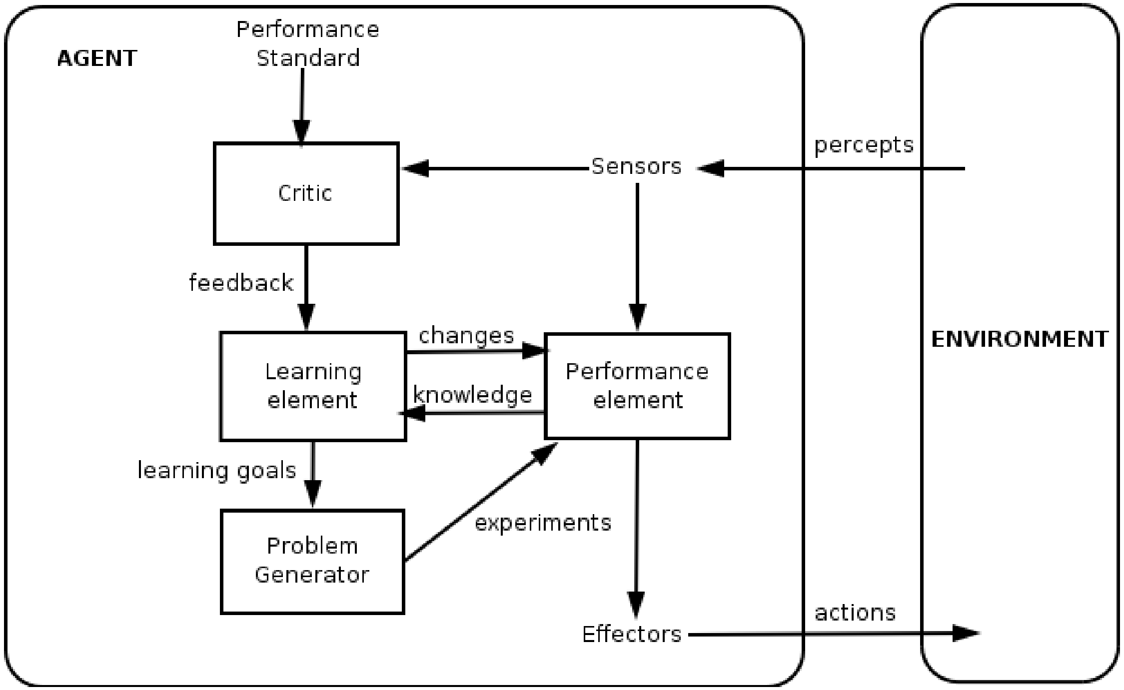




Russell and Norvig (2003)

Agent-Based Modelling

- Borrowing from Artificial Intelligence: From simple to complex
  - Learning agent



Russell and Norvig (2003)

Agent-Based Modelling

- What do we mean by "agent"?
  - Agents are **"objects with attitude"** [Bradshaw 1997]

- Properties:
  - Discrete entities
    - With their own goals and behaviours
    - With their own thread of control
  - Autonomous decisions
    - Capable to adapt
    - Capable to modify their behaviour
  - Proactive behaviour
    - Actions depending on motivations generated from their internal state

Agent-Based Modelling

- The agents can represent individuals, households, organisations, companies, nations, … depending on the application.
- ABMs are essentially **decentralised**; there is no place where global system behaviour (dynamics) would be defined.
- Instead, the individual agents **interact** with each other and their environment **to produce complex collective behaviour** patterns.

Agent-Based Modelling

- Benefits of ABM
  - ABM provides a natural description of a system
  - ABM captures emergent phenomena
- Emergence
  - Emergent phenomena result from the interactions of individual entities. **The whole is more than the sum of its parts** [Aristotle BC] because of the interactions between the parts.
  - An emergent phenomenon can have properties that are decoupled from the properties of the part (e.g. patterns appearing).
  - Example: Traffic Jam Dynamics

Agent-Based Modelling

- When to use ABM? [Siebers et al. 2010]
  - When the problem has a **natural representation as agents** - when the goal is modelling the behaviours of individuals in a diverse population
  - When agents have relationships with other agents, especially **dynamic relationships** - agent relationships form and dissipate, e.g., structured contact, social networks
  - When it is important that individual agents have **spatial or geo-spatial aspects** to their behaviours (e.g. agents move over a landscape)
  - When it is important that agents **learn or adapt**, or populations adapt
  - When agents engage in **strategic behaviour**, and anticipate other agents' reactions when making their decisions
  - ...

Agent-Based Simulation

- Little Computer People (LCP) @ C64 @ 1985
  - This "House on a Disk" is based on the theory that every computer has an "occupant"; every occupant is different
  - You could communicate with your occupant by asking him what you want him to do
    - "Please play with me"
    - "Please play piano"
    - "Please write a letter to me"
    - "Please talk to me"

Agent-Based Simulation

- The Sims: Interactive Organisational Agent-Based Simulation

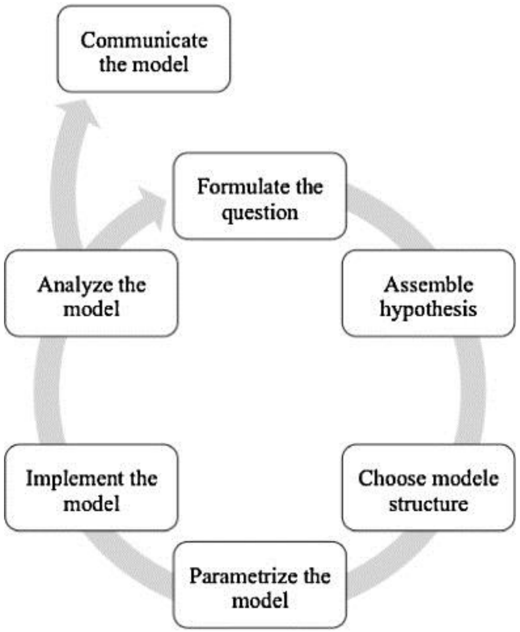
Agent-Based Simulation

- Building an ABS model (OR/MS)
  - Identify active entities (agents)
  - Define their states and behaviour
  - Put them in an environment
  - Establish connections
  - Test the model

AnyLogic Help (2013)

- Validating an ABS model
  - System behaviour is an emergent property
  - Validation on a micro level

- Alternative (e.g. Ecology)



Grimm and Railsback (2005)

Agent-Based Simulation – Updating Information

- Synchronous approach [Macal 2013]
  - Loop over time horizon
    - Loop over randomised list of agents. For each **agent A** in list:
      - Execute **agent A** behaviour
      - Update state of **agent A** (based on **agent A**'s state, the states of agents that interact with **agent A**, and the state of the environment).
      - Update other agents states and the environment (if appropriate)
    - End loop over randomized list of agents
  - Increment t in time loop and repeat until end of simulation time horizon

Agent-Based Simulation – Updating Information

- Asynchronous approach [openABM.org 2014]
  - Event driven
    - An action of one agent may trigger the updating of another agent
      - Example: An **agent A** sending messages to an **agent B**

Object Oriented ABM

Using UML for ABM

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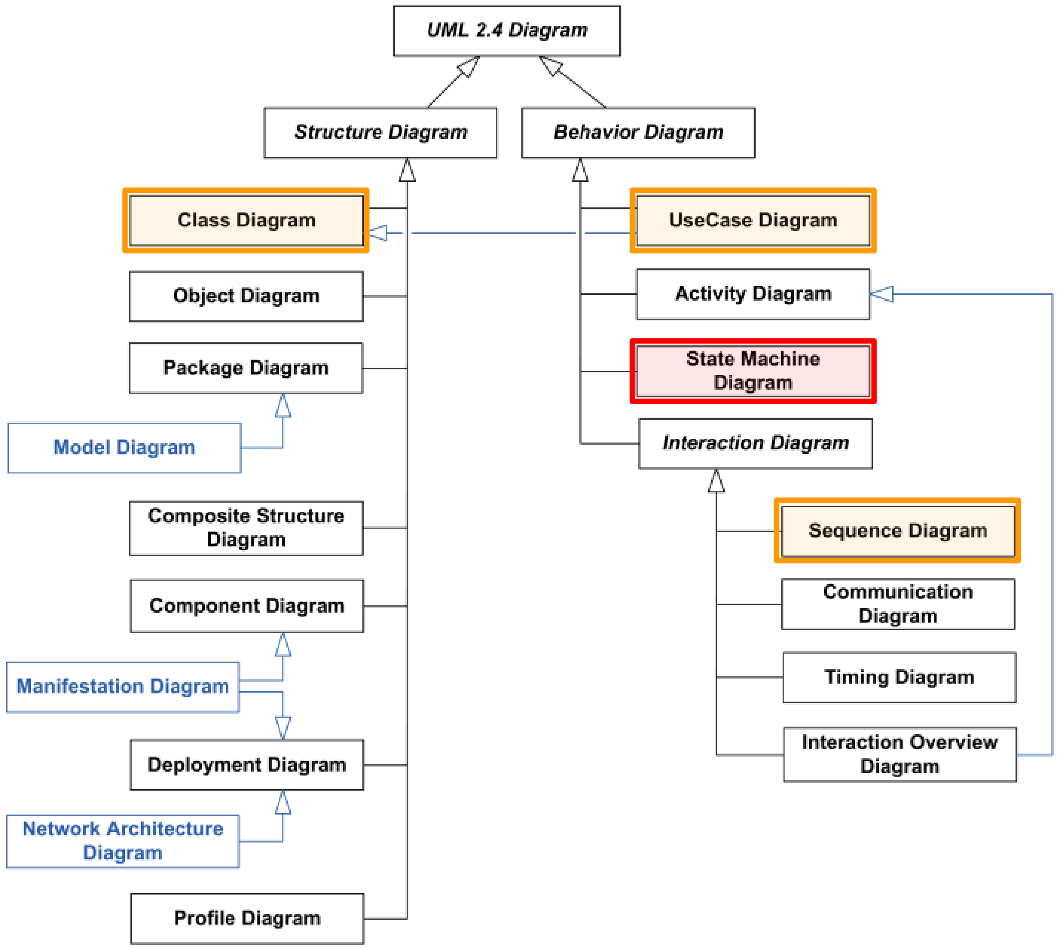
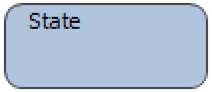
Unified Modelling Language (UML)



Defining Behaviour Using State Charts

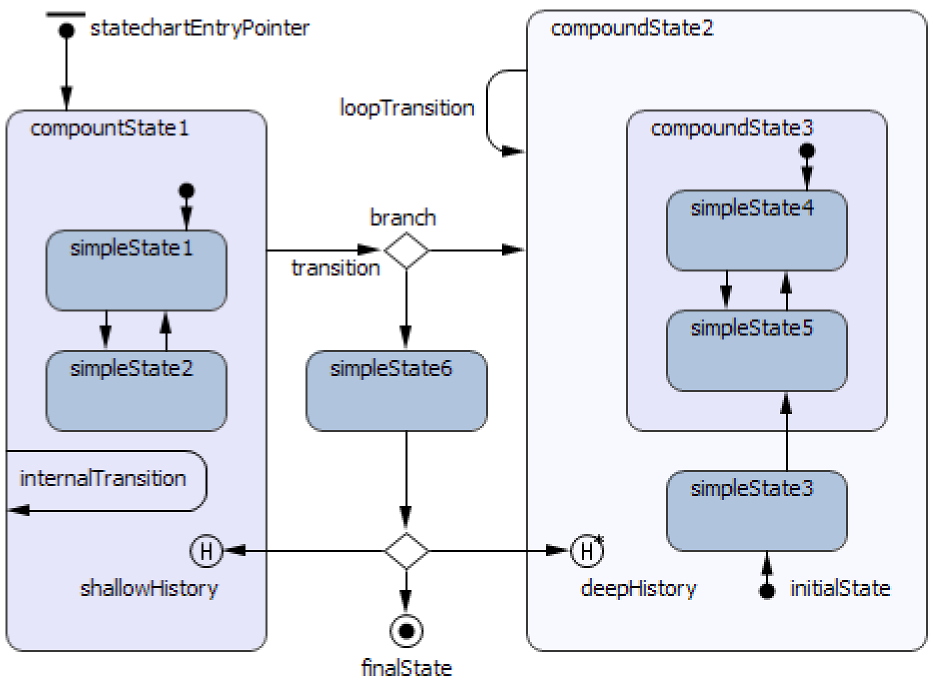
- Typical elements of a state chart diagram
  - States
    - Represents a location of control with a particular set of reactions to conditions and/or events



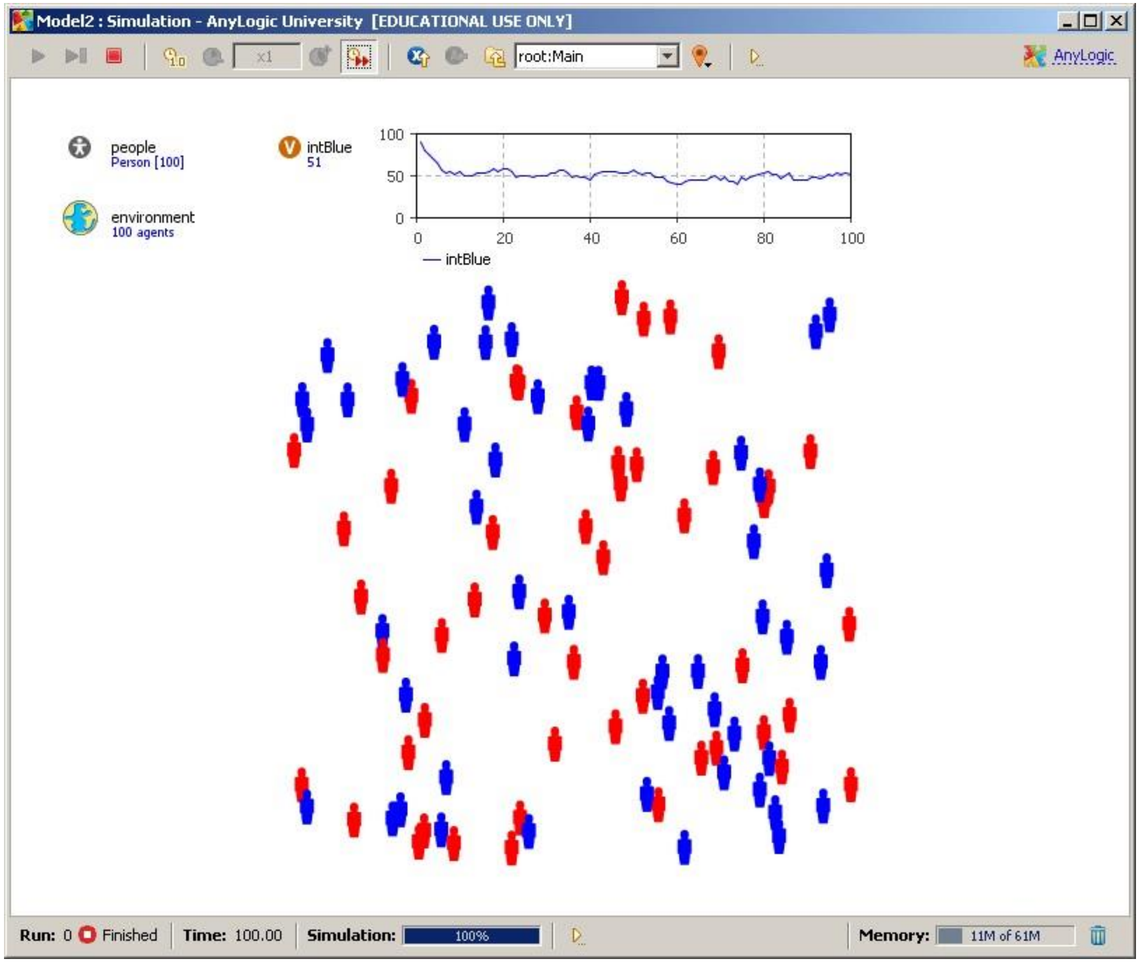
    - Examples
      - Cup can be in state **full** or **empty**
      - Person can be in state **idle** or **busy**
  - Transitions
    - Movement between states, triggered by a specific event

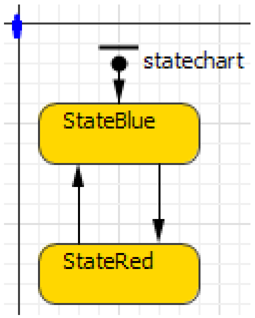
Defining Behaviour Using State Charts

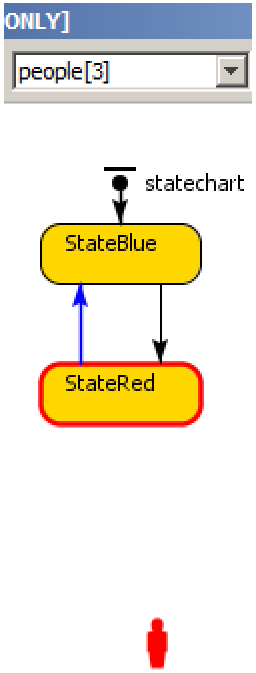
- Typical elements of a state chart diagram



Simple Agent-Based Example





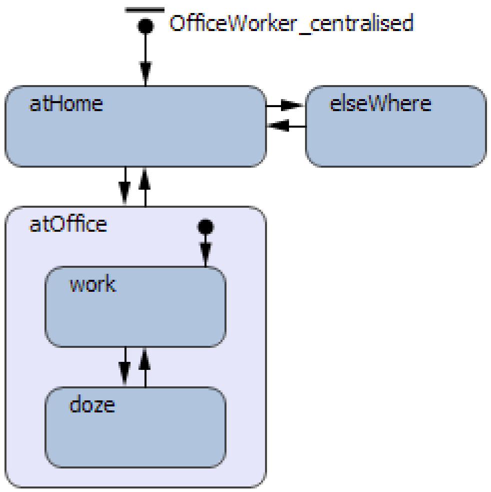


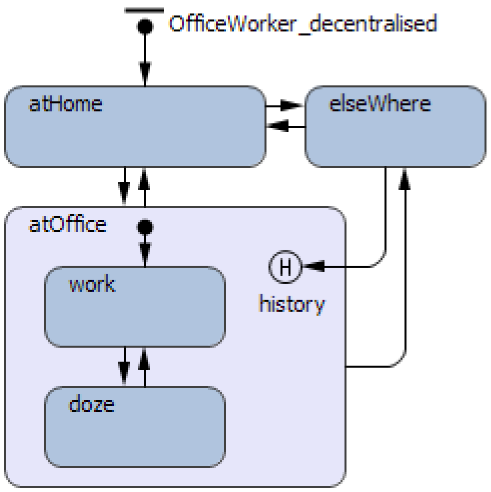
Building Simple State Charts Step-by-Step

- Office workers
  - What question do you want to answer?
  - Who are the actors?
  - What are the key locations you can find them?
  - What are key time consuming activities they get involved in?

Building Simple State Charts Step-by-Step

- What is the principal difference between these solutions?





Challenge

- Try to implement a simple office worker model in AnyLogic?

Agent Oriented DES

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Agent Oriented DES in OR/MS

- Hybrid solution for OR/MS
  - In OR/MS we often have combined DES/ABS models where we represent the process flow as a DES model and then add some active entities (to replace the passive DES entities) that are autonomous and can display proactive behaviour.

Communication layer

Direct interactions
Network activities

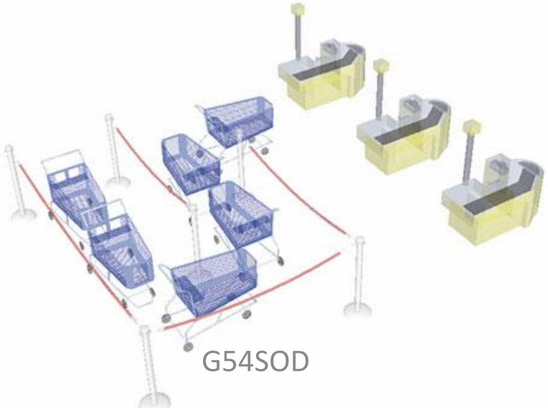
Let entities interact + communicate

Agent layer

Active entities
Behavioural state charts

Replace passive entities by active ones

DES layer



Passive entities
Queues
Processes
Resources

Agent Oriented DES in OR/MS

- Agent Oriented DES version of the booking clerk model?
  - Might respond flexible when too many phone callers are in the line
  - Customers might remember previous experience and act accordingly
  - Modelling word of mouth regarding service quality - how much impact does the reputation of the clerk have on the business?
  - Booking clerk might show symptoms of fatigue during a long shift and therefor vary in service speed

Case Study

Simulation of Rail Passengers to Evaluate Methods to Reduce Dwell Times

(For more details see Perkins et al 2015)

Problem Statement

- The rail network in the UK is fast approaching maximum capacity and passenger numbers are growing 6-7% per year
- One relatively simple (and therefore cheap) way to increase capacity of the rail network is to reduce loading/unloading times (dwell time)

Aim and Approach

- Aim
  - Test the feasibility of using agent based modelling for assessing novel methods of reducing dwell times

- Approach
  - Using Xi's Extended Social Force Model (ESFM) together with a novel decision making algorithm for passengers' door choice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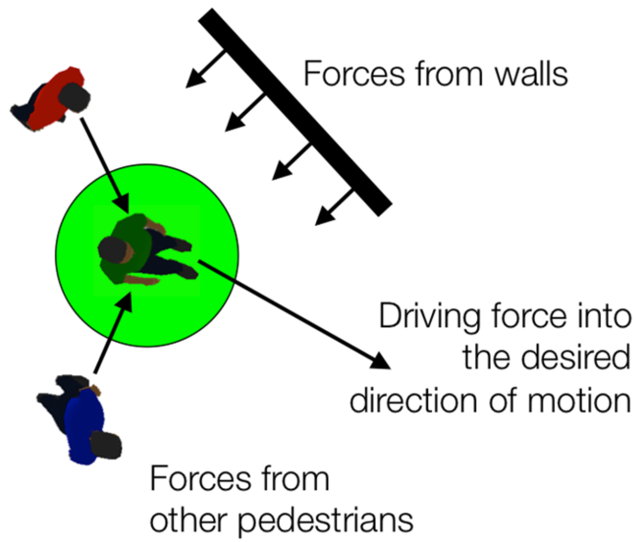
Base Model

- The "social force model" (Helbing and Molnar 1995) assumes that the acceleration, deceleration and directional changes of pedestrians can be approximated by a sum of different forces, each capturing a different desire or interaction effect.



http://futurict.blogspot.it/2014/12/social-forces-revealing-causes-of.html

Base Model

- SFM was implemented by computing the force on an agent at each time step, using the model provided by Xi et al. (2010).

$$m_i \frac{d\boldsymbol{v}_i}{dt} = m_i \frac{v_i^0(t)\boldsymbol{e}_i^0(t) - \boldsymbol{v}_i(t)}{\tau_i} + \sum_{j(\neq i)} \boldsymbol{f}_{ij} + \sum_W \boldsymbol{f}_{iW}$$

$$\boldsymbol{f}_{ij} = \boldsymbol{f}_{ij}^{psy} + \boldsymbol{f}_{ij}^{phy}, \quad \boldsymbol{f}_{ij}^{psy} = A_i \exp\left(\frac{r_{ij} - d_{ij}}{B_i}\right)\boldsymbol{n}_{ij}$$

$$\boldsymbol{f}_{ij}^{phy} = kg\left(r_{ij} - d_{ij}\right)\boldsymbol{n}_{ij} + \kappa g(r_{ij} - d_{ij})\Delta v_{ji}^t \boldsymbol{t}_{ij}$$

- First equation depicts the formulation of changing velocity at time t, where a pedestrian's behaviour is determined by his/her desired speed (v) and direction (e) as well as interactions with other individuals and obstacles. The first term on the right side of first equation represents the impact from the pedestrian's self consciousness, while the other two illustrate interaction forces from other pedestrians and the walls, respectively

- The total force exerted by pedestrian j to pedestrian i is calculated in the second equation. The interaction forces consist of a psychological force resulting from the distance between each other and a physical force inspired by counteractive body compression and sliding friction

Base Model

- We later decided to incorporate an Extended Social Force Model (ESFM) which adds "vision" to the SFM.

- A simple way of considering vision is to use a "form factor" coefficient which modifies the psychological force felt by a passenger.

- We also developed a novel decision making algorithm which is based on a passenger's knowledge of the station, as well as their environment.

Model Calibration

- From this, the parameters used in the SFM could be calibrated in order to produce realistic behaviour (using trial and error).

- Four behaviours are to be expected: (Helbing and Molnar, 1995; Helbing et al. 2000)
  - Clogging at bottlenecks
  - Lane formation
  - Oscillations at doorways
  - Freezing by heating
    - Pedestrians' high desired velocity resulting in slower overall movements

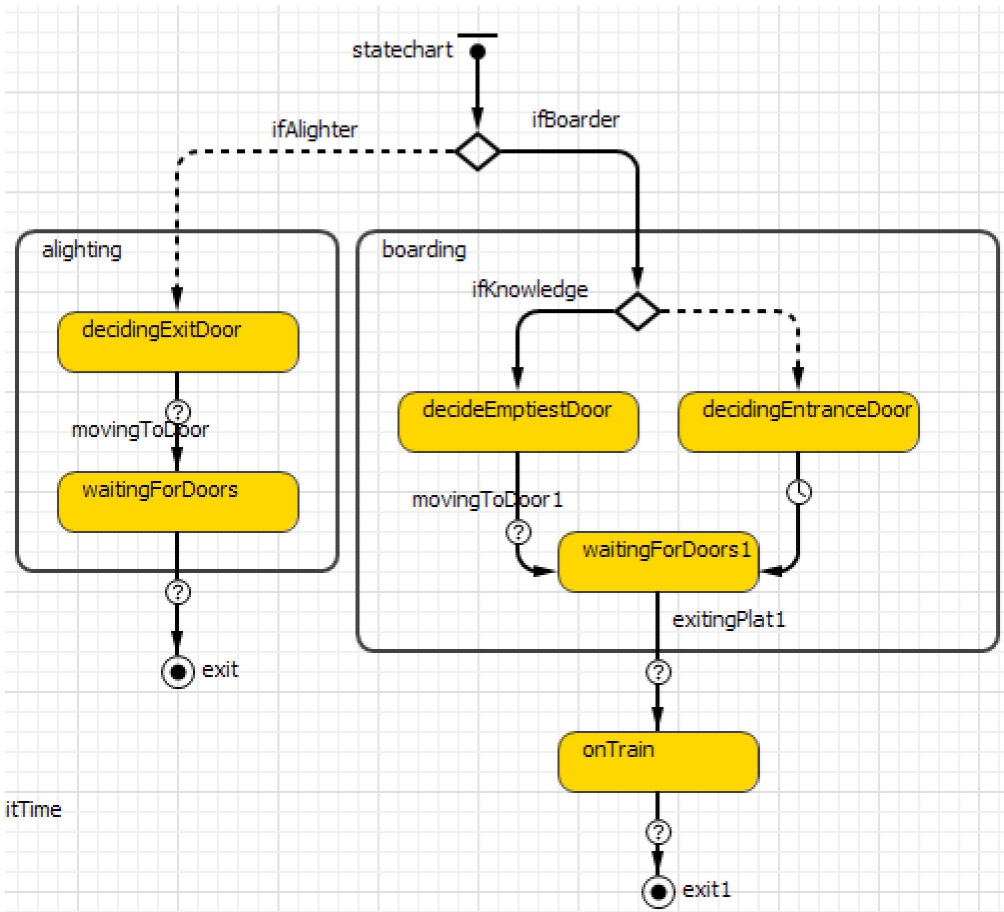
Passenger Types

- Passenger decision-making process depends on "knowledge"
  - If a passenger has knowledge of the station (e.g. commuter) they base their decision on the least crowded door.
  - If a passenger does not have knowledge of the station (e.g. tourist), there are two different decision-making processes, depending on their arrival time relative to the train's arrival time.
    - Early arrivals will move towards the nearest anticipated door area.
    - Late arrivals pass by each door in turn. If the crowdedness at a door is under a specified threshold, the passenger will choose that door to enter.

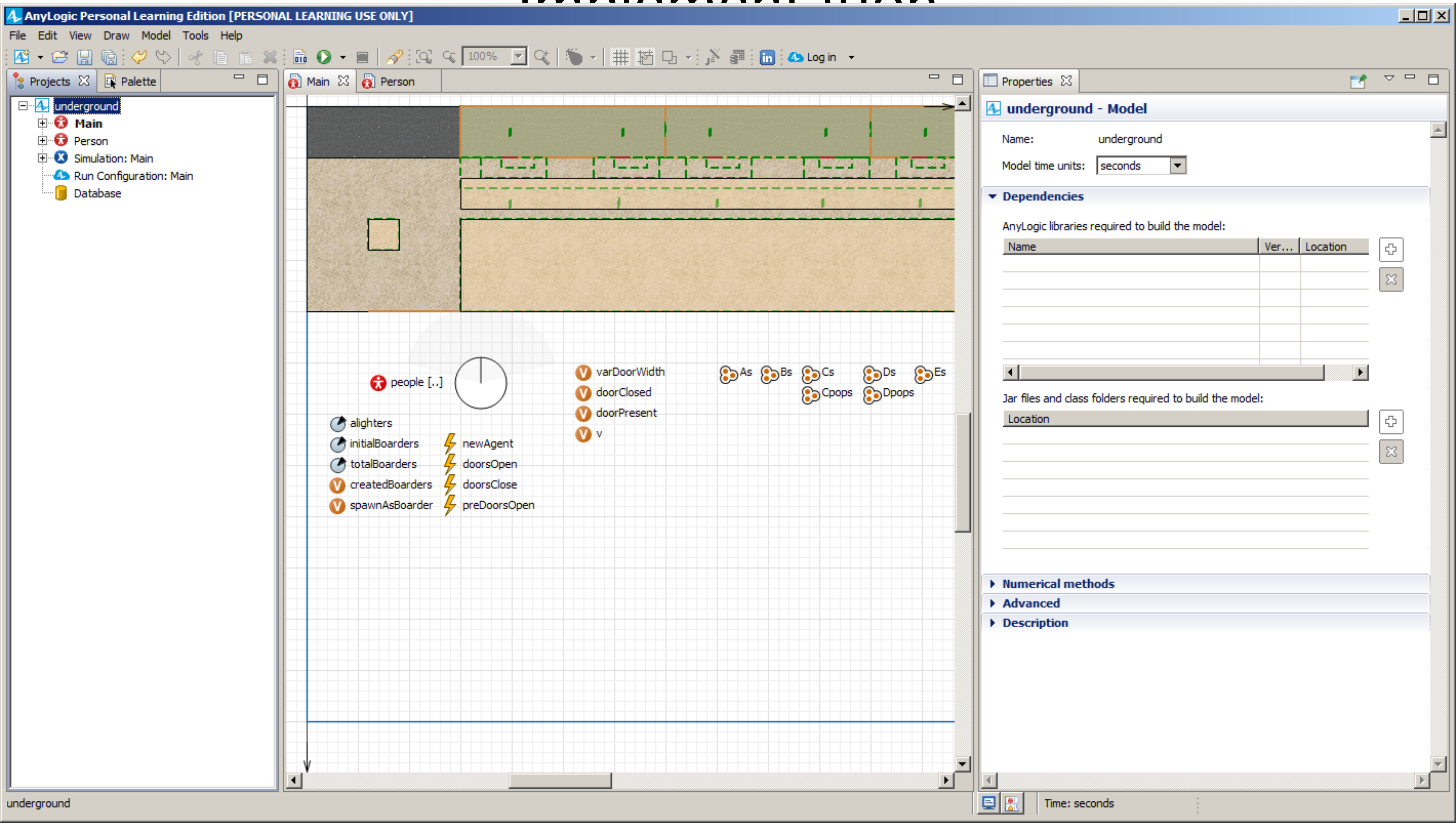
Passenger Types

- For simplicity, it was also assumed that boarders do not wait for alighters before they start moving, and instead it is left to the social force to decide which group moves, hopefully oscillating, depending on relative group sizes.

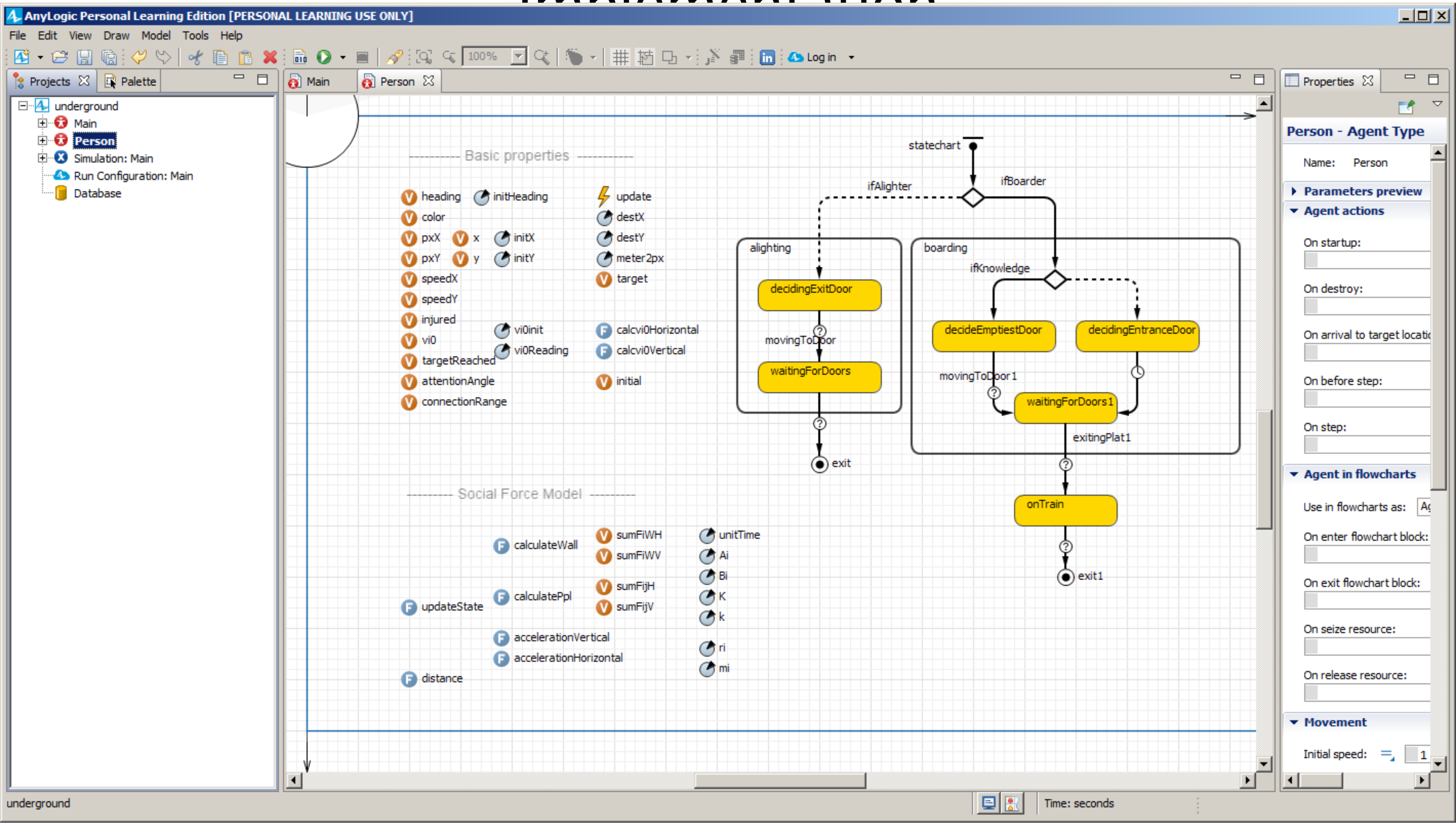
Passenger States



Implementation



Implementation



Implementation

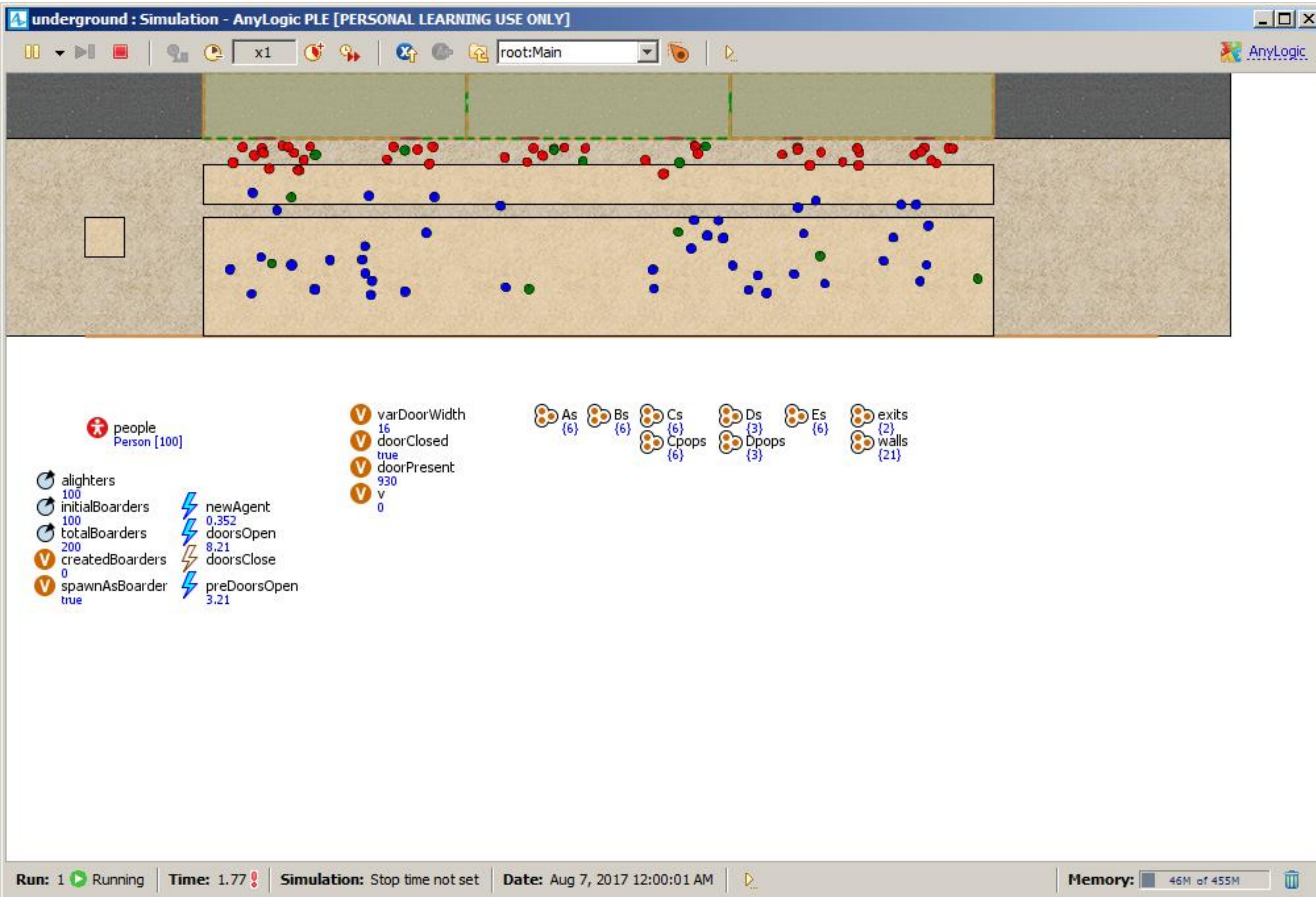
calculateWall - Function

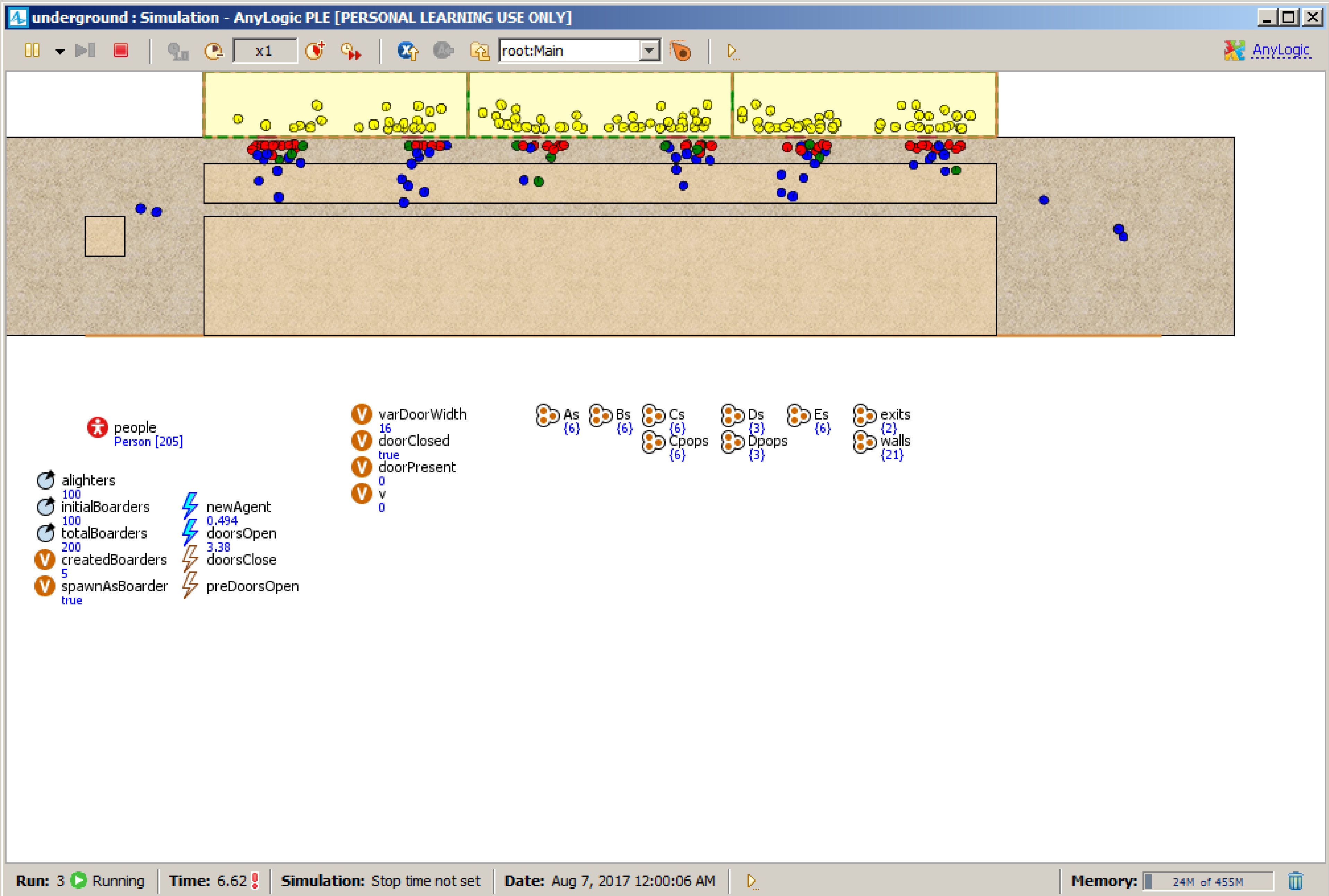
```
sumFiWH = 0;
sumFiWV = 0;
for(Wall w : get_Main().walls){
    Point p = new Point();
    double sqrdist = w.getNearestPoint(pxX,pxY,p);
    double diW = -1;
    if((diW = sqrt(sqrdist)/meter2px) > connectionRange){continue;}

    double theta = atan2(p.getY()-y, p.getX()-x)-atan2(speedY,speedX);
    double cosTheta = 1;
    if(theta<(-attentionAngle/2) || theta>(attentionAngle/2)){
        cosTheta = 0;
    }

    double niW1,niW2,tiW1,tiW2;
    double gx;
    double deltavH, deltavV, deltav;
    double fpsy,fbody,friction;
    double fiWH,fiWV;
    //System.out.println("x="+p.getX()+" y="+p.getY()+"   "+diW);
    niW1 = (x==(p.getX()/meter2px) ? 0:(x-(p.getX()/meter2px))/diW);
    niW2 = (y==(p.getY()/meter2px) ? 0:(y-(p.getY()/meter2px))/diW);
    tiW1 = -niW2;
    tiW2 = niW1;
    gx = (diW>ri ? 0:(ri-diW));
    //System.out.println("ri-diW="+(ri-diW));
    fpsy = Ai*exp((ri-diW)/Bi)*cosTheta;
    fbody = K*gx*100;
    //fpsy = 0;
    //fbody = 0;
    deltavH = -speedX;
    deltavV = -speedY;
    deltav = deltavH*tiW1+deltavV*tiW2;
    friction = k*gx*deltav;
    //friction = 0;
    fiWH = (fpsy+fbody)*niW1+friction*tiW1;
    fiWV = (fpsy+fbody)*niW2+friction*tiW2;
    sumFiWH += fiWH;
    sumFiWV += fiWV;
}
```

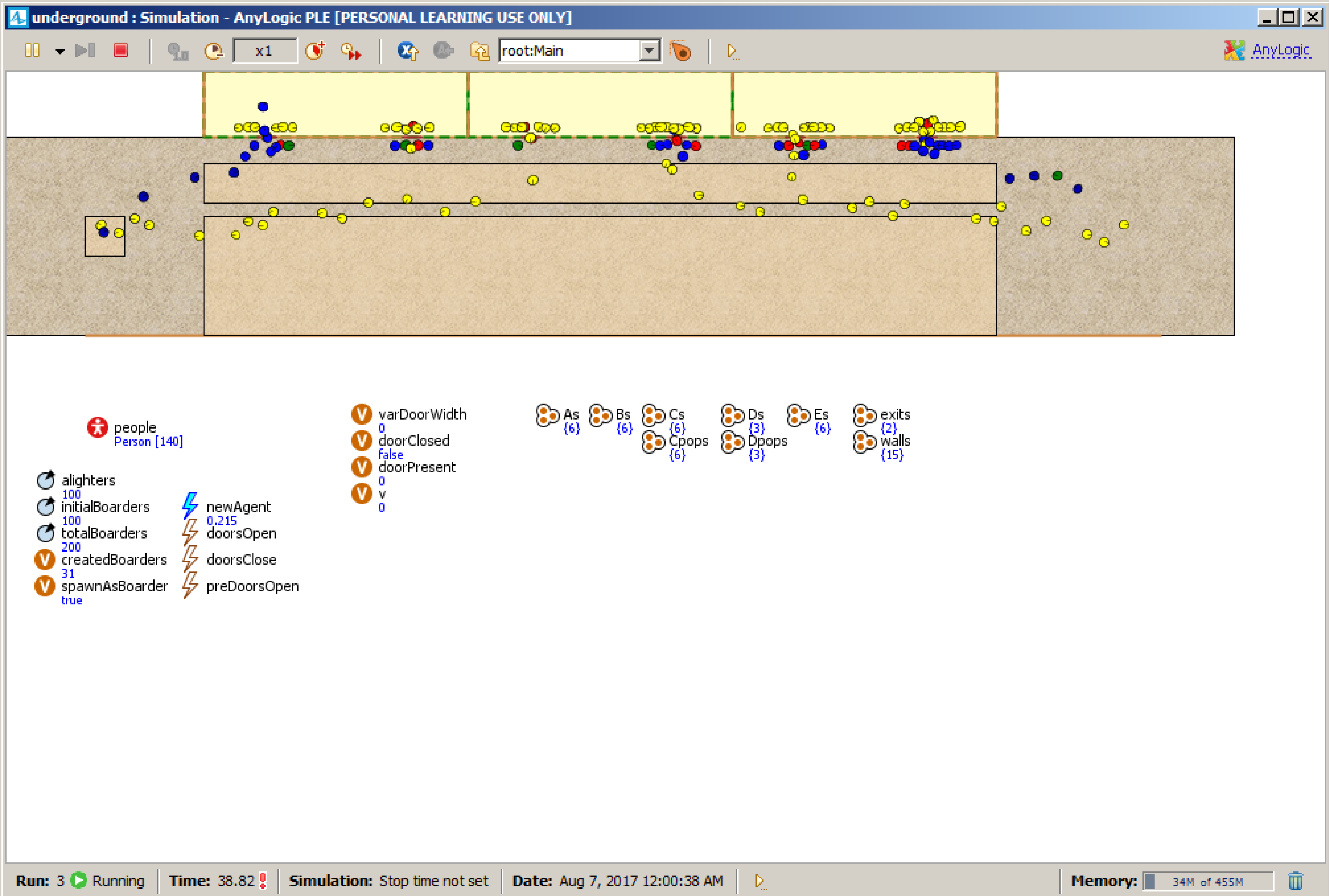
calculatePpl - Function

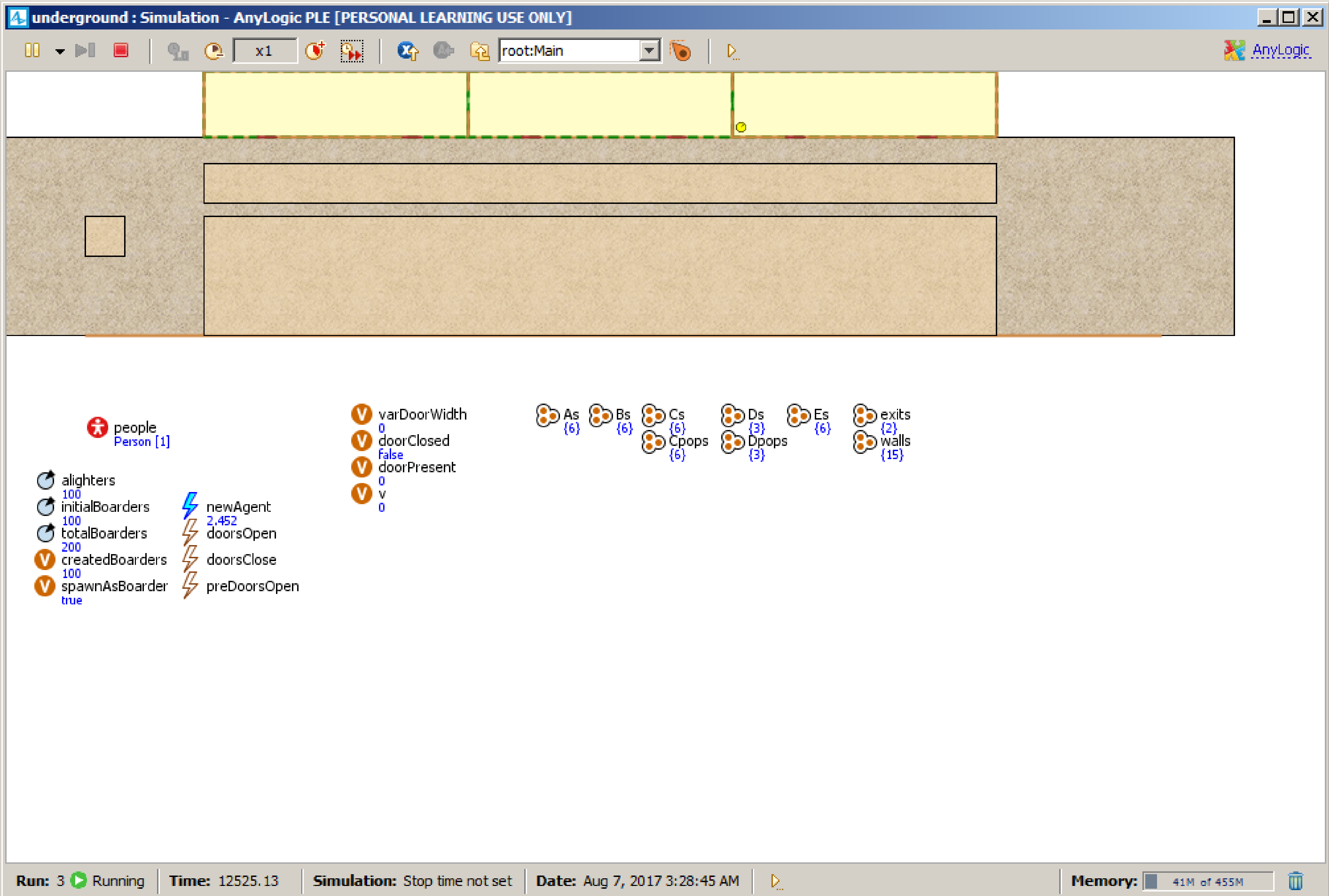
```
sumFijH = 0;
sumFijV = 0;
for(Person j : get_Main().people){
    if(this==j){continue;}
    double dij = -1;
    if((dij = distance(x,y,j.x,j.y)) > connectionRange){continue;}

    double theta = atan2(j.y-y, j.x-x)-atan2(speedY,speedX);
    double cosTheta = 1;
    if(theta<(-attentionAngle/2) || theta>(attentionAngle/2)){
        cosTheta = 0;
    }

    double nij1,nij2,tij1,tij2;
    double rij,gx;
    double deltavH, deltavV, deltav;
    double fpsy,fbody,friction;
    double fijH,fijV;
    rij = ri+j.ri;
    //dij = distance(x,y,j.x,j.y);
    nij1 = (x==j.x ? 0:(x-j.x)/dij);
    nij2 = (y==j.y ? 0:(y-j.y)/dij);
    tij1 = -nij2;
    tij2 = nij1;
    gx = (dij>rij ? 0:(rij-dij));
    fpsy = Ai*exp((rij-dij)/Bi)*cosTheta;

    //fpsy=0;
    //fbody = 0;
    fbody = K*gx;

    deltavH = j.speedX-speedX;
    deltavV = j.speedY-speedY;
    deltav = deltavH*tij1+deltavV*tij2;
    friction = k*gx*deltav;
    //friction = 0;
    fijH = (fpsy+fbody)*nij1+friction*tij1;
    fijV = (fpsy+fbody)*nij2+friction*tij2;
    sumFijH += fijH;
    sumFijV += fijV;
}
```

...

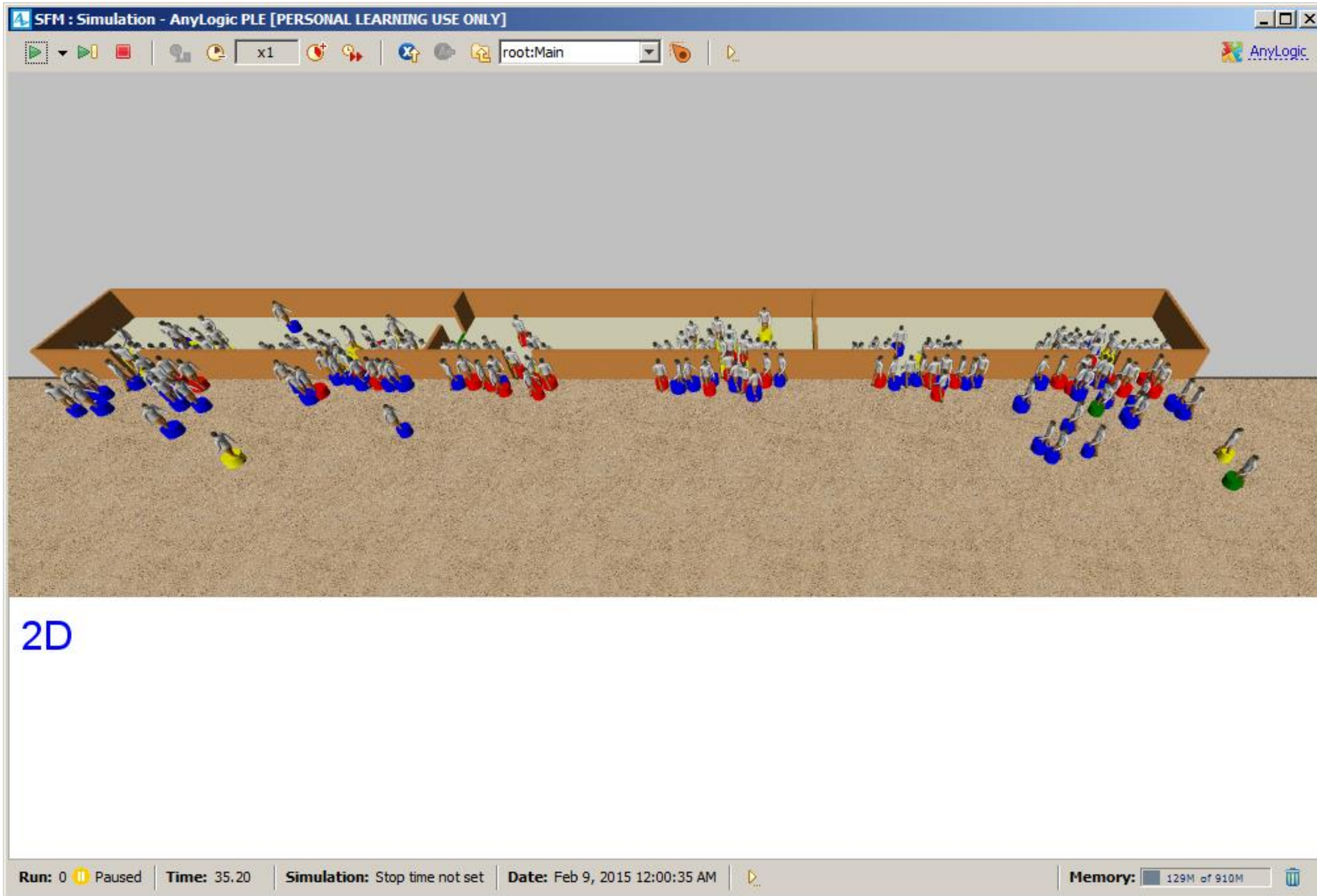

underground : Simulation - AnyLogic PLE [PERSONAL LEARNING USE ONLY]
x1
root:Main
AnyLogic
people
Person [100]
varDoorWidth
16
doorClosed
true
doorPresent
930
v
0
As
{6}
Bs
{6}
Cs
{6}
Cpops
{6}
Ds
{3}
Dpops
{3}
Es
{6}
exits
{2}
walls
{21}
alighters
100
initialBoarders
100
totalBoarders
200
createdBoarders
0
spawnAsBoarder
true
newAgent
0.352
doorsOpen
8.21
doorsClose
preDoorsOpen
3.21
Run: 1 Running
Time: 1.77
Simulation: Stop time not set
Date: Aug 7, 2017 12:00:01 AM
Memory:
46M of 455M

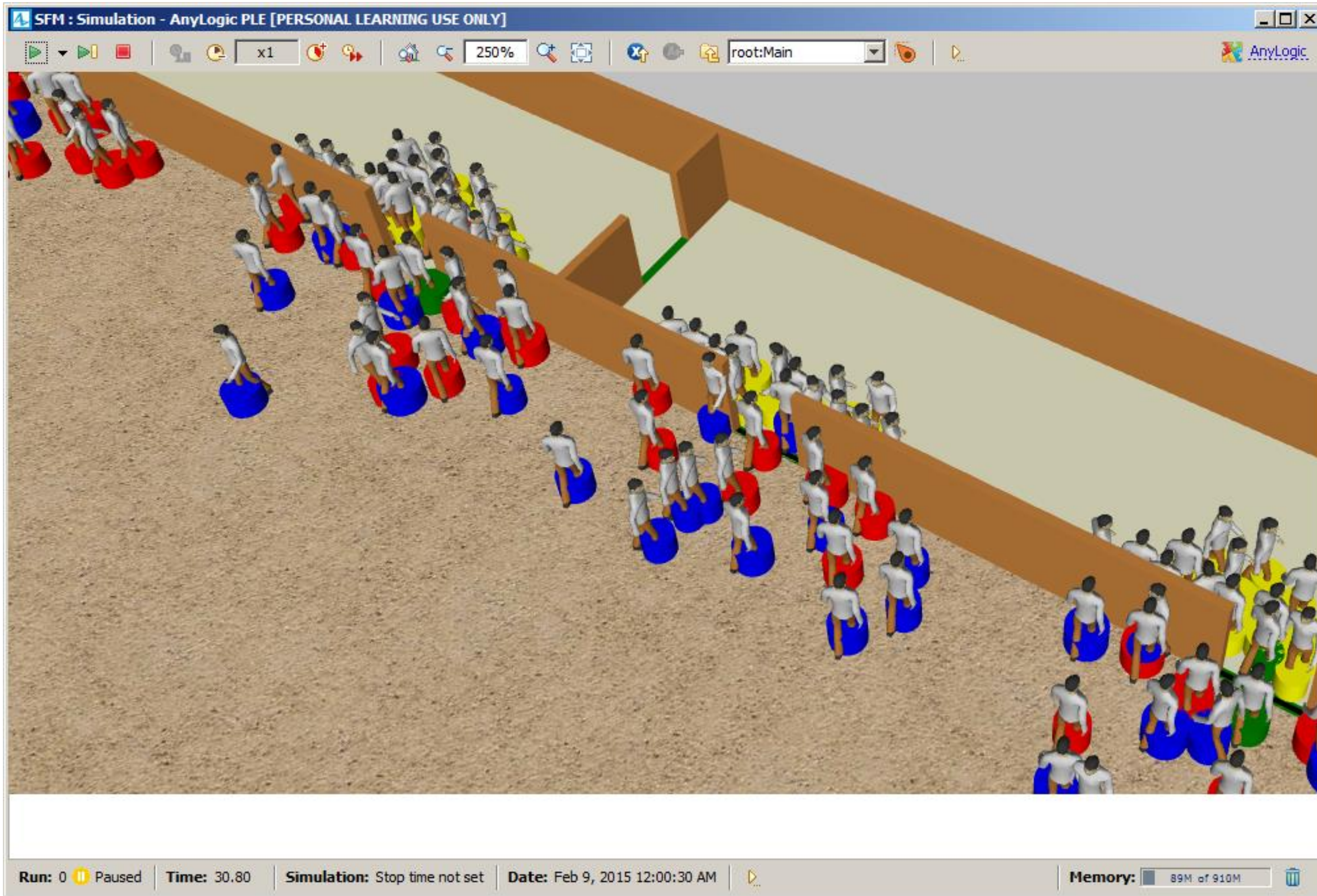

underground : Simulation - AnyLogic PLE [PERSONAL LEARNING USE ONLY]
x1
root:Main
AnyLogic
people
Person [205]
varDoorWidth
16
doorClosed
true
doorPresent
0
v
0
As
{6}
Bs
{6}
Cs
{6}
Cpops
{6}
Ds
{3}
Dpops
{3}
Es
{6}
exits
{2}
walls
{21}
alighters
100
initialBoarders
100
totalBoarders
200
createdBoarders
5
spawnAsBoarder
true
newAgent
0.494
doorsOpen
3.38
doorsClose
preDoorsOpen
Run: 3 Running
Time: 6.62
Simulation: Stop time not set
Date: Aug 7, 2017 12:00:06 AM
Memory:
24M of 455M


underground : Simulation - AnyLogic PLE [PERSONAL LEARNING USE ONLY]
x1
root:Main
AnyLogic
people
Person [140]
varDoorWidth
0
doorClosed
false
doorPresent
0
v
0
As
{6}
Bs
{6}
Cs
{6}
Cpops
{6}
Ds
{3}
Dpops
{3}
Es
{6}
exits
{2}
walls
{15}
alighters
100
initialBoarders
100
totalBoarders
200
createdBoarders
31
spawnAsBoarder
true
newAgent
0.215
doorsOpen
doorsClose
preDoorsOpen
Run: 3 Running
Time: 38.82
Simulation: Stop time not set
Date: Aug 7, 2017 12:00:38 AM
Memory: 34M of 455M



underground : Simulation - AnyLogic PLE [PERSONAL LEARNING USE ONLY]
x1
root:Main
AnyLogic
people
Person [1]
alighters
100
initialBoarders
100
totalBoarders
200
createdBoarders
100
spawnAsBoarder
true
newAgent
2.452
doorsOpen
doorsClose
preDoorsOpen
varDoorWidth
0
doorClosed
false
doorPresent
0
v
0
As
{6}
Bs
{6}
Cs
{6}
Cpops
{6}
Ds
{3}
Dpops
{3}
Es
{6}
exits
{2}
walls
{15}
Run: 3 Running
Time: 12525.13
Simulation: Stop time not set
Date: Aug 7, 2017 3:28:45 AM
Memory: 41M of 455M


SFM : Simulation - AnyLogic PLE [PERSONAL LEARNING USE ONLY]
x1
root:Main
AnyLogic
2D
Run: 0 Paused
Time: 35.20
Simulation: Stop time not set
Date: Feb 9, 2015 12:00:35 AM
Memory: 129M of 910M


SFM : Simulation - AnyLogic PLE [PERSONAL LEARNING USE ONLY]
x1
250%
root:Main
AnyLogic
Run: 0
Paused
Time: 30.80
Simulation: Stop time not set
Date: Feb 9, 2015 12:00:30 AM
Memory:
89M of 910M

Experimentation

- Four scenarios are considered (1/2)
  - Scenario 1: The "standard" generic scenario.
    - 600 passengers (split evenly between boarders, alighters, and stayers)
    - Normal distribution of desired walking speeds (mean = 1.3m/s; standard deviation = 0.2m/s)
    - 10% of passengers have "knowledge" of emptiest door
  - Scenario 2: The "rush hour" scenario in which the majority of the passengers are expected to be middle-aged commuters.
    - 1200 passengers (split equally between boarders, alighters and stayers)
    - Normal distribution of desired walking speeds (mean = 1.47m/s; standard deviation = 0.2m/s)
    - 50% of passengers have "knowledge" of the emptiest door

Experimentation

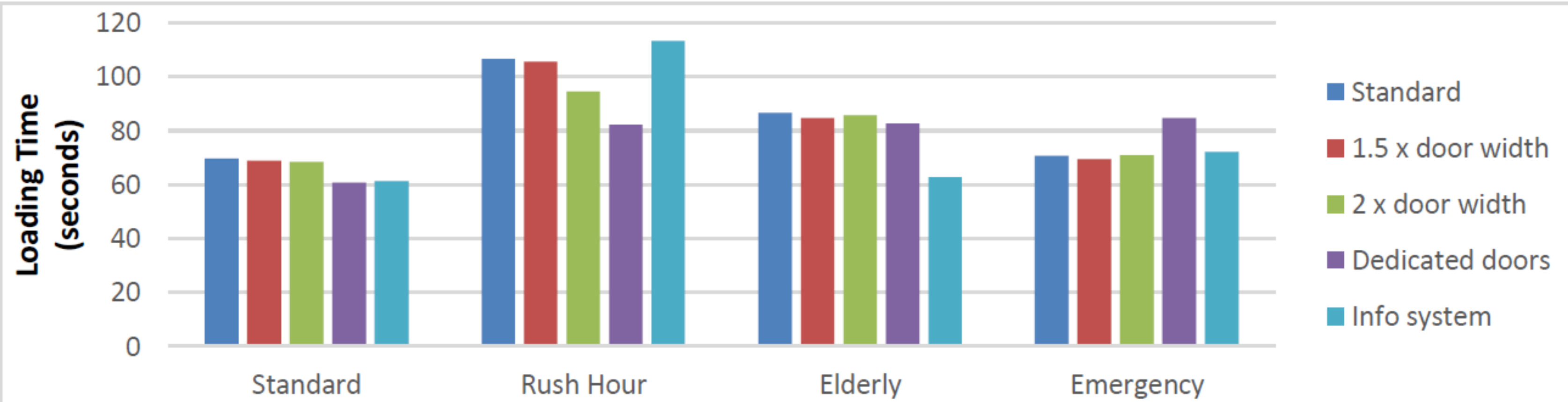
- Four scenarios are considered (2/2)
  - Scenario 3: "OAP day out" in which a large number of passengers are elderly passengers.
    - 600 passengers (split evenly between boarders, alighters, and stayers)
    - Normal distribution of desired walking speeds (mean = 1.0m/s; standard deviation = 0.5m/s)
    - 10% of passengers have "knowledge" of emptiest door
  - Scenario 4: The "Emergency" scenario, to assess how well the train and platform can be cleared, including a higher desired velocity representing panic.
    - 400 passengers (all of which being alighters)
    - Normal distribution of desired walking speeds (mean = 3.0m/s; standard deviation = 1.0m/s)
    - 10% of passengers have "knowledge" of emptiest door

Experimentation

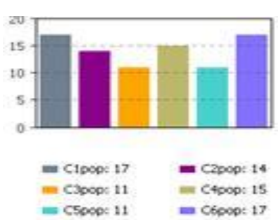
- For the four scenarios we compare five strategies:
  - Base case
  - 1.5x wider doors
  - 2x wider doors
  - Designated boarding and alighting door
  - An active passenger information system

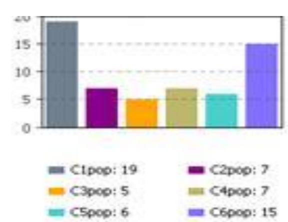
Experimentation

- The quantitative output was total loading time



- There are a number of other numerical outputs available
  - Separation of boarding and alighting times
  - Door utilisation dynamics





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Future Work

- This was just a feasibility study!
  - There are still bugs

- Next steps:
  - Modelling the interior of the train
  - Modelling groups: The ESFM also includes a socially attractive force between members of a group
  - Adding rules to let alighters off first (as it is the rule in Britain)
  - Adding agent learning

Questions and Comments

References

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A special thanks goes to Jamie Rodgers for finding a long lost reference for me.