



# Modelling and Simulation of Rail Passengers to Evaluate Methods to Reduce Dwell Times

Peer-Olaf Siebers

[pos@cs.nott.ac.uk](mailto:pos@cs.nott.ac.uk)

# Motivation

- Part 1
  - Introduce the concepts of object oriented Agent-Based Social Simulation (ooABSS)
- Part 2
  - Demonstrate the applicability of ooABSS to evaluate methods to reduce dwell times for rail passengers
- Part 3
  - Give you a brief overview of some other projects related to ooABSS

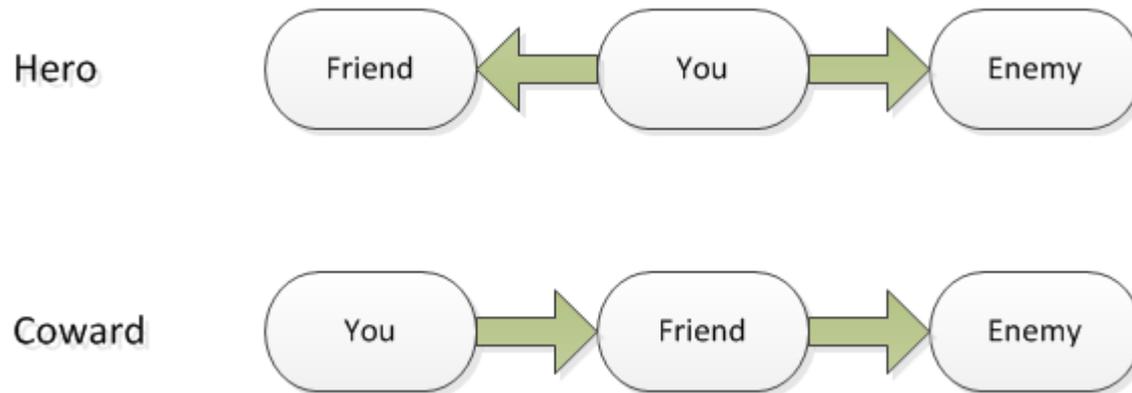
# Part 1

## Object Oriented Agent-Based Social Simulation



# Agent-Based Modelling

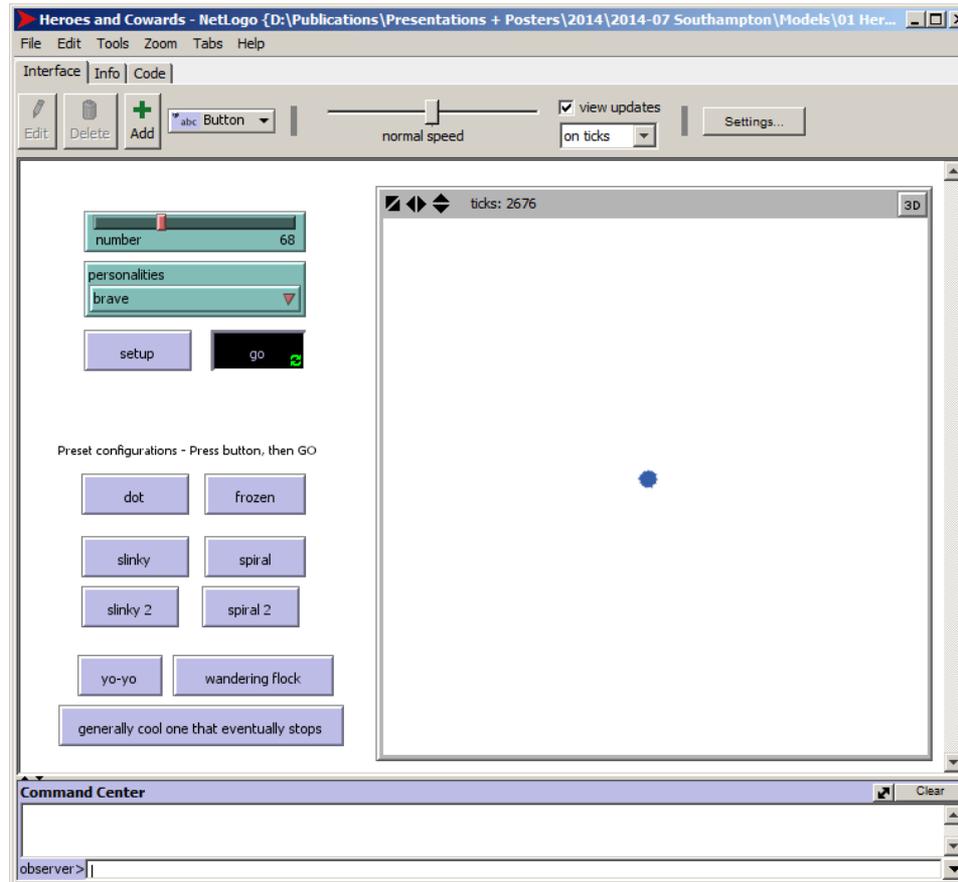
- Heroes and Cowards Game [Wilensky and Rand 2013]





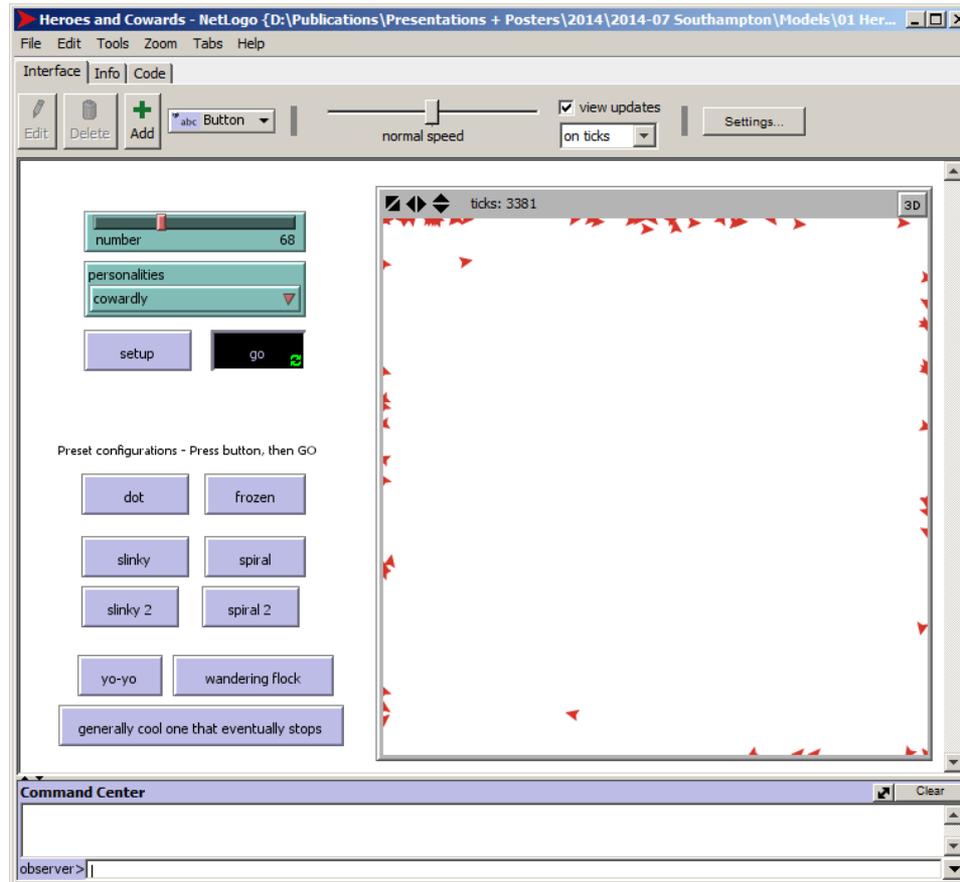
# Agent-Based Modelling

- Heroes and Cowards Game : All heroes



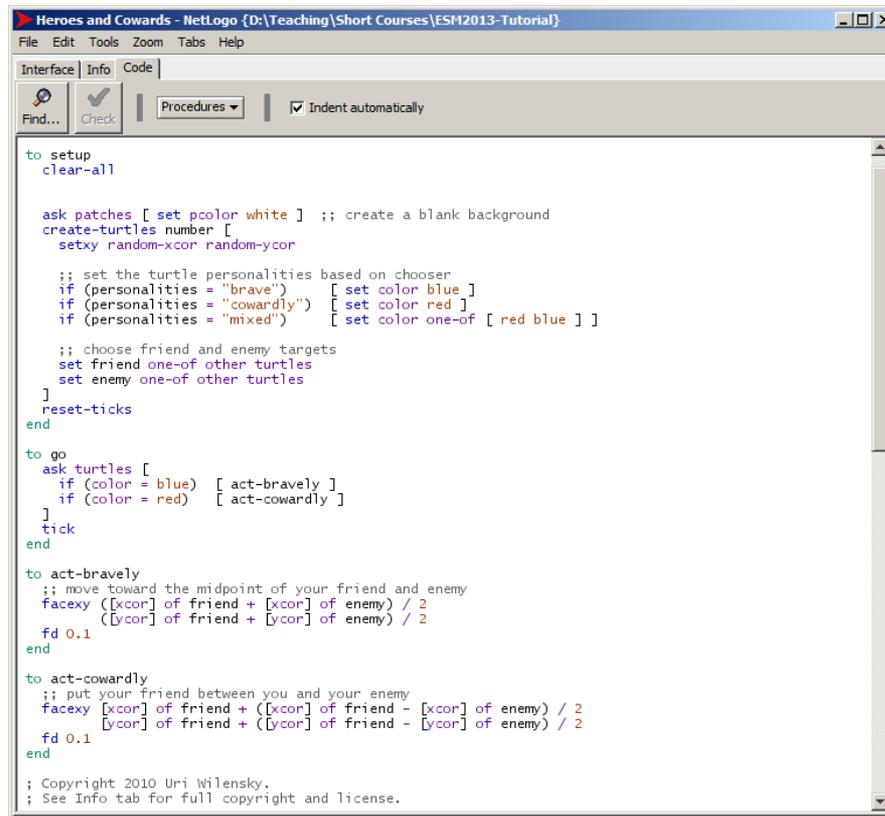
# Agent-Based Modelling

- 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

- 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

- What do we mean by "agent"?
  - Agents are **objects with attitude!**
- 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

- The Sims: Interactive Organisational Agent-Based Simulation

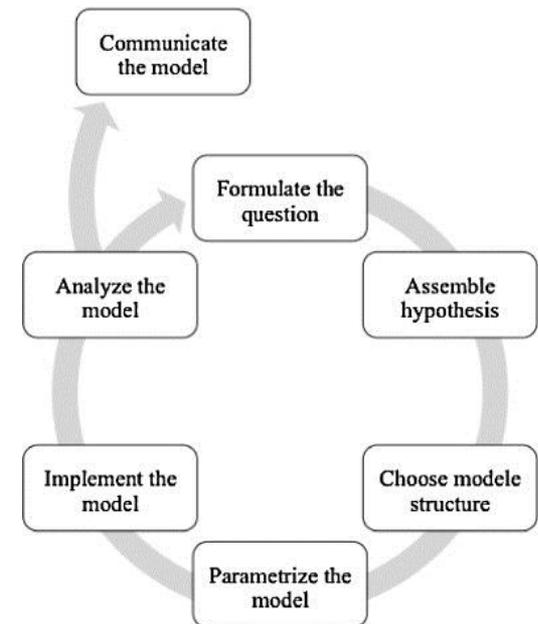


# Agent-Based Simulation

- 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)

- Alternative (e.g. Ecology)



Grimm and Railsback (2005)

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

# Agent-Based Simulation

- Simulation facts in different disciplines

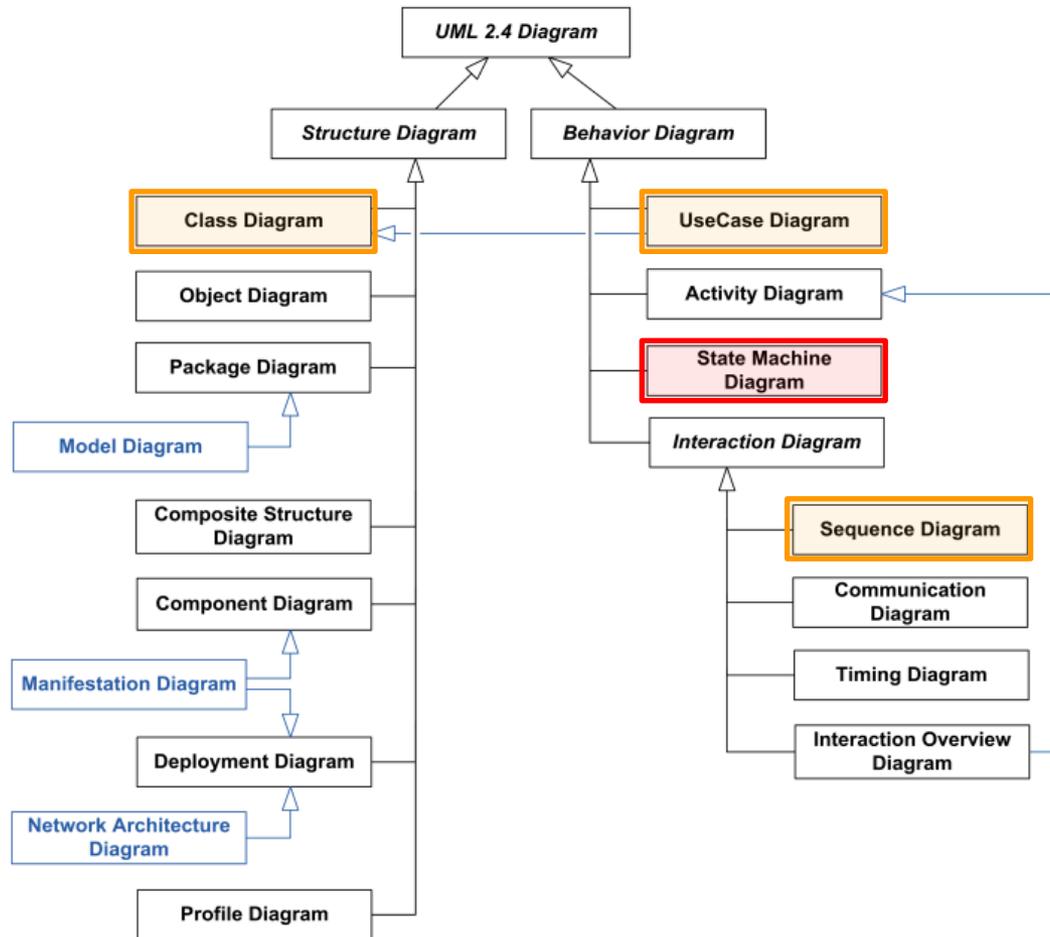
<b>Operations Research</b>	<b>Business, Economics, Social Science</b>
Empirical basis	Theoretical basis
Improving the real world	Thinking about the real world
Data collection and analysis	Dynamic hypothesis
Validation: Sufficient accuracy for purpose	Plausibility: Seeming reasonable or probable
Implementing findings	Learning + understanding

after Robinson (2010)

# Agent-Based Simulation

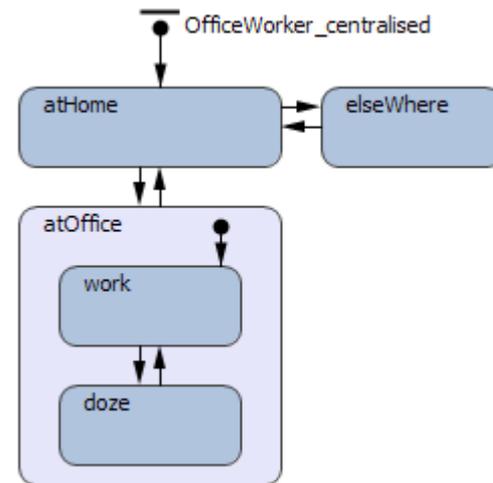
- Synchronous approach [Macal 2013]
  - Loop over time horizon
    - Loop over randomised list of agents. For each **agent A** in list:
      - Execute **agent A** behaviour
      - Update state of **agent A** (based on **agent A**'s state, the states of agents that interact with **agent A**, and the 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
- 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**

# Using Software Engineering Tools

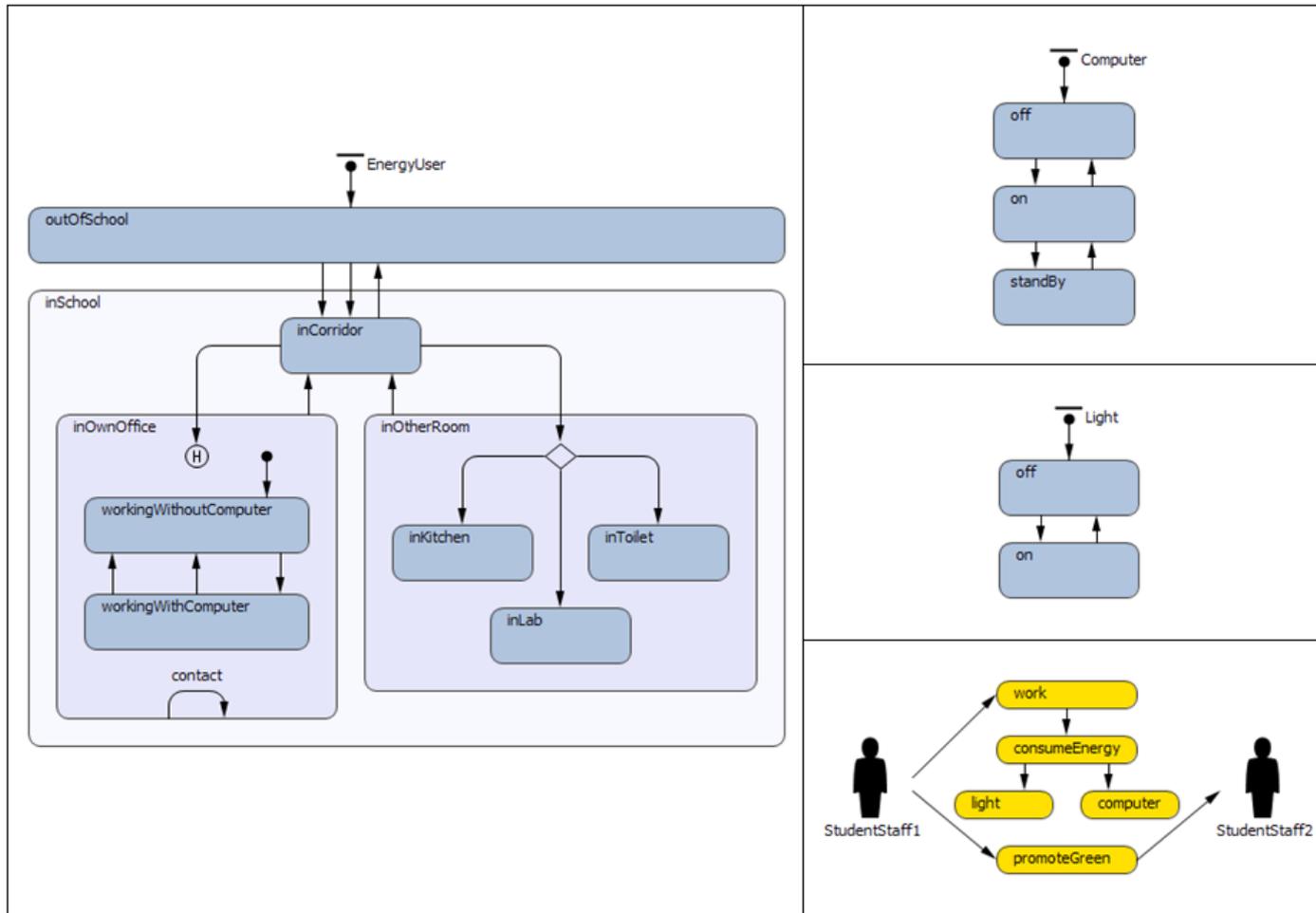


# Using Software Engineering Tools

- Building a state chart step-by-step
  - Who are the actors?
  - What are the key locations you can find them?
  - What are key time consuming activities they get involved in?



# Case Study: Office Energy Consumption [Zhang et al 2011]



# Part 2

## Case Study: Simulation of Rail Passengers to Evaluate Methods to Reduce Dwell Times

[Perkins et al 2015]



# Introduction



# 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

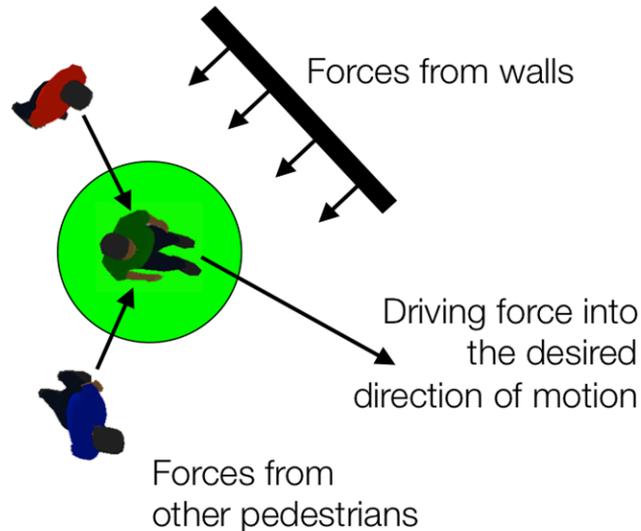


# Modelling Theory



# Social Force Model (SFM)

- 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>

# Agent-Based Modelling

- In Agent-Based Modelling (ABM) a system is modelled as a collection of autonomous interacting decision-making entities called agents.
- Each agent individually assesses its internal and external situation and makes decisions on the basis of a set of rules.
- ABM is well suited to modelling systems with heterogeneous, autonomous and proactive actors, such as human-centred systems.

# Modelling Practice



# 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).

$$m_i \frac{dv_i}{dt} = m_i \frac{v_i^0(t) e_i^0(t) - v_i(t)}{\tau_i} + \sum_{j(\neq i)} \mathbf{f}_{ij} + \sum_W \mathbf{f}_{iW}$$
$$\mathbf{f}_{ij} = \mathbf{f}_{ij}^{psy} + \mathbf{f}_{ij}^{phy}, \quad \mathbf{f}_{ij}^{psy} = A_i \exp\left(\frac{r_{ij} - d_{ij}}{B_i}\right) \mathbf{n}_{ij}$$
$$\mathbf{f}_{ij}^{phy} = kg(r_{ij} - d_{ij}) \mathbf{n}_{ij} + \kappa g(r_{ij} - d_{ij}) \Delta v_{ji}^t \mathbf{t}_{ij}$$

# Base Model

- To add some novelty we decided to incorporate the Extended Social Force Model (ESFM) proposed by Xi et al. (2010) 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.

# Base Model

- 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

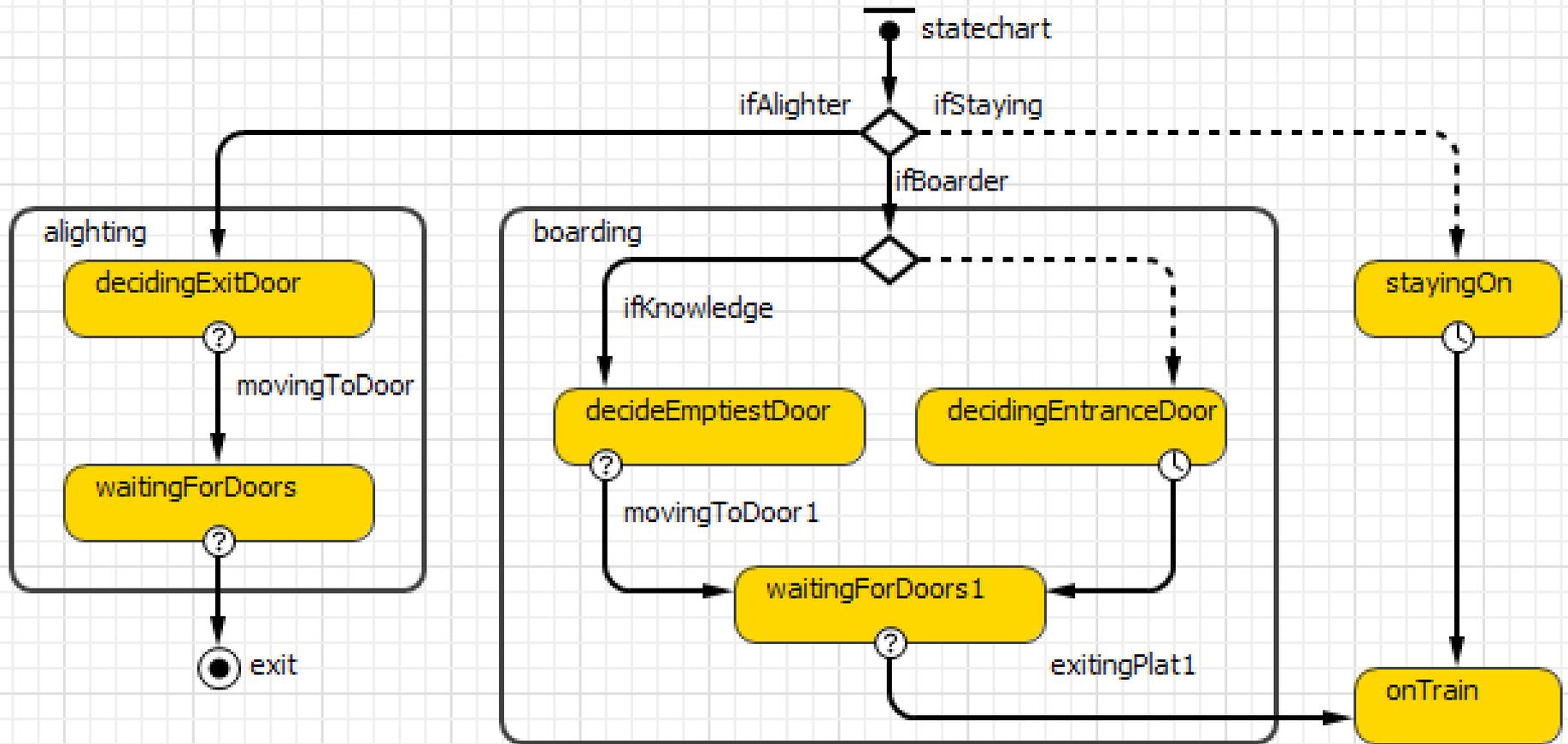
- Passenger decision-making process depends on "knowledge"
  - If a passenger has knowledge of the station they base their decision on the least crowded door.
  - If a passenger does not have knowledge of the station, there are two different decision-making processes, depending on their arrival time 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



# Model Implementation



# Pre Train Arrival

SFM : Simulation - AnyLogic University [EDUCATIONAL USE ONLY]

passengers[110] | 110

```

statechart
    [*] --> statechart
    statechart --> ifAlighter
    statechart --> ifStaying
    statechart --> ifBoarder
    ifAlighter --> alighting
    ifStaying --> stayingOn
    ifBoarder --> ifKnowledge
    ifBoarder --> decidingEntranceDoor
    ifKnowledge --> decideEmptiestDoor
    decideEmptiestDoor --> movingToDoor1
    movingToDoor1 --> waitingForDoors1
    waitingForDoors1 --> exitingPlat1
    decidingEntranceDoor --> exitingPlat1
    exitingPlat1 --> onTrain
    alighting --> decidingExitDoor
    decidingExitDoor --> movingToDoor
    movingToDoor --> waitingForDoors
    waitingForDoors --> exit
    
```

**type boarder**  
 target (335.5967541862913, 64.323480...)  
 target1 (335.5967541862913, 64.323480...)  
 target2 (469.8571459833327, 60.294417...)  
 target3 (536.1898784722695, 57.570228...)  
 target4 (666.9987644006043, 60.453386...)  
 target5 (747.3818888158375, 55.836662...)  
 C1pop 0  
 C2pop 0  
 C4pop 0  
 C5pop 0

**vOParam**  
 40.468  
 2  
 Tau  
 1  
 200  
 A  
 8.178  
 38  
 K  
 300  
 Twor  
 4.634  
 px  
 335.597  
 ri  
 2.317  
 ux  
 3.939  
 vx  
 3.847  
 vjx  
 0.683  
 x  
 276.615  
 xj  
 790  
 nijx  
 0.923  
 tijx  
 -0.384  
 sumForcex  
 -113.593  
 nearestPointx  
 0  
 nearestPoint

**initial**  
 (100.39586528060443, 122.2662...)  
 colour blue  
 m  
 61.767  
 connectionRange 20  
 connectionRangeWalls 20  
 knowledge false  
 targetTemp  
 emptiestDoor 1,000  
 doorThreshold 18  
 shortestDist 0  
 timeOfStartup 14.168  
 targetReached false  
 dip 63.421  
 rij 5.452  
 dij 515  
 deltaVx 1.25  
 deltaVy -3.538  
 rijdij 0  
 ridij -17.427  
 physx 0  
 psycx 21.394  
 physy 0  
 psycy 40.755  
 eox 0.937  
 destx 59.275  
 desty -22.555  
 lambda 0.1  
 cosAB 0.045  
 formFac 0.57

**Run:** 0 Paused | **Time:** 20.55 | **Simulation:** Stop time not set | **Date:** Sep 20, 2015 11:30:48 AM | **Memory:** 52M of 910M

# Train arrival

SFM : Simulation - AnyLogic University [EDUCATIONAL USE ONLY]

passengers[201] 201

statechart

ifAlighter

ifStaying

alighting

decidingExitDoor

waitingForDoors

exit

boarding

decideEmptiestDoor

decidingEntranceDoor

waitingForDoors1

onTrain

stayingOn

ifKnowledge

movingToDoor

movingToDoor1

exitingPlat1

type alighter

target (638.8053310279482, 98.029207...)

target1 (896.8028413023677, 110.18449...)

target2

target3

target4

target5

C1pop 0

C2pop 0

C4pop 0

C5pop 0

vOParam 24.901

v0 24.901

Tau 1

A 200

B 8.891

k 38

K 300

Twor 6.142

px 638.805

ri 3.071

ux 1.809

vx 1.902

vjx 0.181

x 632.679

xj 790

nijx 0

tijx 1

sumForcex 151.686

nearestPointx 0

nearestPoint

initial (631.7372462703067, 32.148151... true)

colour yellow

m 81.877

connectionRange 20

connectionRangeWalls 20

knowledge

targetTemp (896.802841302367)

emptiestDoor 1,000

doorThreshold 20

shortestDist 276.314

timeOfStartup 20

targetReached false

dip 62.006

rij 5.927

dij 157.459

deltaVx 1.809

deltaVy 0

rijdij -2.819

ridij -10.588

physx 0

psycx 0

physy 0

psycy -265.699

exx 0.181

destx 6.264

desty 61.689

lambda 0.1

cosAB -0.073

formFac 0.517

py 98.029

rj 2.856

uy 10.111

vy 10.736

vjy 1.66

y 37.114

yj 36.34

nijy 0

tijy 0

sumForcex 1.023.299

nearestPointy 0

Memory: 40M of 910M

Run: 0 Paused Time: 20.55 Simulation: Stop time not set Date: Sep 20, 2015 11:30:48 AM

# Train Stop Time

SFM : Simulation - AnyLogic University [EDUCATIONAL USE ONLY]

passengers[150] | 150

```

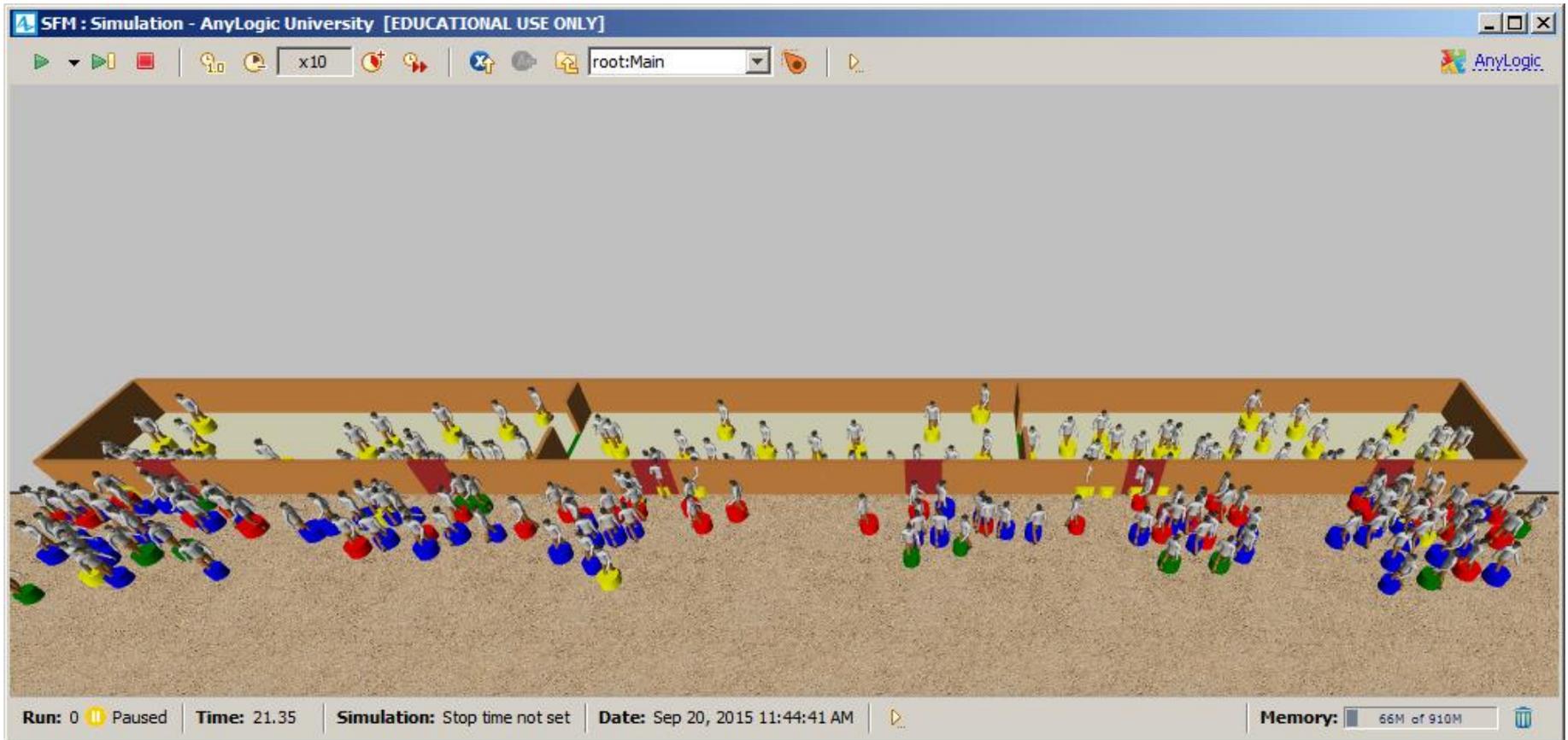
stateDiagram-v2
    [*] --> statechart
    statechart --> alighting : ifAlighter
    statechart --> stayingOn : ifStaying
    statechart --> boarding : ifBoarder
    alighting --> alighting : decidingExitDoor
    alighting --> waitingForDoors : movingToDoor
    waitingForDoors --> exit : 
    boarding --> boarding : ifKnowledge
    boarding --> decideEmptiestDoor : 
    decideEmptiestDoor --> waitingForDoors1 : movingToDoor1
    waitingForDoors1 --> boarding : 
    boarding --> decidingEntranceDoor : 
    decidingEntranceDoor --> waitingForDoors1 : 
    waitingForDoors1 --> onTrain : exitingPlat1
    stayingOn --> onTrain : 
    
```

Variables:

- vOParam: 2.849
- v0: 2.849
- Tau: 1
- A: 200
- B: 8.651
- k: 38
- K: 300
- Twor: 5.495
- px: 543.937
- ri: 2.748
- ux: 0.504
- vx: 0.526
- vjx: 2.032
- x: 513.015
- xj: 790
- nijx: 0
- tijx: 1
- sumForcex: 33.608
- nearestPointx: 0
- nearestPoint: 0
- initial: (499.9975788179482, 40.30640...false)
- colour: yellow
- m: 73.254
- connectionRange: 20
- connectionRangeWalls: 20
- py: 98.309
- rj: 3.019
- uy: 0.397
- vy: 0.414
- vjy: 0.137
- y: 31.522
- yj: 31.492
- nijy: 0
- tijy: 0
- sumForcey: 24.405
- nearestPointy: 0
- knowledge: false
- targetTemp: (881.9600375502864, 122.16696...)
- emptiestDoor: 1,000
- doorThreshold: 20
- shortestDist: 390.636
- timeOfStartup: 20
- targetReached: false
- dip: 73.642
- rij: 5.767
- dij: 277.023
- deltaVx: 0.504
- deltaVy: 0
- rijdij: -11.603
- ridij: -15.76
- physx: 0
- psycx: 0
- physy: 0
- psycy: -114.532
- eax: 0.47
- destx: 30.96
- desty: 66.817
- lambda: 0.1
- cosAB: -0.049
- formFac: 0.528

Run: 0 Paused | Time: 37.35 | Simulation: Stop time not set | Date: Sep 20, 2015 11:31:05 AM | Memory: 61M of 910M

# 3D Display



# Experimentation



# Experimentation

- Four scenarios are considered
  - 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

- 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

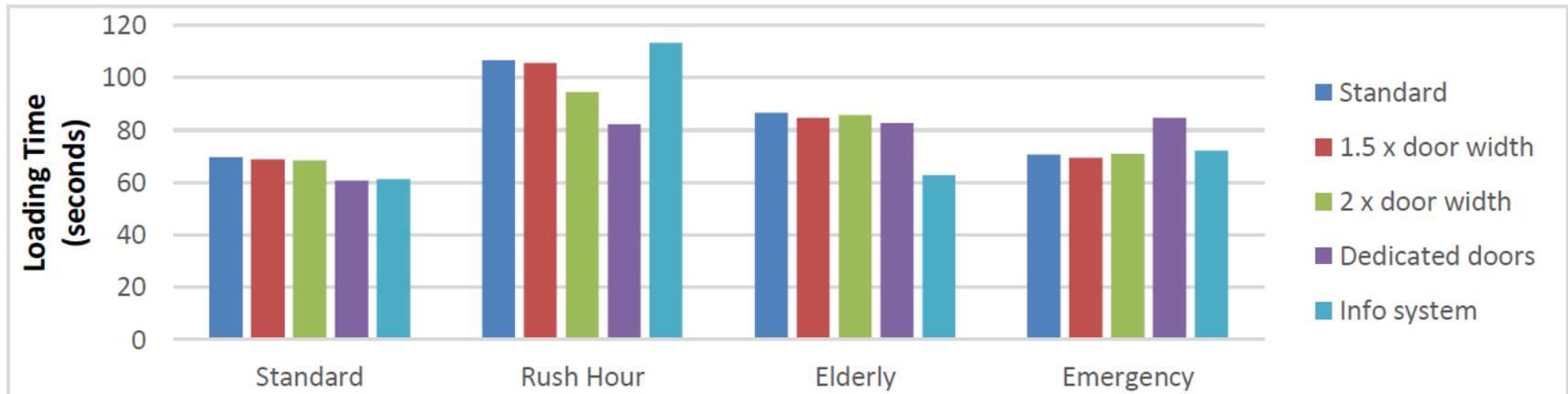
# Experimentation

- 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

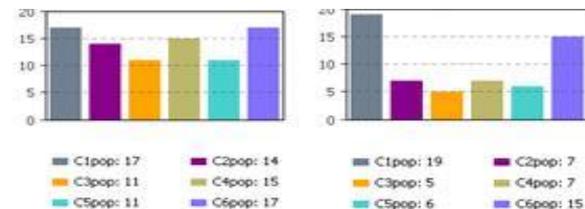


# Results

- 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



# Future Work



# Future Work

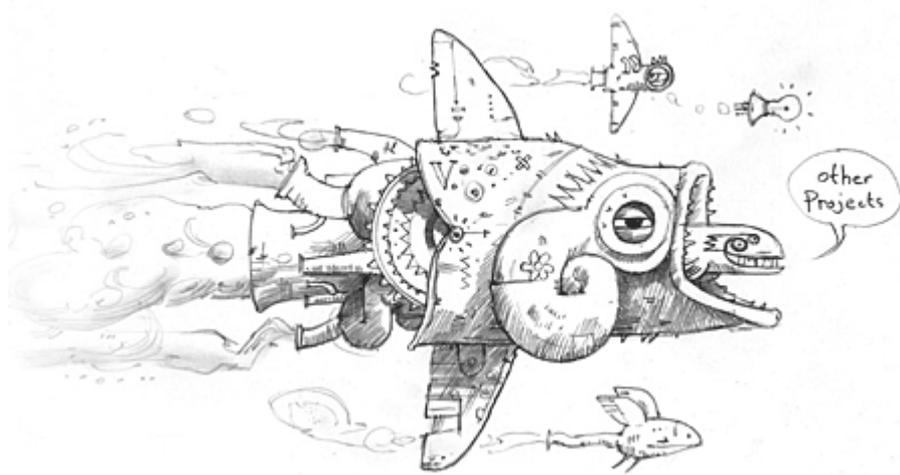
- This was just a feasibility study!
  - There are still bugs



- 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

# Part 3

## Other Projects



LUCAS is a cross-faculty interdisciplinary team directed by Darren Robinson (Chair in Building and Urban Physics), working to better understand how cities function, socially and physically, and how this functioning and its consequences for social, economic and environmental sustainability can be improved upon.

LUCAS is a key component of the University's Sustainable and Resilient Cities Research Priority Area

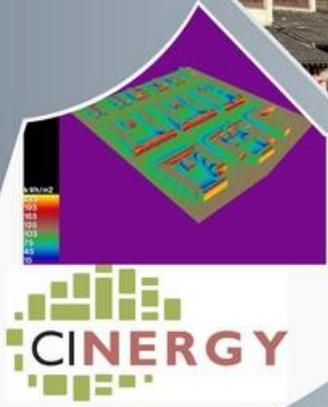
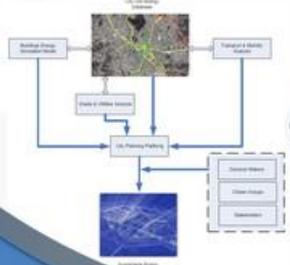
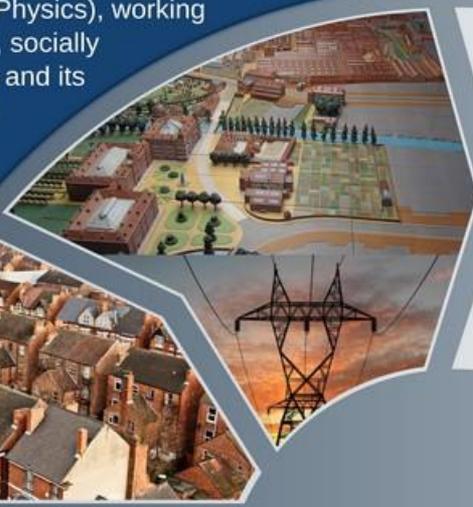
# LABORATORY OF URBAN COMPLEXITY AND SUSTAINABILITY

**Contact LUCAS**  
 Room B6 Paton House,  
 University Park,  
 Nottingham, NG7 2RD, UK

Director - Professor Darren Robinson  
 Darren.Robinson@nottingham.ac.uk

**InSMART:**  
 Integrative Smart City Planning project

brings together cities and scientific organizations in order to establish a methodology for enhancing sustainable planning for both the current and future city needs through an integrative and multidisciplinary planning approach.



At the core of our activities is the Leverhulme Research Programme Grant



The Leverhulme Trust



The University of Nottingham

UNITED KINGDOM · CHINA · MALAYSIA

## "Sustaining urban habitats: an interdisciplinary approach"

### Research themes

**Environmental:** realistic measures of urban sustainability and options for improving resilience and resource flows

**Social and Cultural:** patterns of consumption by different groups and social perspectives on measures and scenarios for improving sustainability

**Economic:** factors shaping economic activity and migration, and prospects for balancing economic and social capital with environmental capital

**Measurement and Data:** effective ways of managing the different forms of data from themes 1, 2 and 3 to develop appropriate indicators of sustainability

**Modelling and Optimisation:** minimising resource demands in response to underlying stimuli and constraints

**Policy and Governance:** the role of public policies and policy-maker perspectives on the indicators and scenarios that we develop



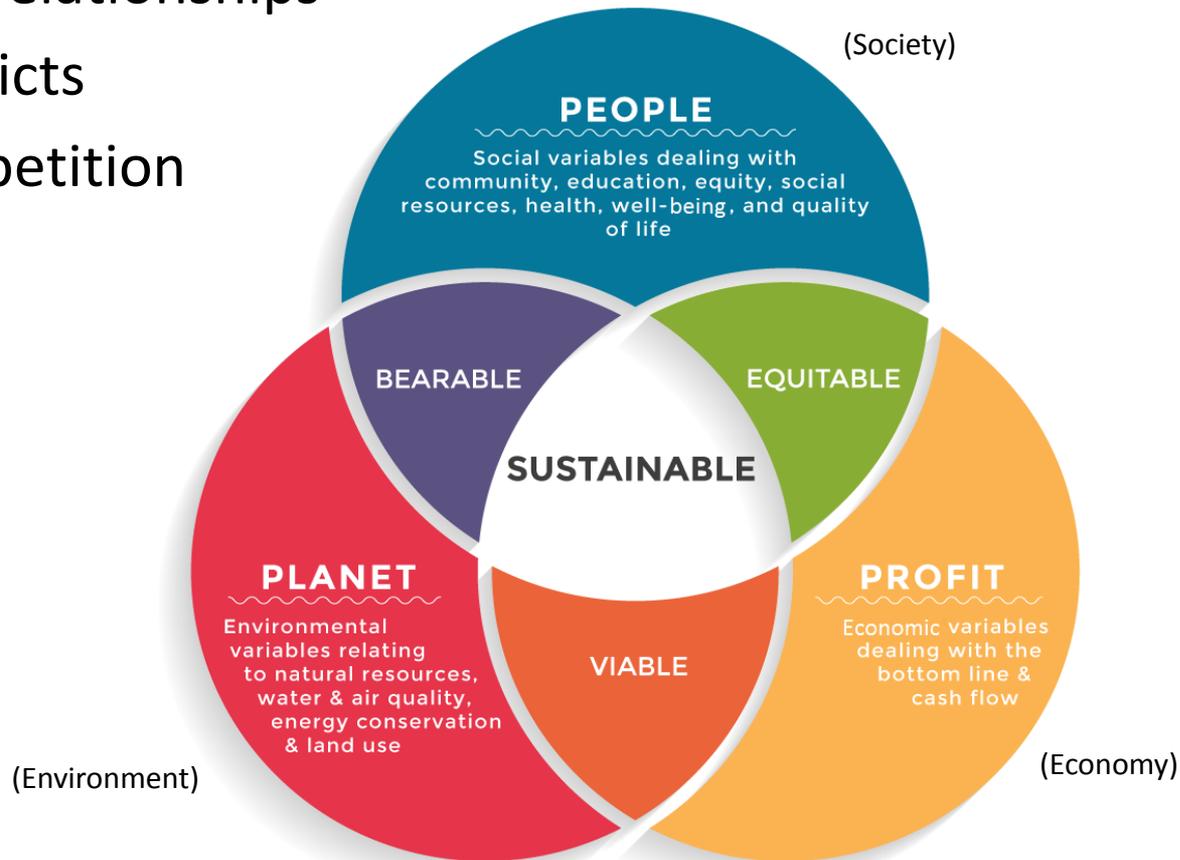
### CiNERGY:

Smart cities with sustainable energy systems

Marie Curie International Training Network (ITN) project is training young scientists to develop urban decision-making and urban energy system models that help decision makers to maximise energy efficiency and renewable energy integration toward a low carbon urban future.

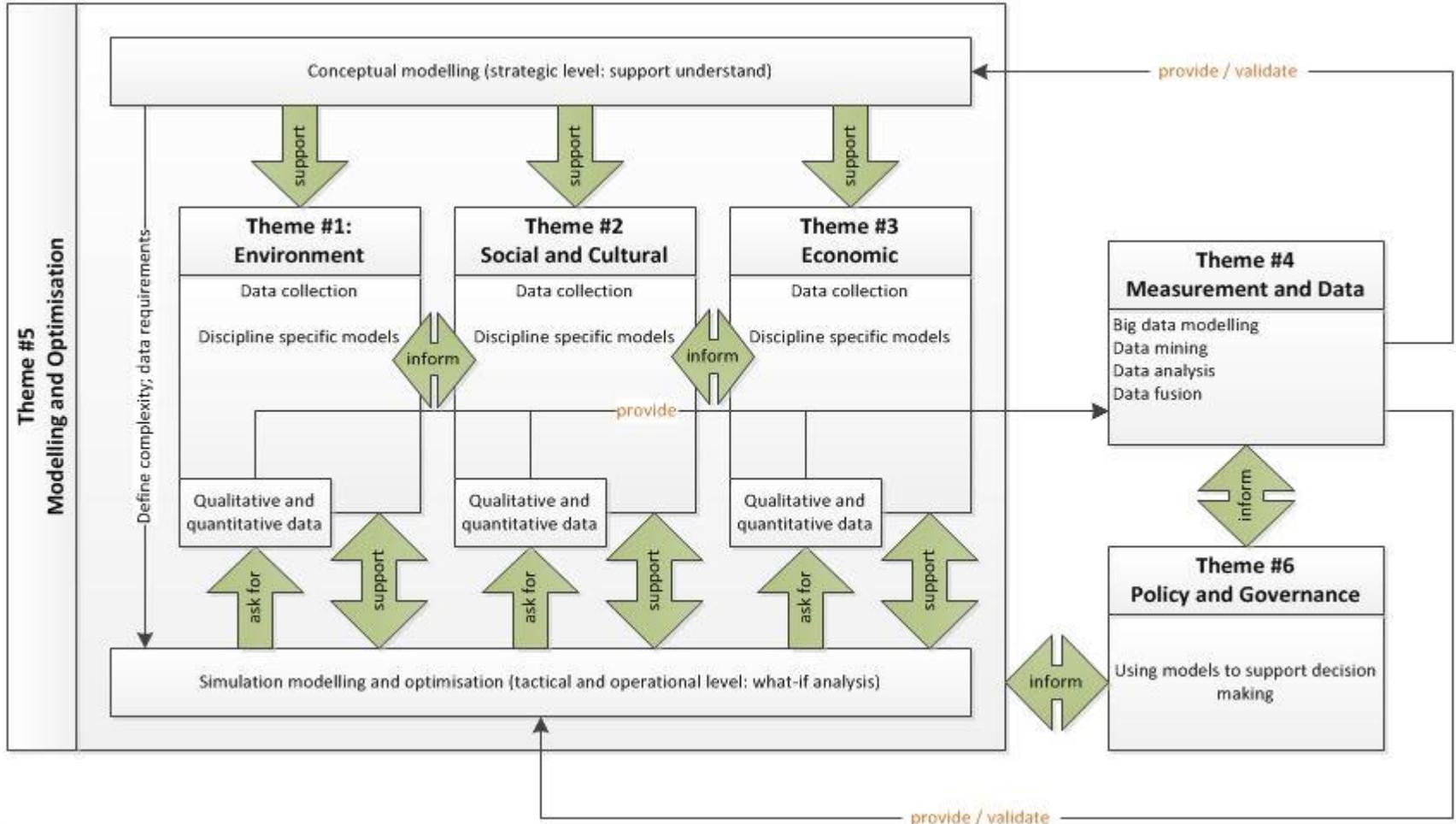
# Sustaining Urban Habitats

- Interrelationships
- Conflicts
- Competition

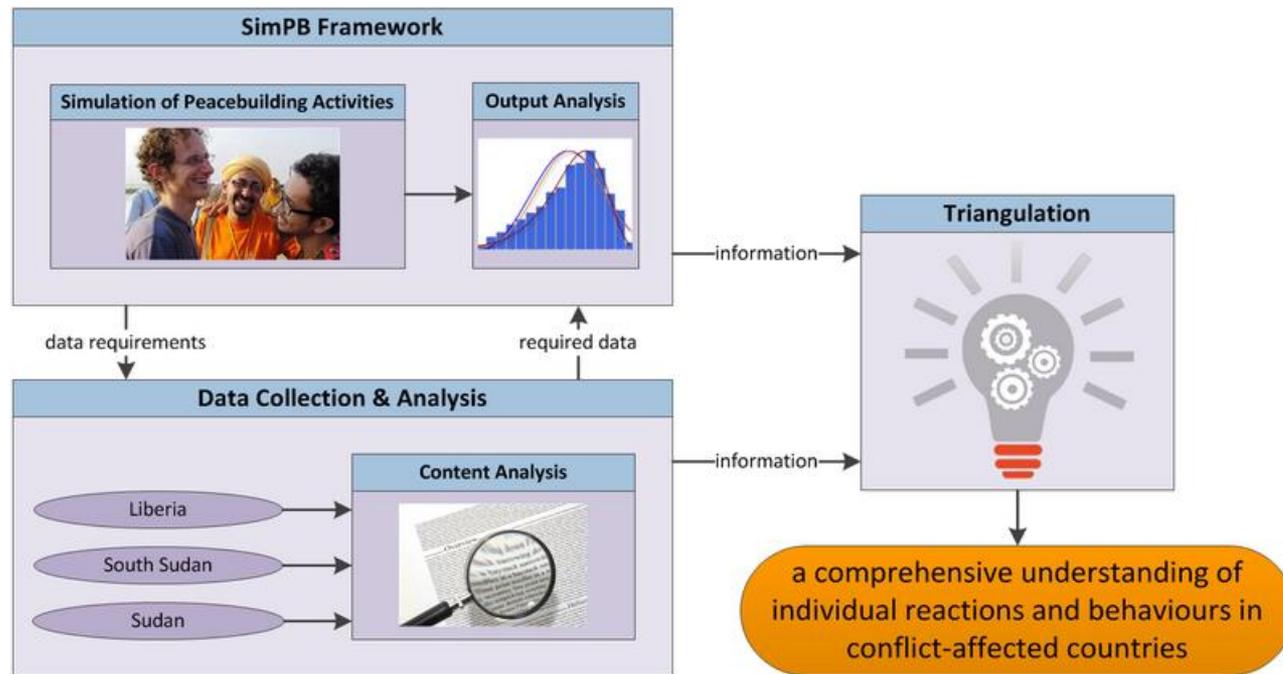


<http://www.fourewesdesign.com/about>

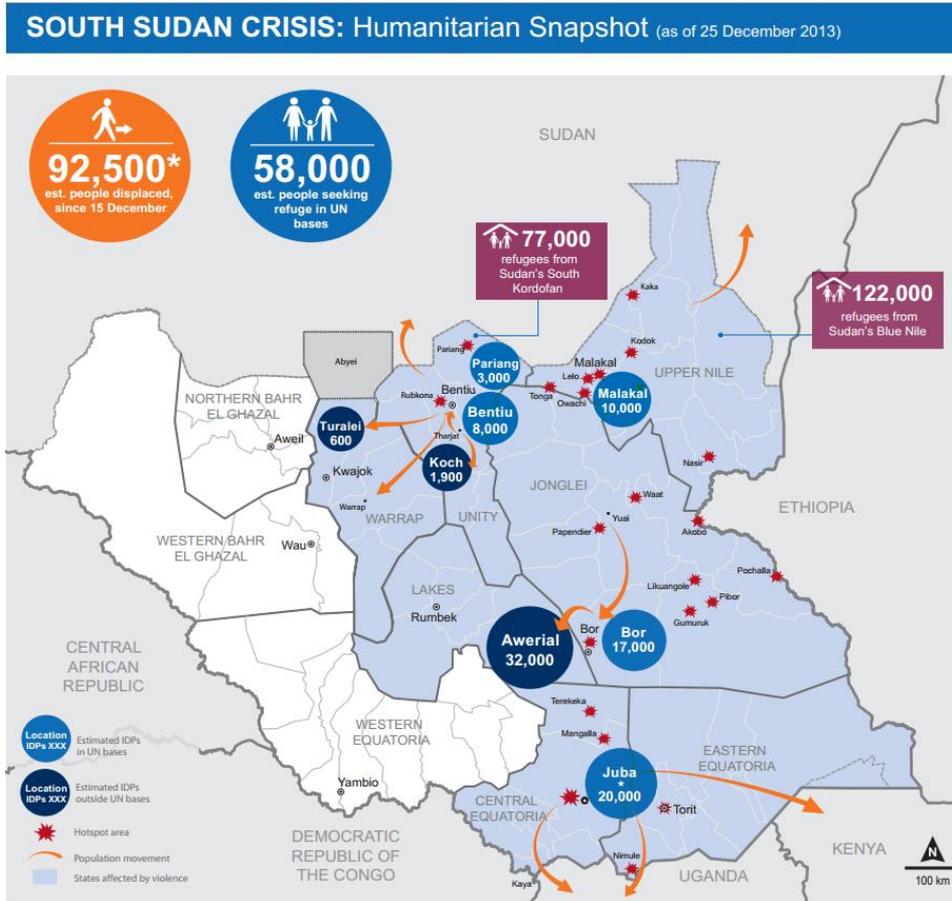
# Sustaining Urban Habitats



# Simulating Peace Building

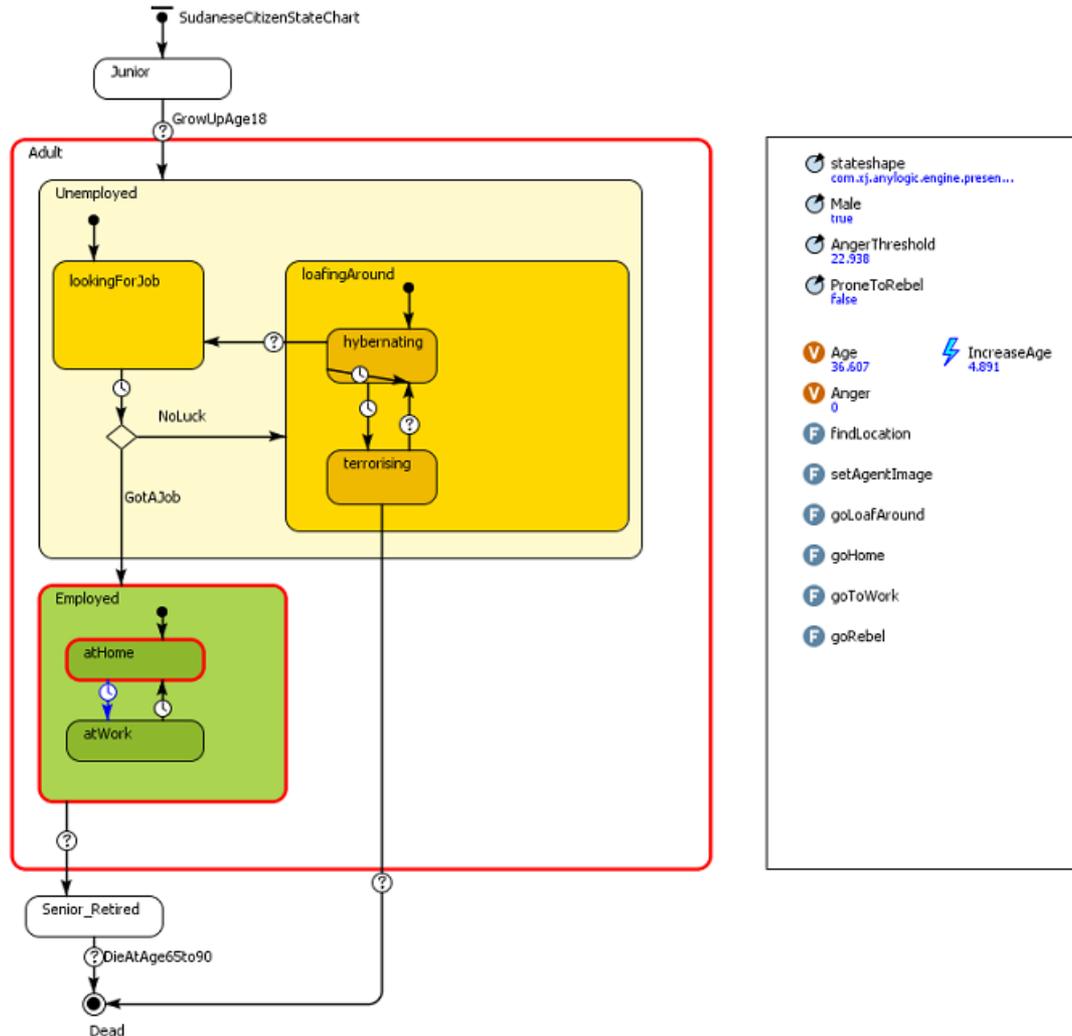


# SimPB: Simulating Peace Building



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The screenshot displays the 'Agent Based Population Model' simulation interface. The window title is 'Agent Based Population Model : Simulation - AnyLogic University [EDUCATIONAL USE ONLY]'. The interface is divided into several sections:

- Map:** A central area with four quadrants: 'At home' (purple figures), 'Looking for Job/Loafing around' (purple figures), 'At work' (orange factory icon), and 'Rebelious' (black airplane icon).
- Simulation:** A tabbed interface with 'Map', 'Simulation', and 'Charts' options.
- Control Panels:**
  - Security:** 'Change Security Forces:' with a slider.
  - Governance:** 'Change Govern Representation:', 'Change Fairness in Justice:', and 'Change Citizen Participation:' with sliders.
  - Economy:** 'Change Inflation Rate:' with a slider.
  - Wellbeing:** 'Water Source:', 'Human Rights Index', 'Religious Opression:', and 'Tribal Discord:' with sliders.
- Status Bar:** Shows 'Run: 0' (Running), 'Time: 1.41', 'Simulation: Stop time not set', and 'Memory: 141M of 27M'.

# References



# References

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# The End

