Agent-Oriented Modelling and Simulation of Human Centric Systems

Southampton Seminar

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The University of Nottingham

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Motivation

- Introduce you to the relevant terminology
- Show you how an ABS works internally
- Show you how to build an ABM model from scratch
- Discuss the idea of hybrid models in OR/MS
- Demonstrate how all of this can be applied in practice

Personal Introduction

Personal Introduction

- My research mission
  - Developing human behaviour models which can be used to better represent people and their behaviours in OR/MS simulation models

  - Combining ideas from OR, Social Science, Psychology, Sociology, and Software Engineering to achieve this
    - More interested in developing frameworks and testing them
    - Less interested in solving/investigating specific cases

  - Using well established OOA/D principles and methods from Software Engineering for developing reusable components and the environment they live in.

Personal Introduction

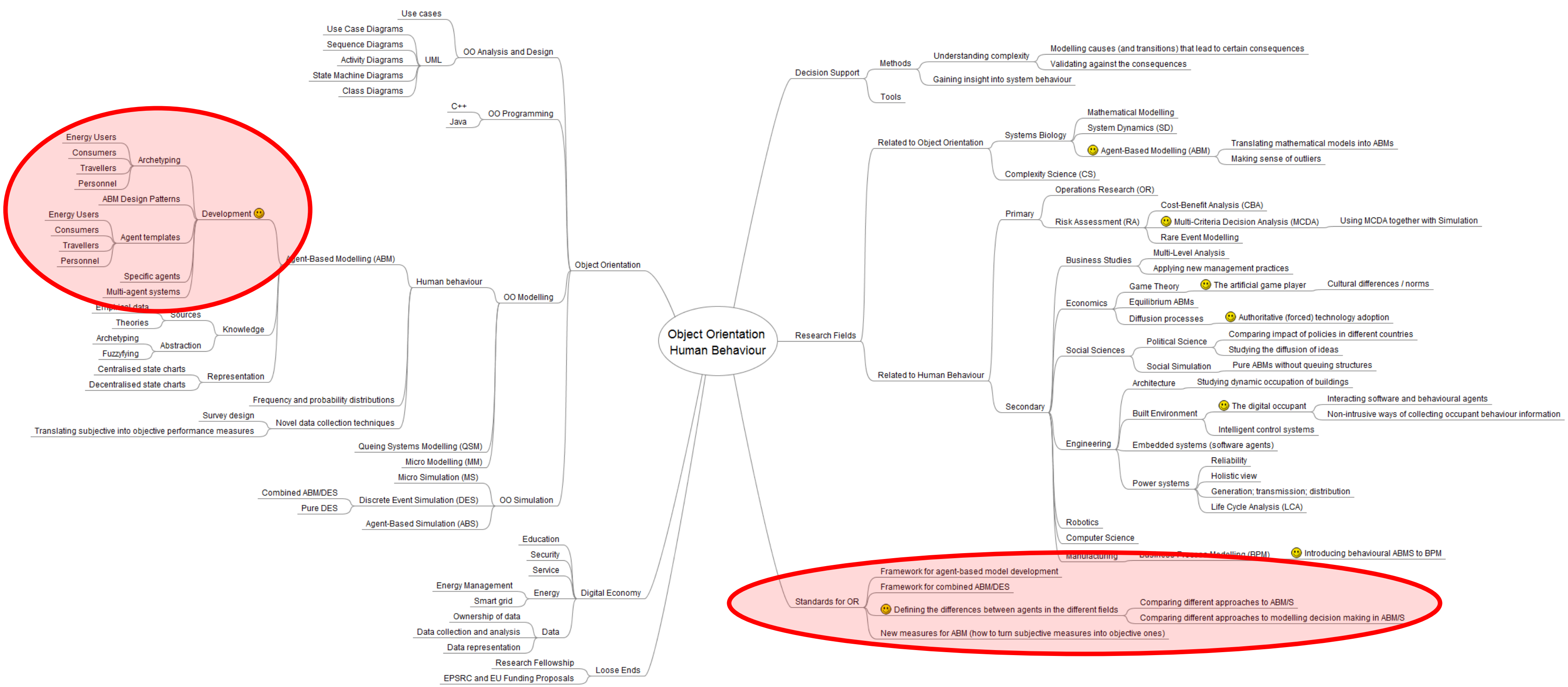
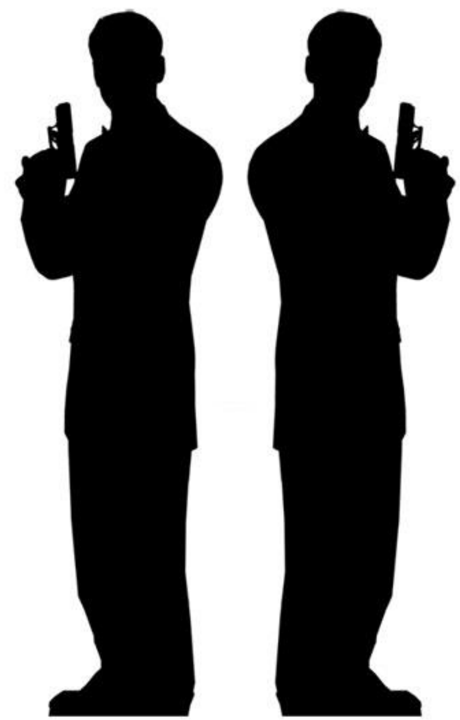


Chart from 2012

Personal Introduction

- Technical aspects

- Agent-Based Modelling (ABM)
  - Development 🙂
    - Archetyping
      - Energy Users
      - Consumers
      - Travellers
      - Personnel
    - ABM Design Patterns
    - Agent templates
      - Energy Users
      - Consumers
      - Travellers
      - Personnel
    - Specific agents
    - Multi-agent systems



- Standards for OR
  - Framework for agent-based model development
  - Framework for combined ABM/DES
  - 🙂 Defining the differences between agents in the different fields
    - Comparing different approaches to ABM/S
    - Comparing different approaches to modelling decision making in ABM/S
  - New measures for ABM (how to turn subjective measures into objective ones)

Personal Introduction

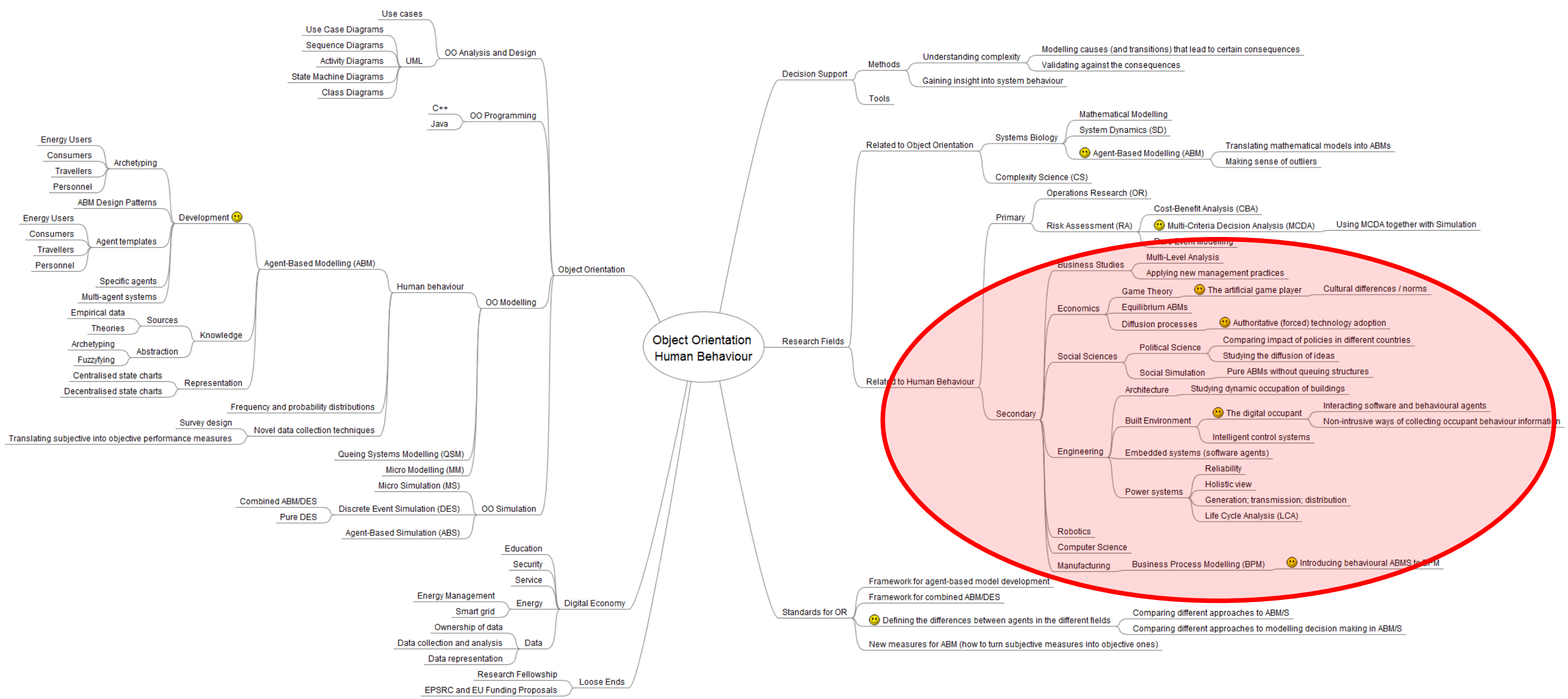
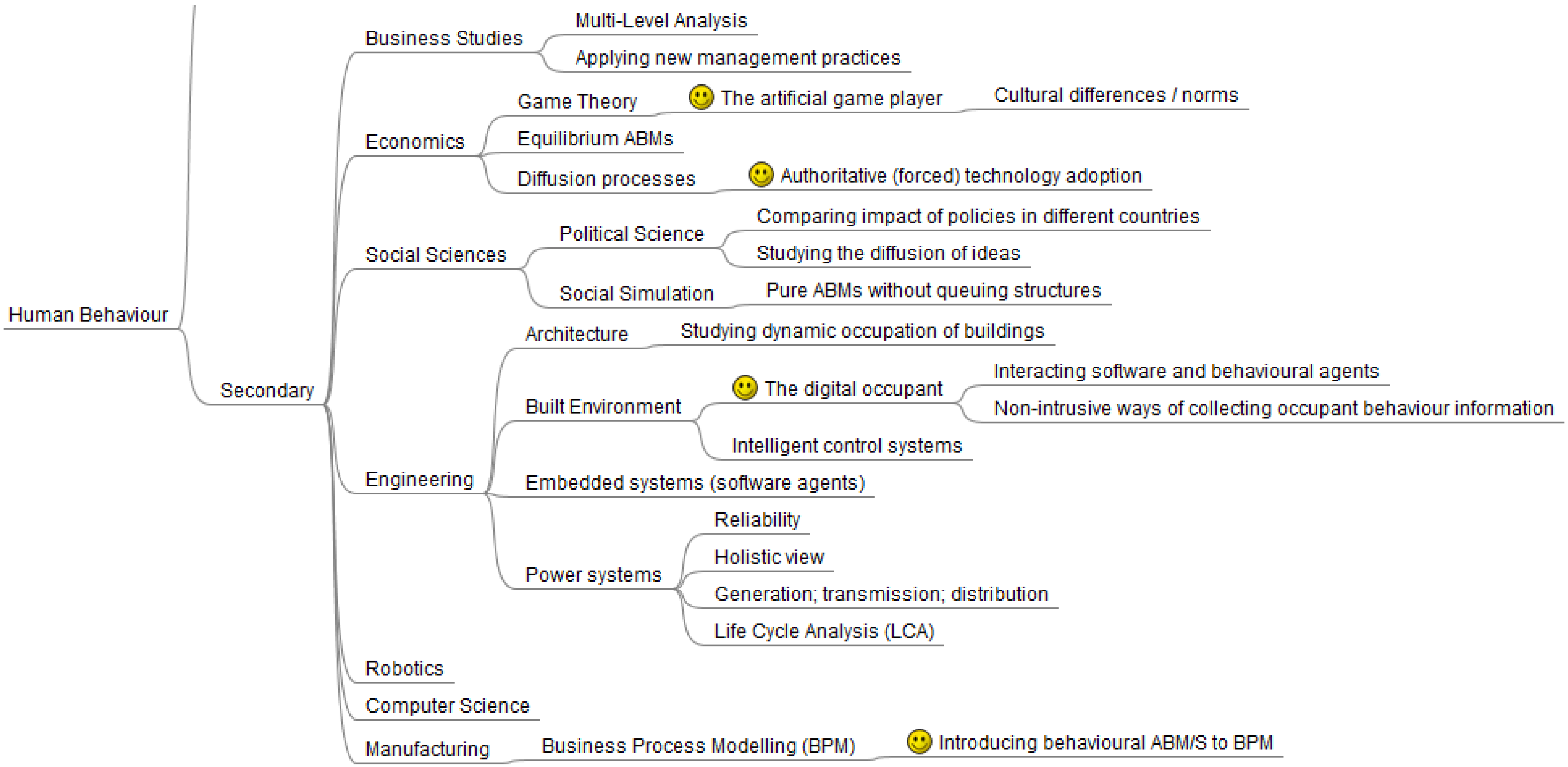


Chart from 2012

Personal Introduction

- Applications



Personal Introduction

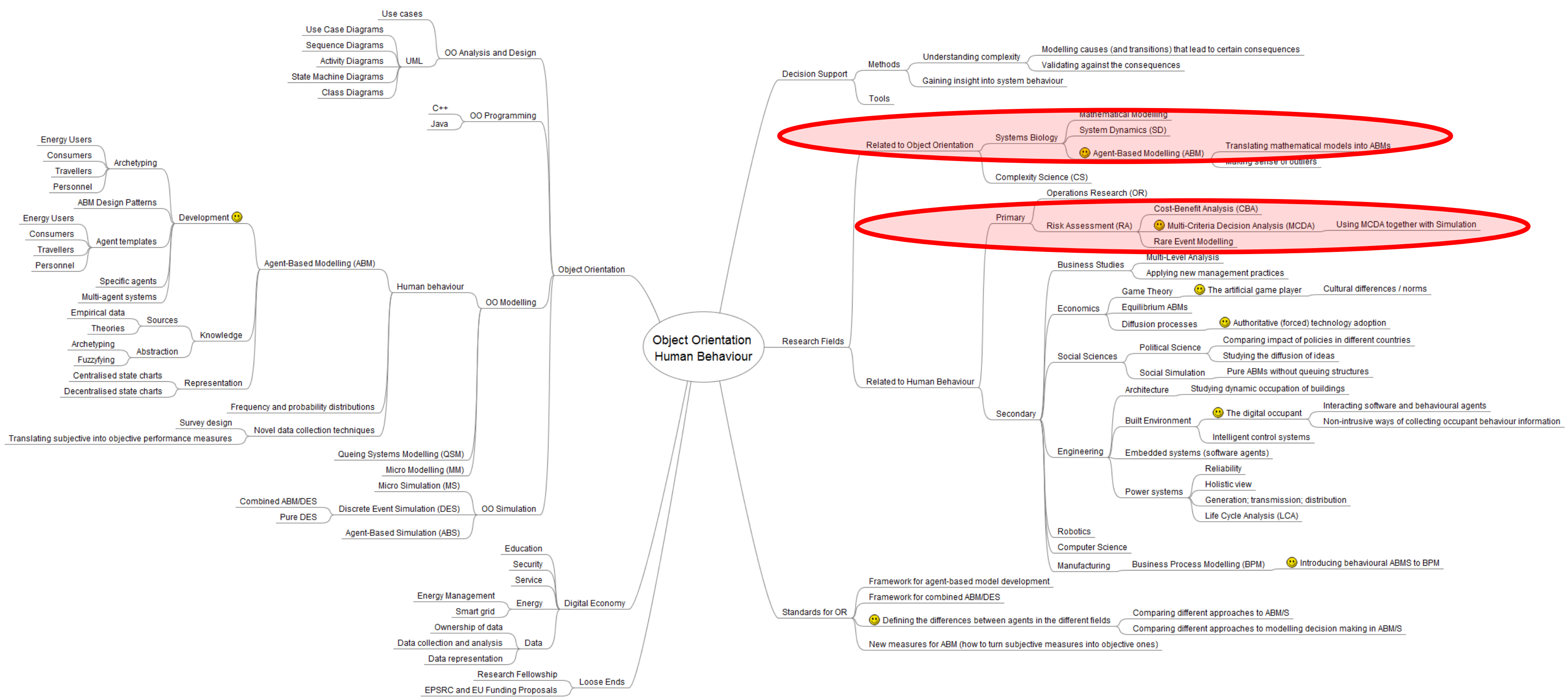
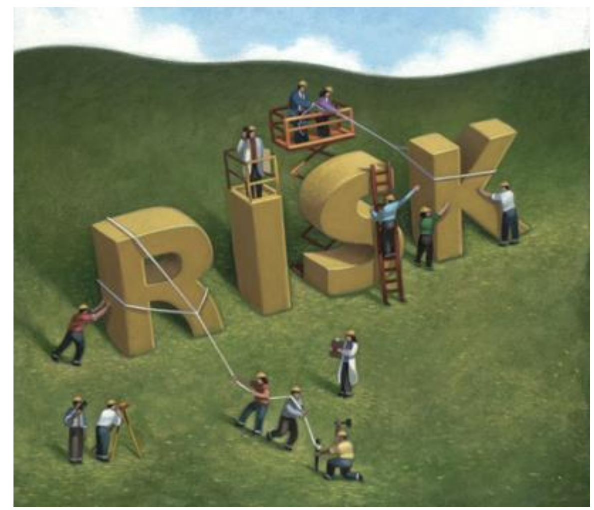


Chart from 2012

Personal Introduction

- Related topics

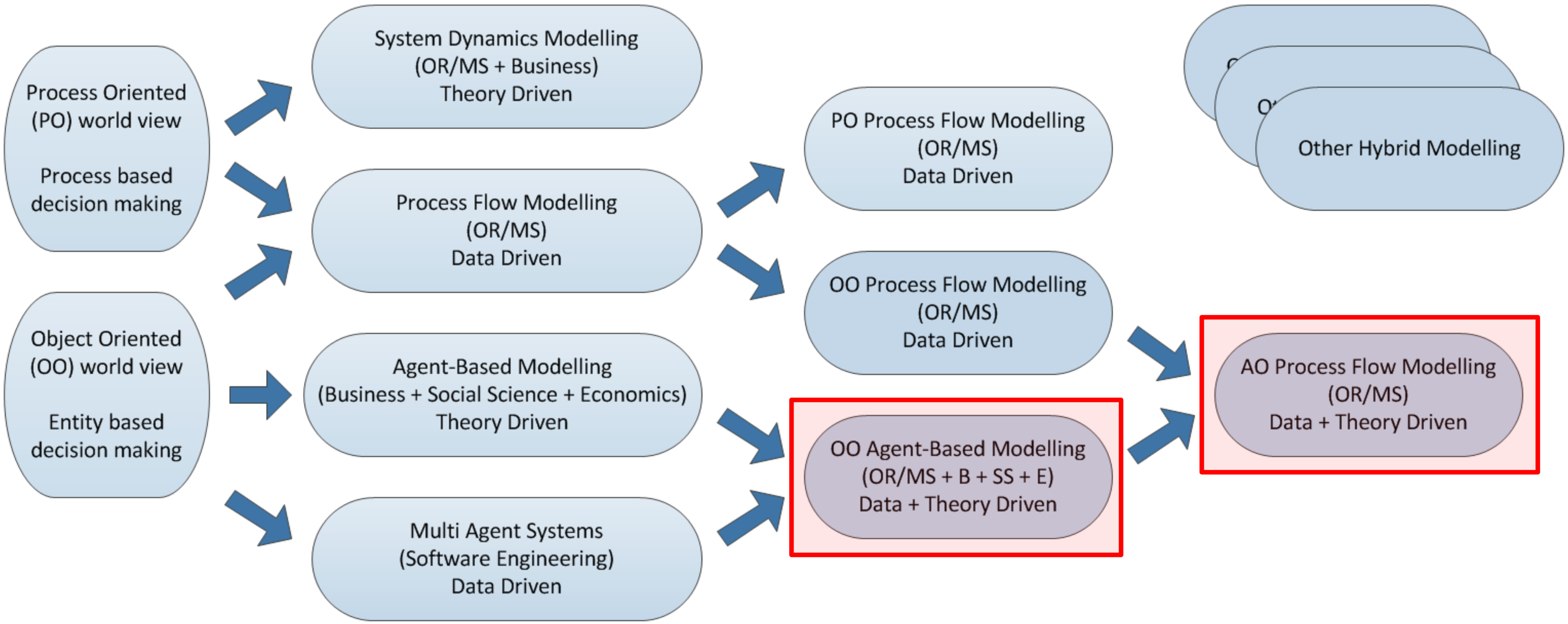
- Systems Biology
  - Mathematical Modelling
  - System Dynamics (SD)
  - Agent-Based Modelling (ABM)
    - Translating mathematical models into ABMs
    - Making sense of outliers



- Risk Assessment (RA)
  - Cost-Benefit Analysis (CBA)
  - Multi-Criteria Decision Analysis (MCDA)
    - Using MCDA together with Simulation
  - Rare Event Modelling

Simulation Modelling Approaches

Simulation Modelling Approaches

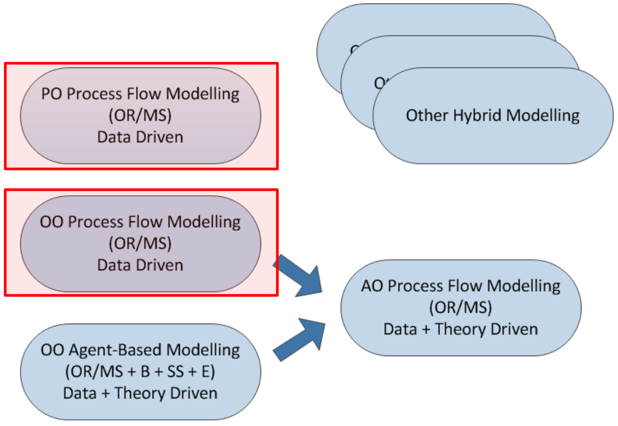


Data Driven: Data for model formulation (in Social Sciences can be quantitative and qualitative); data for model validation
Theory Driven: Theories for model formulation; data for model validation

Simulation Modelling Approaches

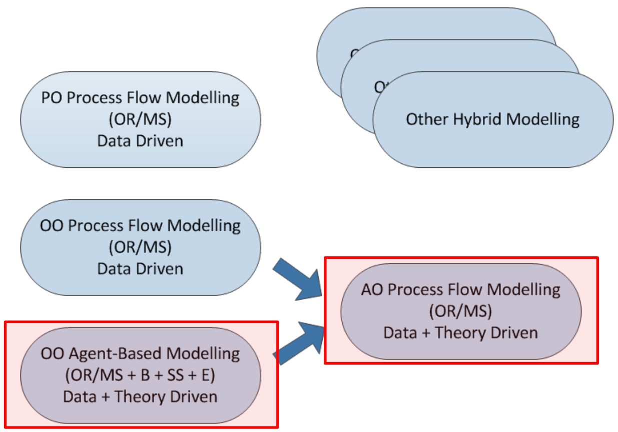
- Process Oriented Process Flow Modelling
  - Traditional DES Modelling (what is described in books and papers)
  - Entities are routed through the system

- Object Oriented Process Flow Modelling
  - Entities defined as classes
  - Entities make decisions where to go



Simulation Modelling Approaches

- Object Oriented Agent-Based Modelling
  - Entities defined as classes
  - Entities are intelligent objects that interact
  - Entities make decisions and have a memory
  - Process: No concept of queues and flows



- Agent Oriented Process Flow Modelling
  - Entities defined as classes
  - Entities are intelligent objects that interact
  - Entities make decisions and have a memory
  - Process: Organised in terms of queues and flows

Object Oriented
Agent-Based Modelling and Simulation

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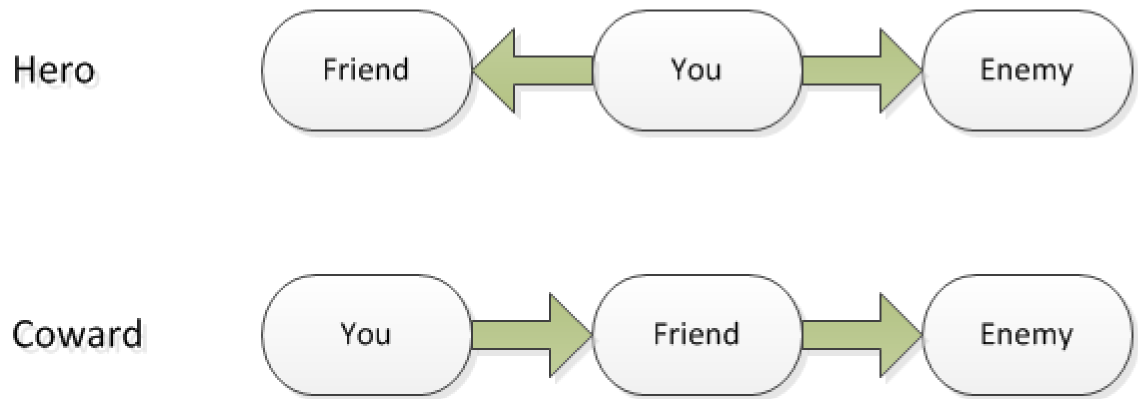
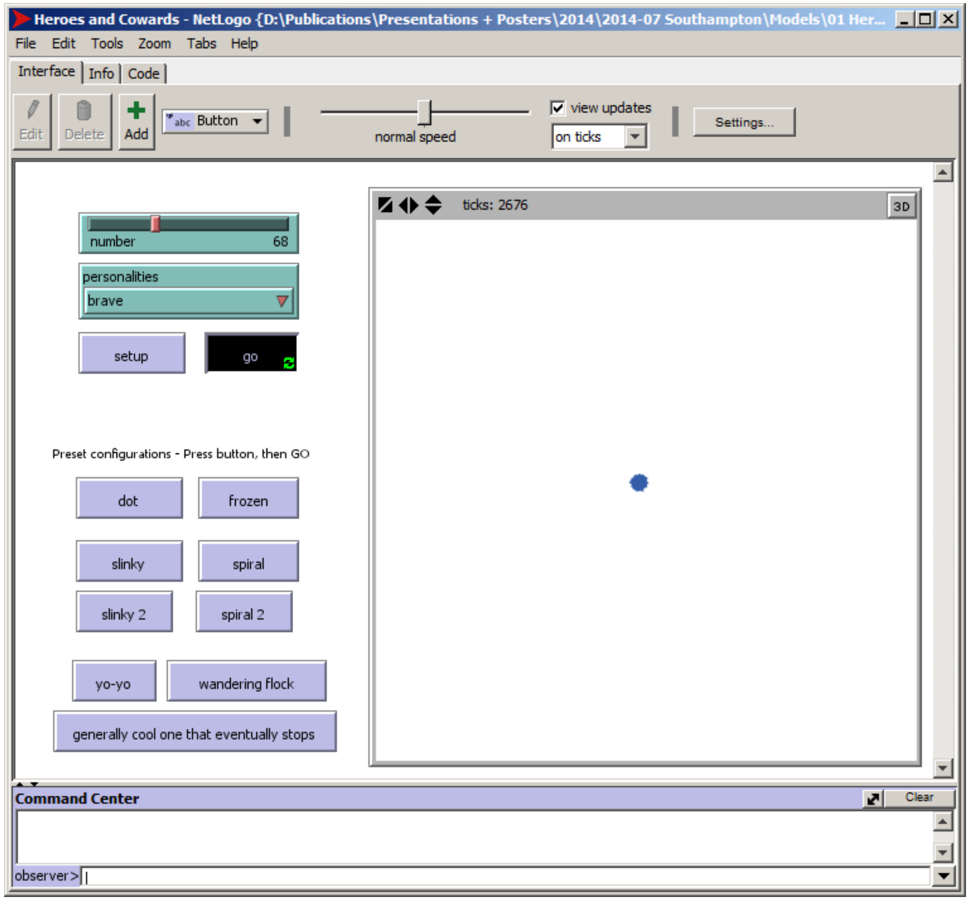
Agent-Based Modelling

- Heroes and Cowards Game [Wilensky and Rand in press]



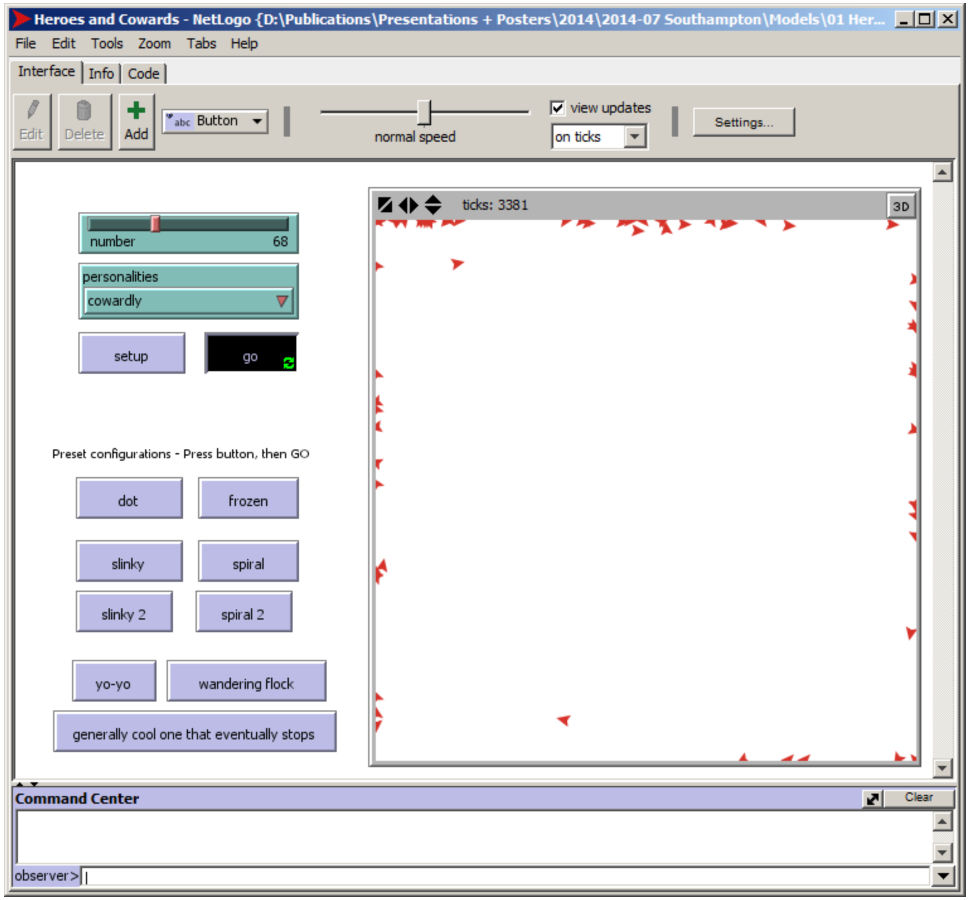
Agent-Based Modelling

- Heroes and Cowards Game : All heroes



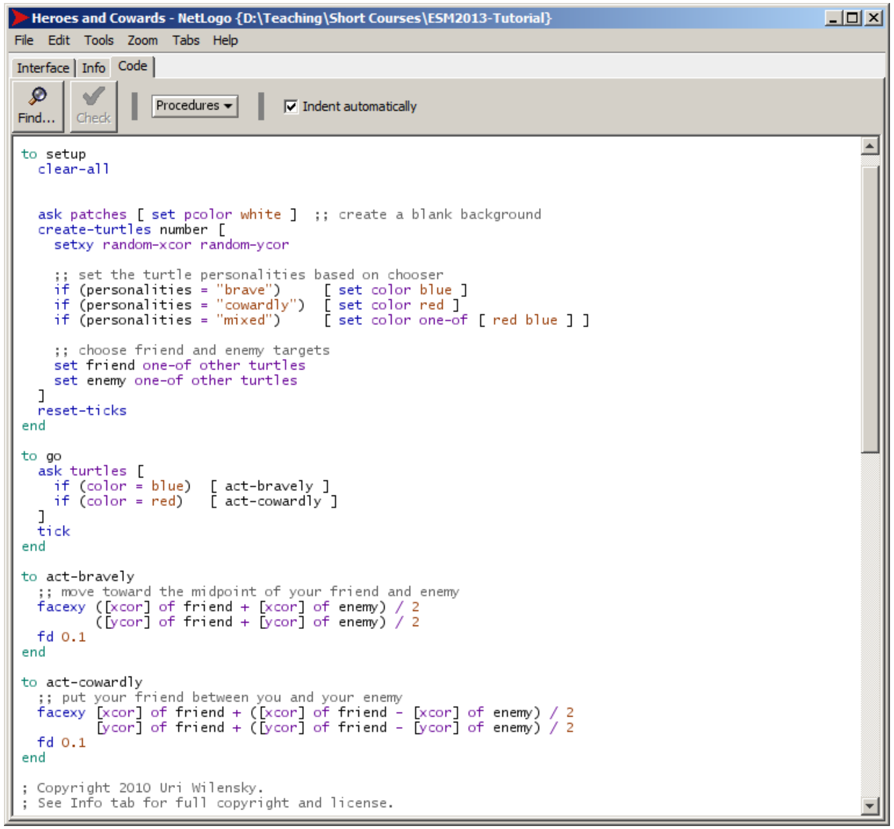
Agent-Based Modelling

- Heroes and Cowards Game: All cowards



Agent-Based Modelling

- Heroes and Cowards Game [Wilensky and Rand in press]




```
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

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```
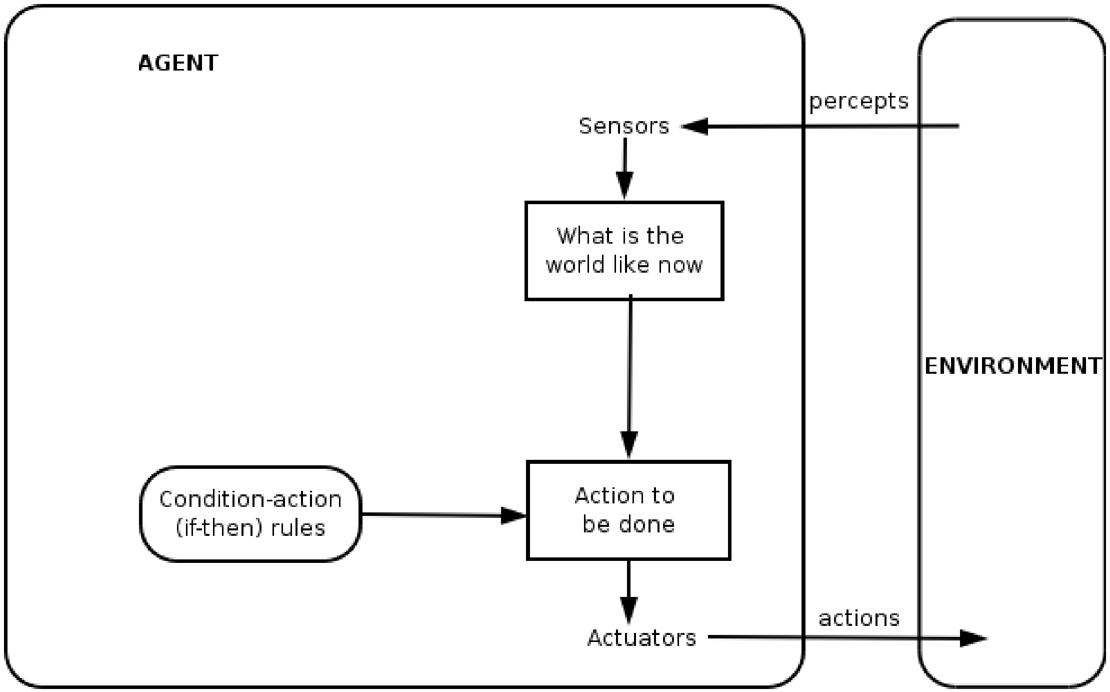
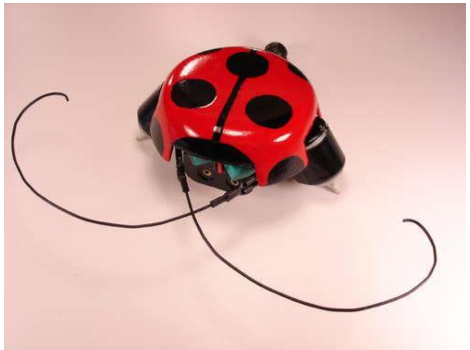

Agent-Based Modelling

- 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

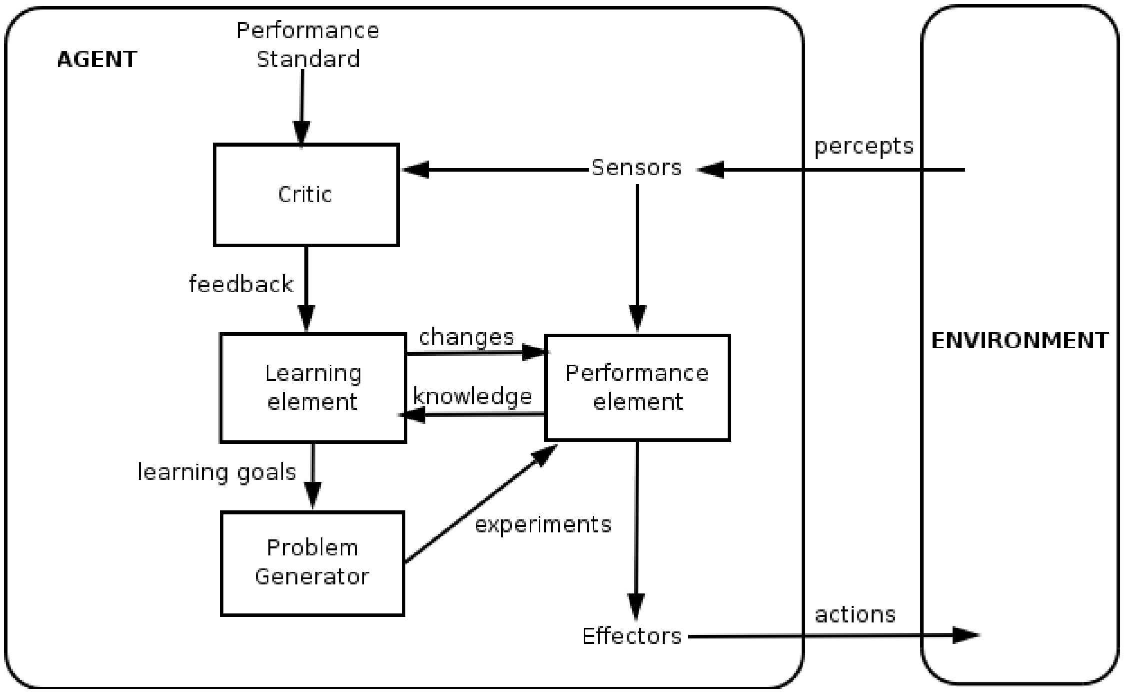




Russell and Norvig (2003)

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**!
- Properties:
  - Discrete entities
    - With their own goals and behaviours
    - With their own memory
    - 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 systems
  - 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 (in OR/MS)

- Agent-Based Simulation (ABS) is the process of designing an ABM of a system and **conducting experiments** with this model for the purpose of **understanding the behaviour** of the system and/or **evaluating various strategies** to influence the behaviour of entities within the system [adapted from Shannon, 1975]

Agent-Based Simulation

- A word of caution:
  - Many different developments have been going on under the slogan of Agent Based Simulation in very different disciplines

- Two main paradigms:
  - Multi-agent decision systems
    - Usually embedded agents or a simulation of embedded agents
    - Focus is on decision making
  - Multi-agent simulation systems
    - The multi-agent system is used as a model to simulate some real-world domain and recreate some real world phenomena

Agent-Based Simulation

- The Sims: Interactive Organisational Agent-Based Simulation

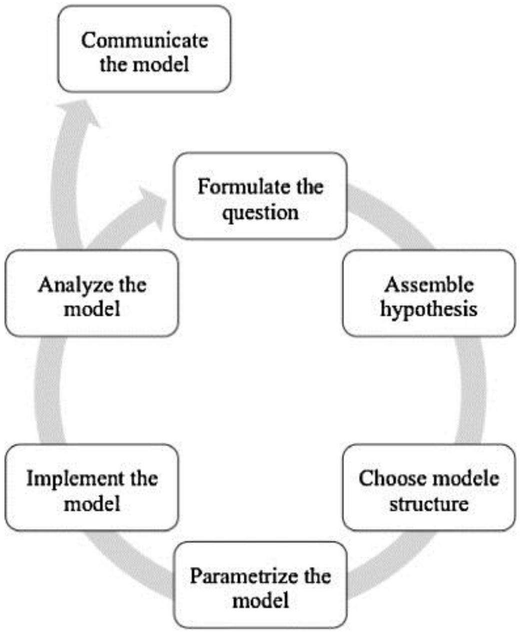
Agent-Based Simulation

- 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

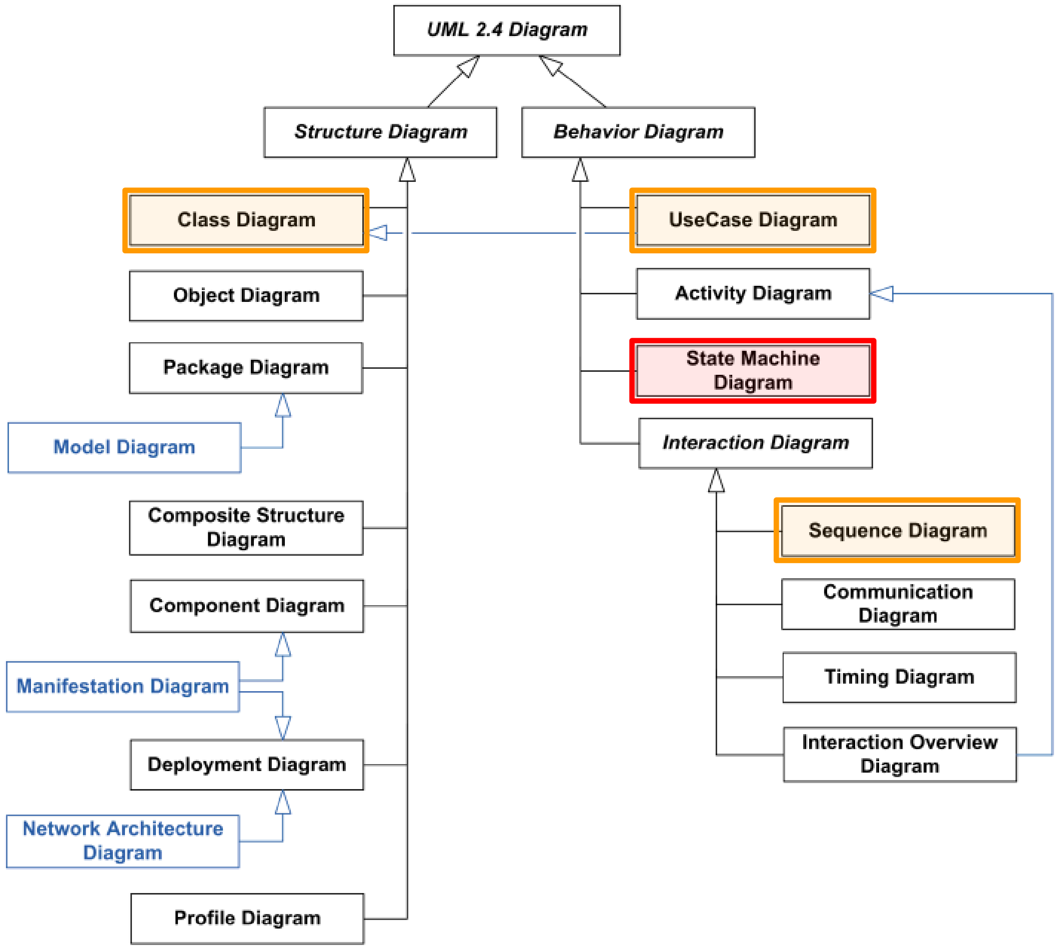
- Synchronous approach [Macal 2013]
  - Loop over time horizon
    - Loop over randomised list of agents. For each **agent A** in list:
      - Execute **agent A** behaviour
      - Update state of **agent A** (based on **agent A**'s state, the states of agents that interact with **agent A**, and the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

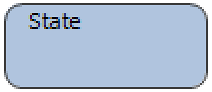
Using UML for ABM

Unified Modelling Language (UML)



Defining Behaviour Using State Charts

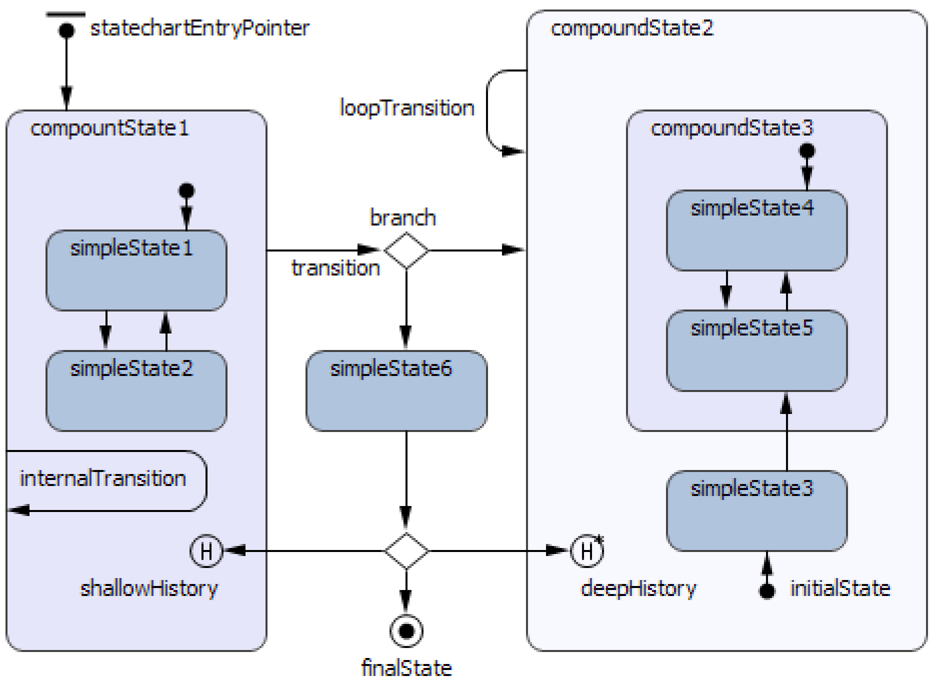
- Typical elements of a state chart diagram
  - States
    - Represents a location of control with a particular set of reactions to conditions and/or events



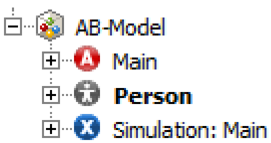
    - Examples
      - Cup can be in state **full** or **empty**
      - Person can be in state **idle** or **busy**
  - Transitions
    - Movement between states, triggered by a specific event

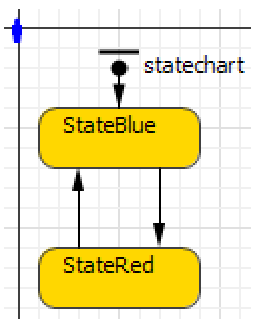
Defining Behaviour Using State Charts

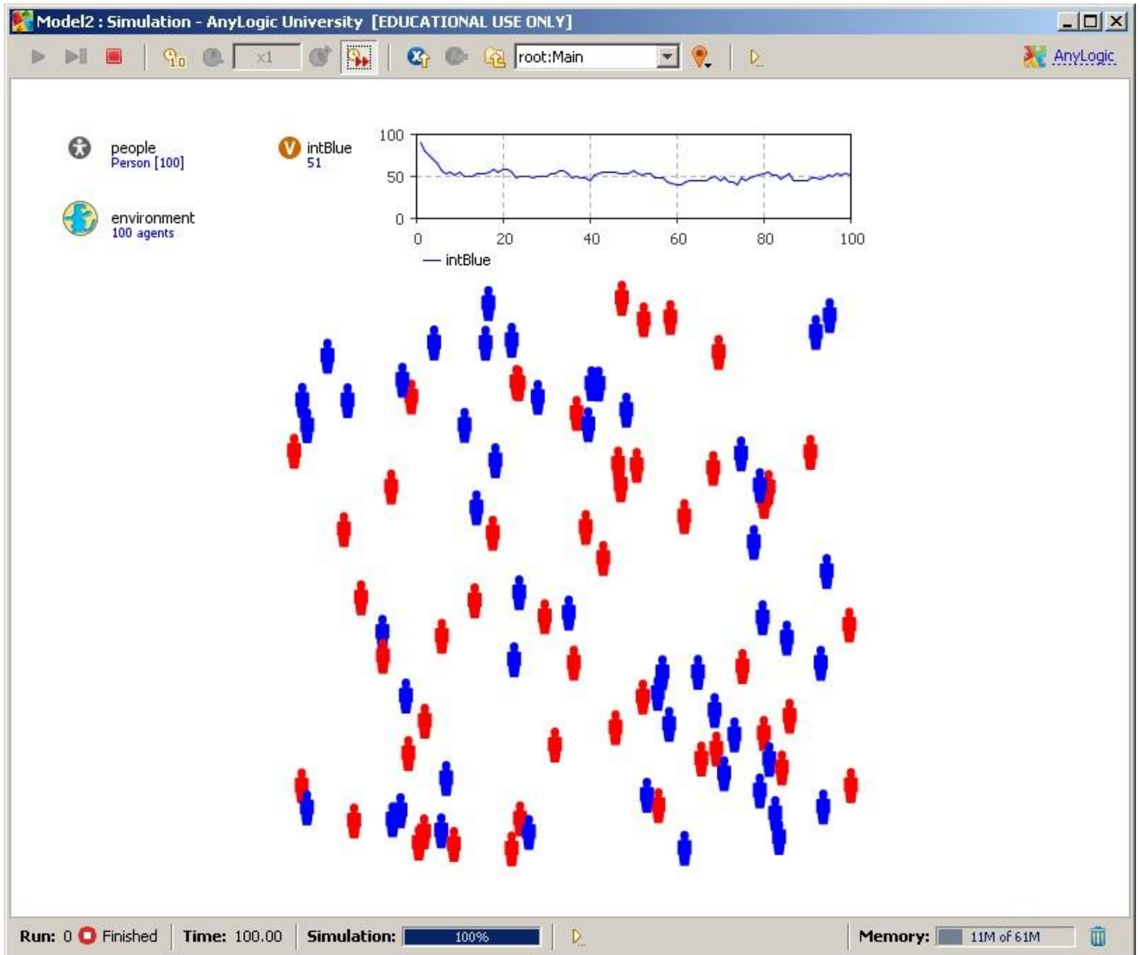
- Typical elements of a state chart diagram

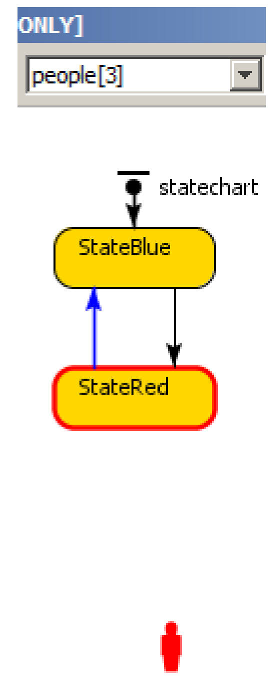


Simple Agent-Based Simulation Example







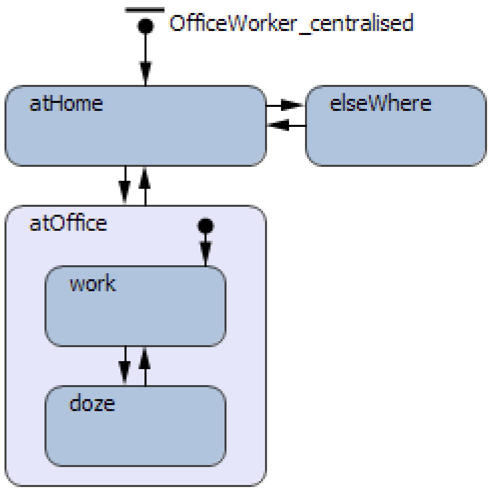


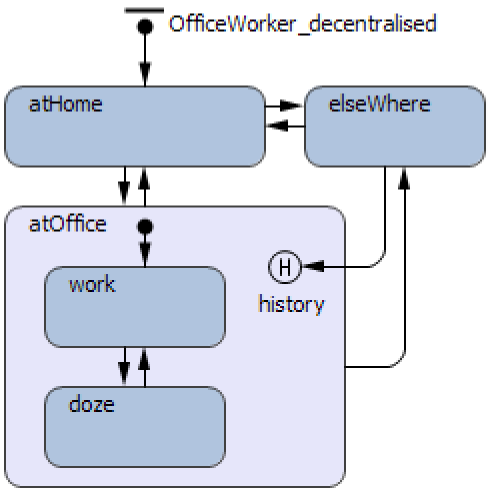
Building a Simple State Chart Step-by-Step

- Simulation an Office
  - Who are the actors?
  - What are the key locations you can find them?
  - What are key time consuming activities they get involved in?

Building a Simple State Chart Step-by-Step

- What is the principal difference between these solutions?





Agent Oriented Process Flow Modelling

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Agent-Based Simulation in OR/MS

- Simulation facts in different disciplines

Operations Research	Business, Economics, Social Science
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 in OR/MS

- Hybrid solution for OR/MS
  - Combining process flow and agent based modelling ideas
    - Representing the process flow using a process flow modelling approach but replacing the passive entities usually used in process flow models by active entities that have a memory, 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

Case Study 1
Department Store Customer Service

(For more details see Siebers and Aickelin 2011)

A queuing system

Case Study 1: Context

- Case study sector
  - Retail (department store operations)
- Developing some tools for understanding the impact of management practices on company performance
  - Operational management practices are well researched
  - People management practices are often neglected
- Problem:
  - How can we model proactive customer service behaviour?

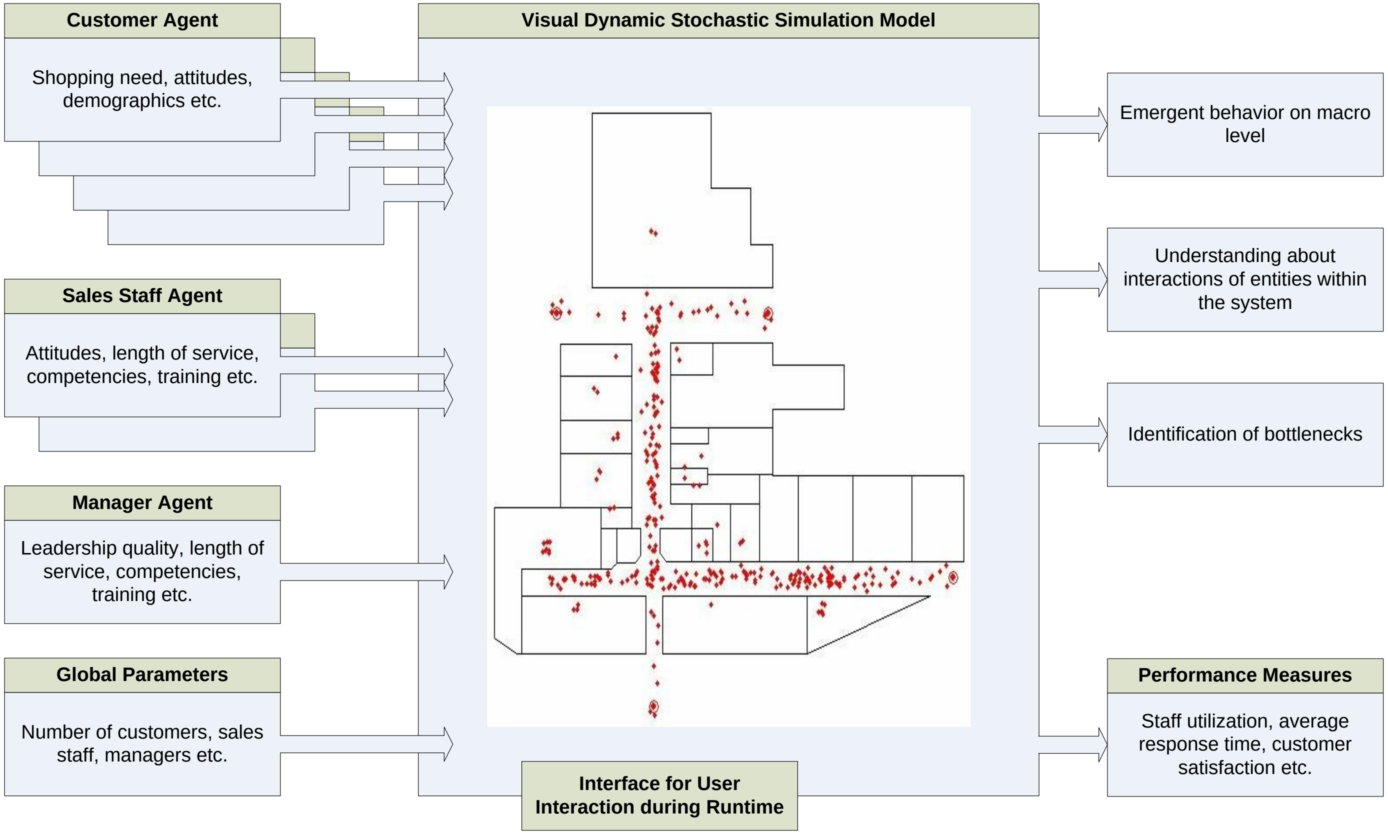
Case Study 1: Modelling

- Two case studies at two different locations
  - Two departments (A&TV and WW) at two department stores

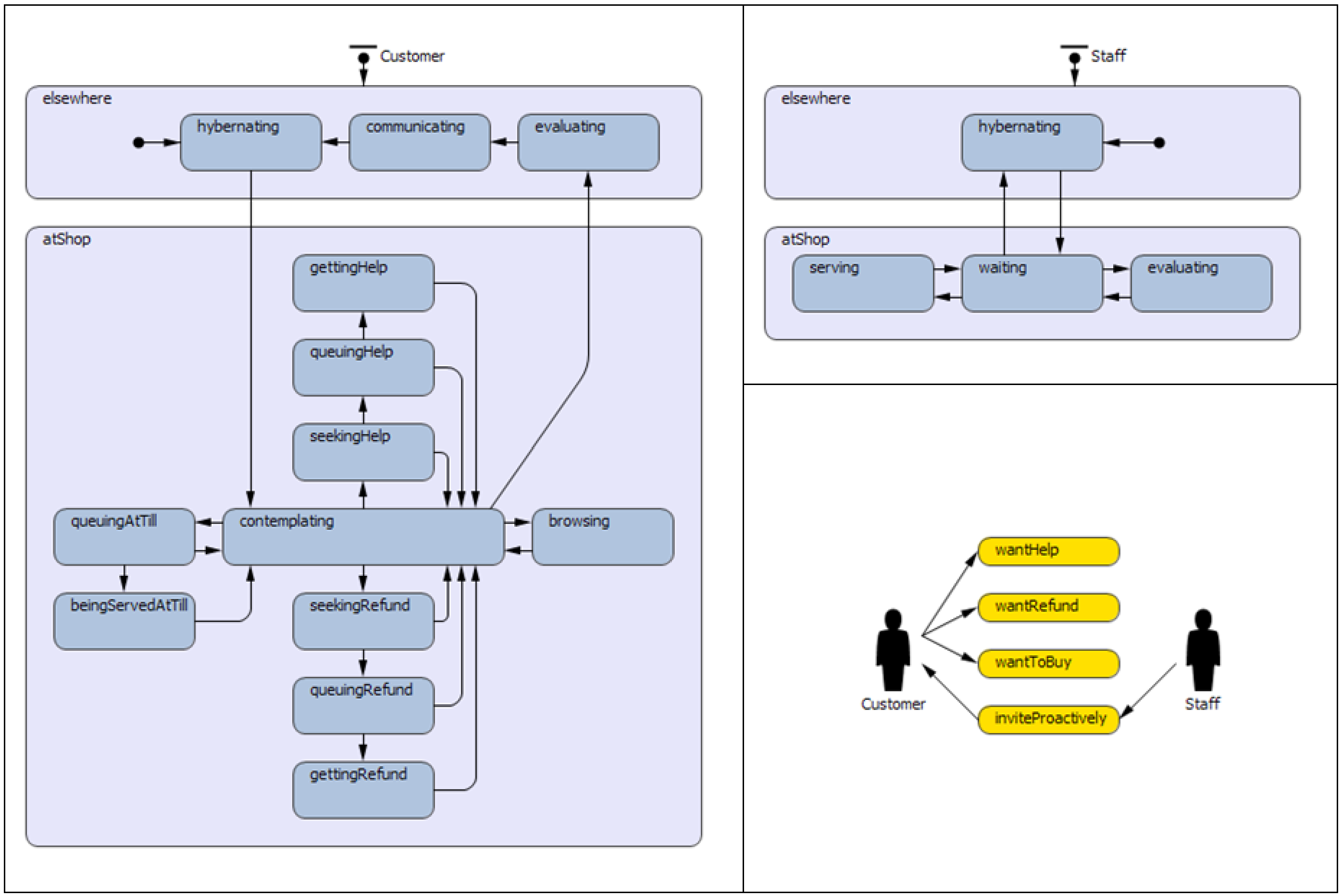
- Knowledge gathering
  - Informal participant observations
  - Staff interviews
  - Informational sources internal to the case study organisation

Case Study 1: Modelling

- Conceptual model

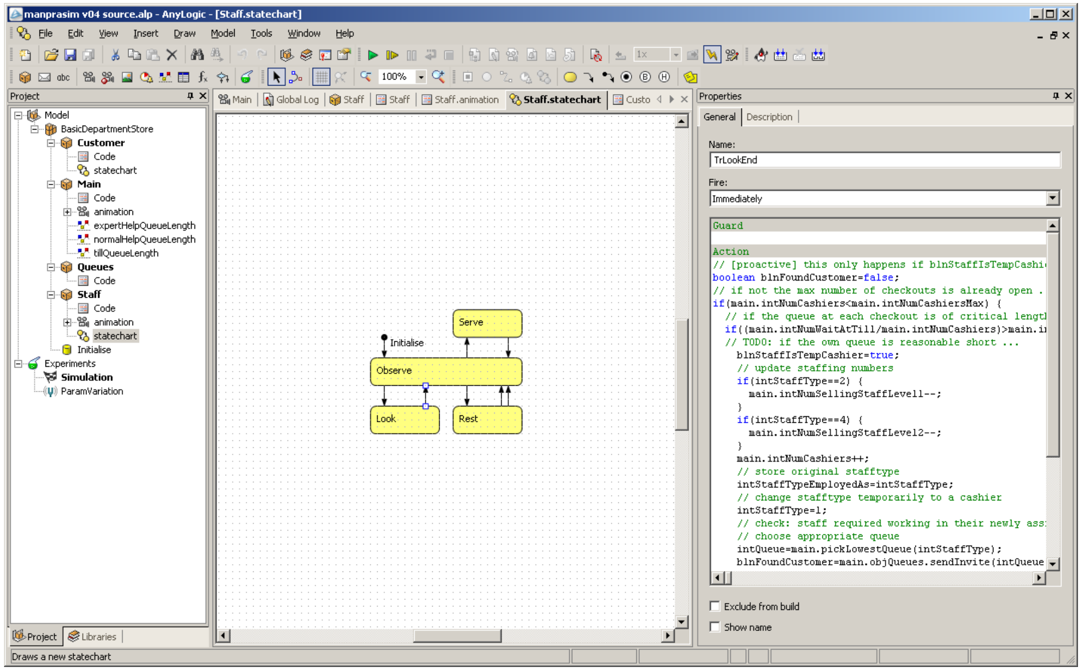


Case Study 1: Modelling



Case Study 1: Implementation

- Software: AnyLogic v5
  - Multi-method simulation software (SD, DES, ABS)
  - State charts + Java code



Case Study 1: Implementation

- Knowledge representation
  - Frequency distributions for determining state change delays

Situation	Min.	Mode	Max.
Leave browse state after …	1	7	15
Leave help state after …	3	15	30
Leave pay queue (no patience) after …	5	12	20

  - Probability distributions to represent decisions made

Event	Probability of event
Someone makes a purchase after browsing	0.37
Someone requires help	0.38
Someone makes a purchase after getting help	0.56

Case Study 1: Implementation

- Implementation of customer archetypes

Customer type	Likelihood to			
	buy	wait	ask for help	ask for refund
Shopping enthusiast	high	moderate	moderate	low
Solution demander	high	low	low	low
Service seeker	moderate	high	high	low
Disinterested shopper	low	low	low	high
Internet shopper	low	high	high	low

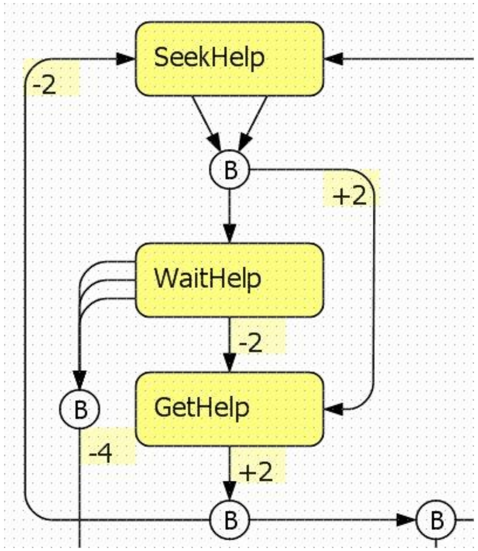
```
for (each threshold to be corrected) do  {
   if (OT < 0.5) limit = OT/2 else limit = (1-OT)/2
   if (likelihood = 0) CT = OT – limit
   if (likelihood = 1) CT = OT
   if (likelihood = 2) CT = OT + limit
}
where:       OT = original threshold
             CT = corrected threshold
             likelihood: 0 = low, 1 = moderate, 2 = high
```

Case Study 1: Implementation

- Implementation of staff proactiveness
  - Non-cashier staff opening and closing tills proactively depending on demand and staff availability
  - Expert staff helping out as normal staff

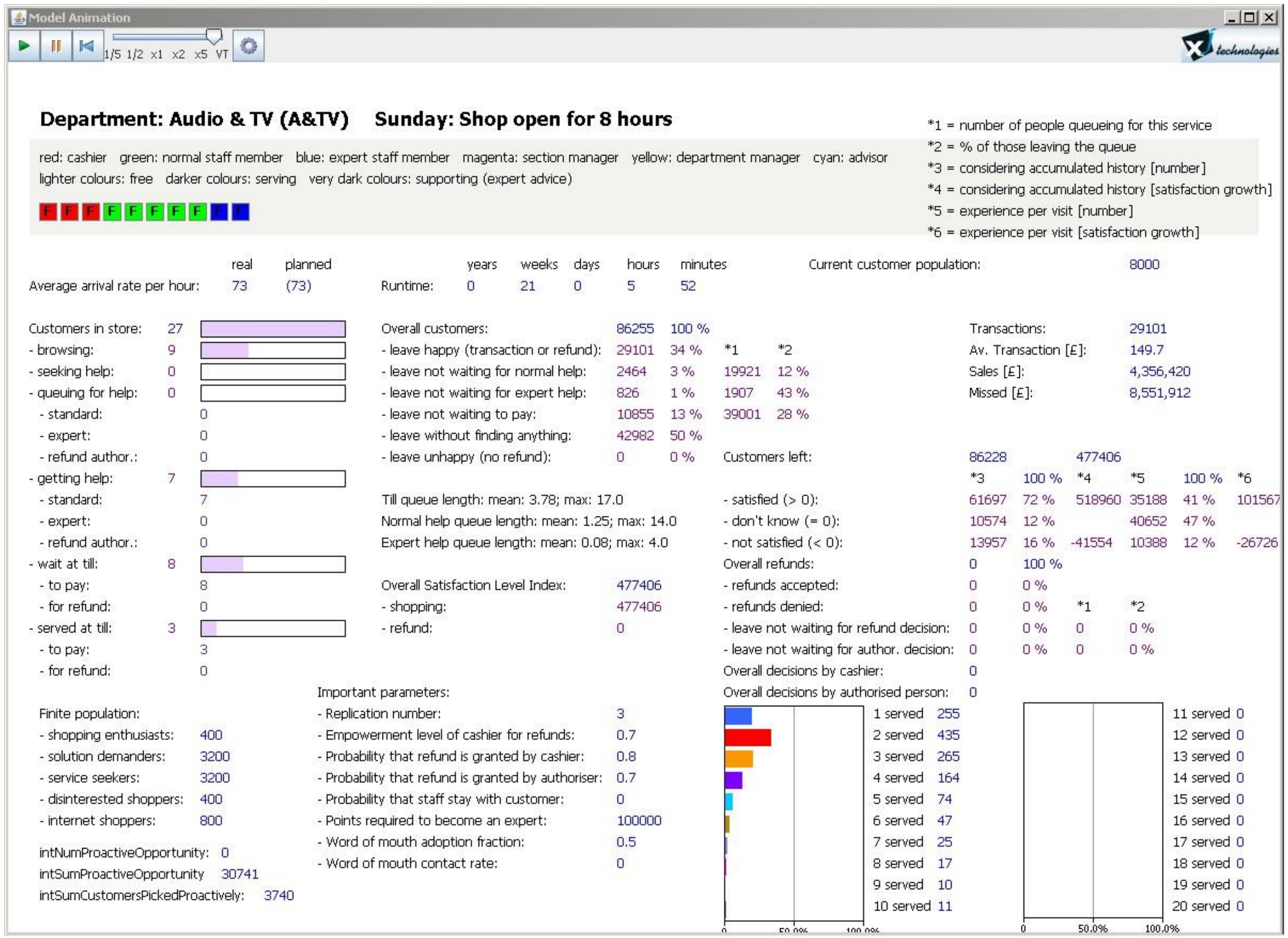
- Other noteworthy features of the model
  - Realistic footfall and opening hours
  - Staff pool (static)
  - Customer pool (dynamic)
  - Customer evolution through internal stimulation (triggered by memory of ones own previous shopping experience)
  - Customer evolution through external stimulation (word of mouth)

Case Study 1: Implementation



- Performance measures
  - Service performance measures
    - Service experience
  - Utilisation performance measures
    - Staff utilisation
    - Staff busy times in different roles
  - Level of proactivity
    - Frequency and duration of role swaps
  - Monetary performance measures (productivity and profitability)
    - Overall staff cost per day
    - Sales turnover
    - Sales per employee
    - ...

Case Study 1: Experimentation



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Case Study 1: Experimentation

- Real world (practical)
  - Staffing levels
  - Staff autonomy (refund, learning)
  - Staff training requirements
- Abstract (theoretical)
  - Extreme populations (customer types)
  - Level of detail (noise vs. noise reduction mode)
  - Different forms of customer pool implementations
  - Advertisement through spread of the word of mouth
- Validation
  - Testing parameters

Case Study 2
Office Energy Consumption

(For more details see Zhang et al 2010)

A non-queuing system

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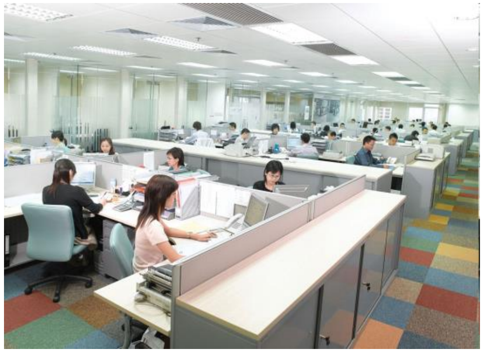
Case Study 2: Context



- Office building energy consumption
  - We focus on modelling electricity consumption
  - Organisational dilemma
    - Need to meet the energy needs of staff
    - Need to minimise its energy consumption through effective organisational energy management policies/regulations

- Objective
  - Test the effectiveness of different electricity management strategies, and solve practical office electricity consumption problems

Case Study 2: Modelling

- Electricity consumption (case study)
  - Base electricity consumption: security devices, information displays, computer servers, shared printers and ventilation systems.
  - Flexible electricity consumption: lights and office computers.

- Current electricity management technologies (case study)
  - Each room is equipped with light sensors
  - Each floor is equipped with half-hourly metering system

- Strategic questions to be answered (case study)
  - Automated vs. manual lighting management
  - Local vs. global energy consumption information

Case Study 2: Modelling

- We distinguishing base appliances and flexible appliance
  - Examples for **base appliances**
    - Security cameras
    - Information displays
    - Computer servers
    - Refrigerators
  - Examples for **flexible appliances**
    - Lights
    - Desktop computers
    - Printers

Case Study 2: Modelling

- The mathematical model
  - Ctotal = Cbase + Cflexible
    - where Cflexible = β1*Cf1+ β2*Cf2+ … + βn*Cfn
    - and Cf1 …Cfn = maximum electricity consumption of each flexible appliance
    - and β1 … βn = parameters reflecting the behaviour of the electricity user
      - β close to 0 = electricity user switches flexible appliances always off
      - β close to 1 = electricity user leaves flexible appliances always on
  - Ctotal = Cbase + (β1*Cf1+ β2*Cf2+ … + βn*Cfn)

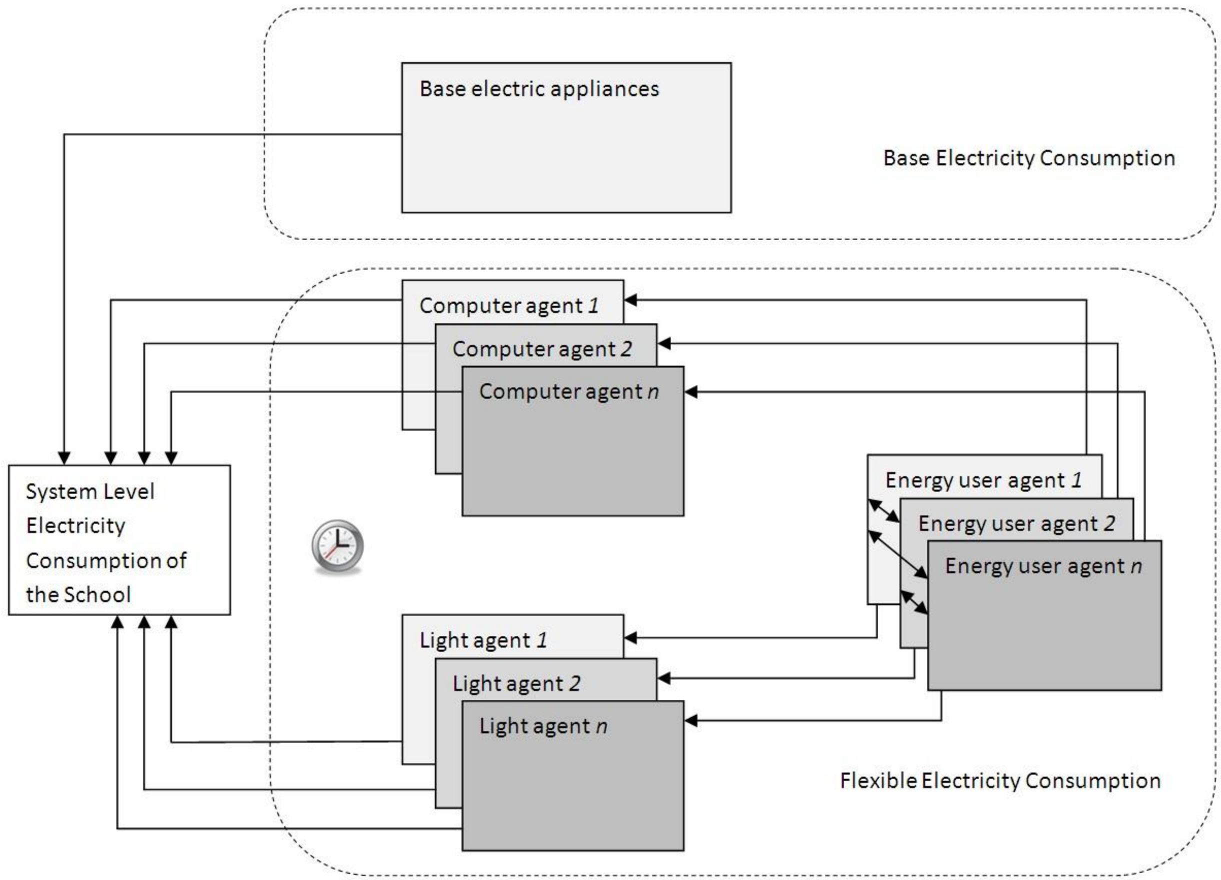
Case Study 2: Modelling

- Knowledge gathering
  - Consultations with the school's director of operations and the university estate office
  - Survey amongst the school's 200 PhD students and staff on electricity use behaviour (response rate 71.5%)

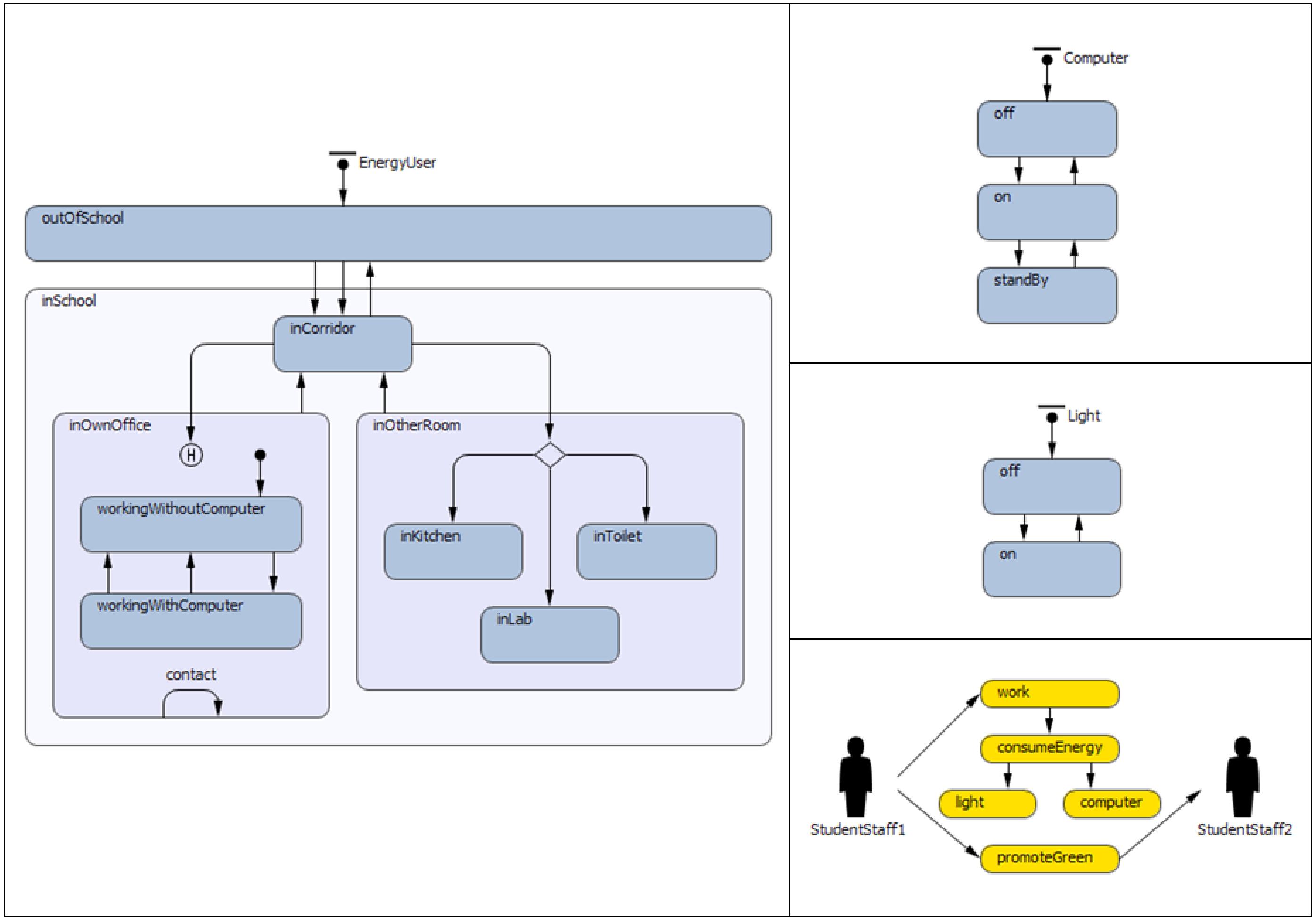
- User stereotypes
  - Working hour habits
    - Early birds, timetable compliers, flexible workers
  - Energy saving awareness
    - Environment champion; energy saver; regular user; big user

Case Study 2: Modelling

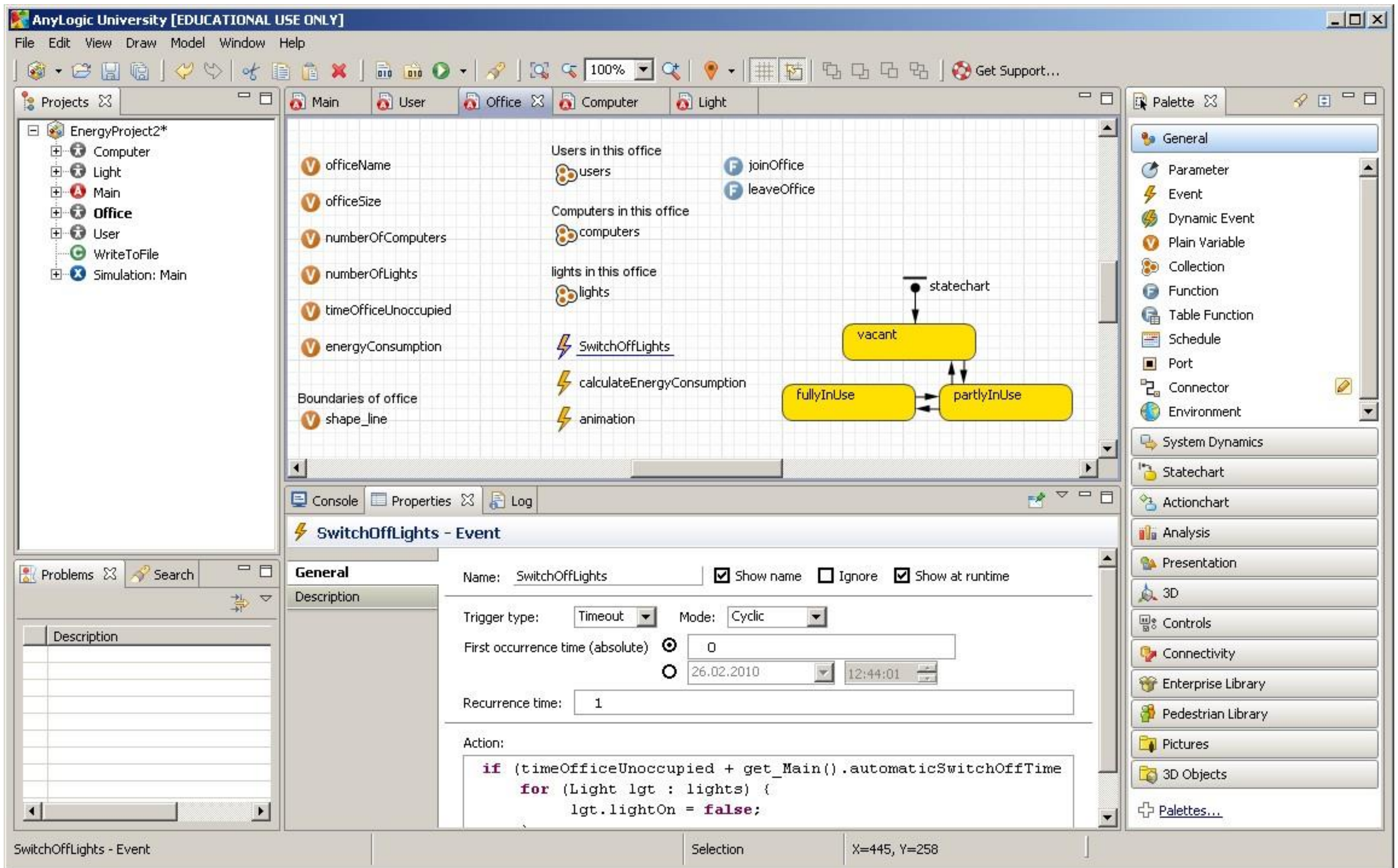
- Conceptual model



Case Study 2: Modelling



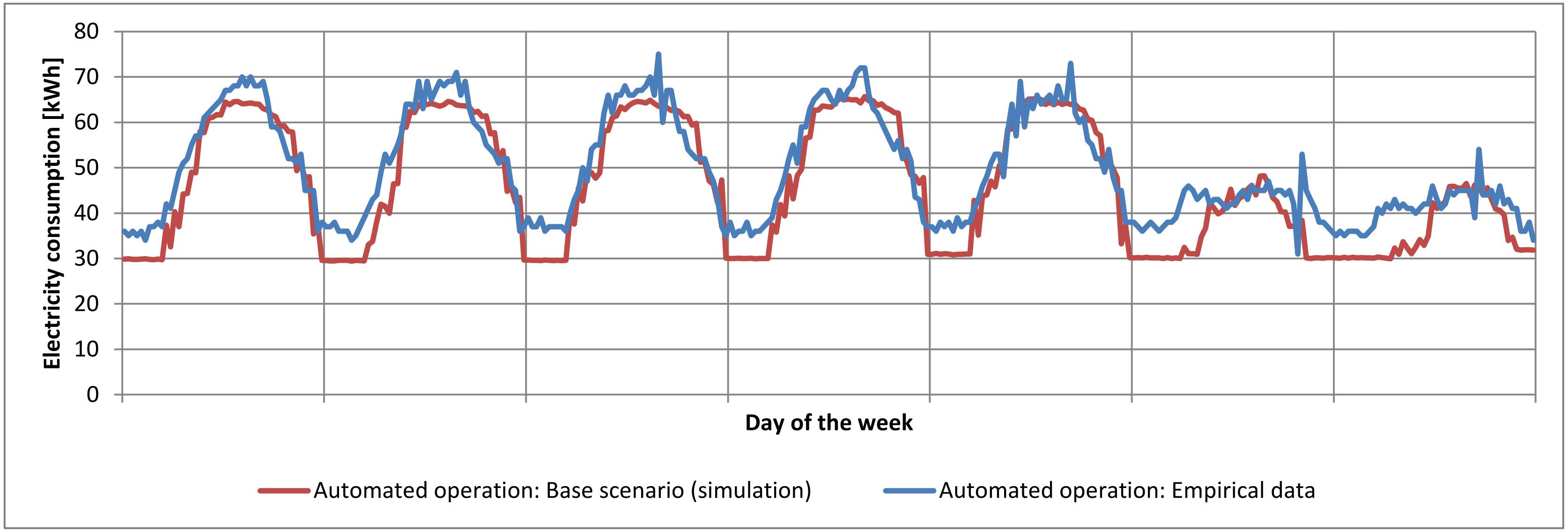
Case Study 2: Implementation



Case Study 2: Experimentation

Case Study 2: Experimentation

- Validation
  – Comparing **simulation** and **empirical results**



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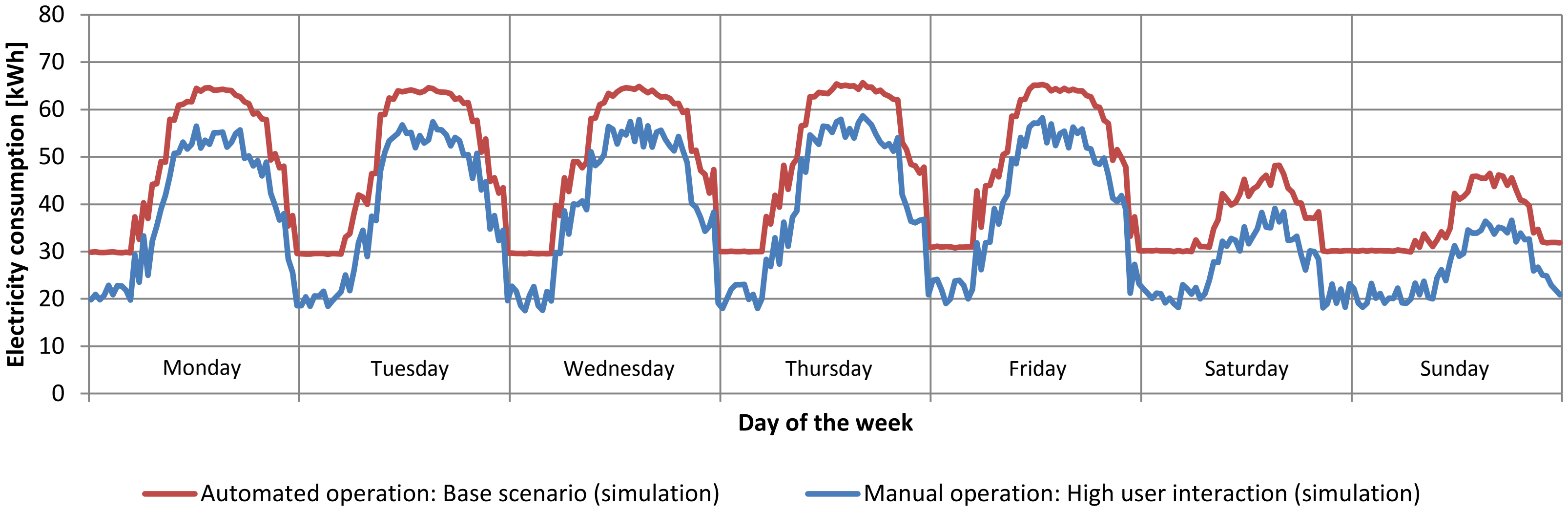
Case Study 2: Experimentation

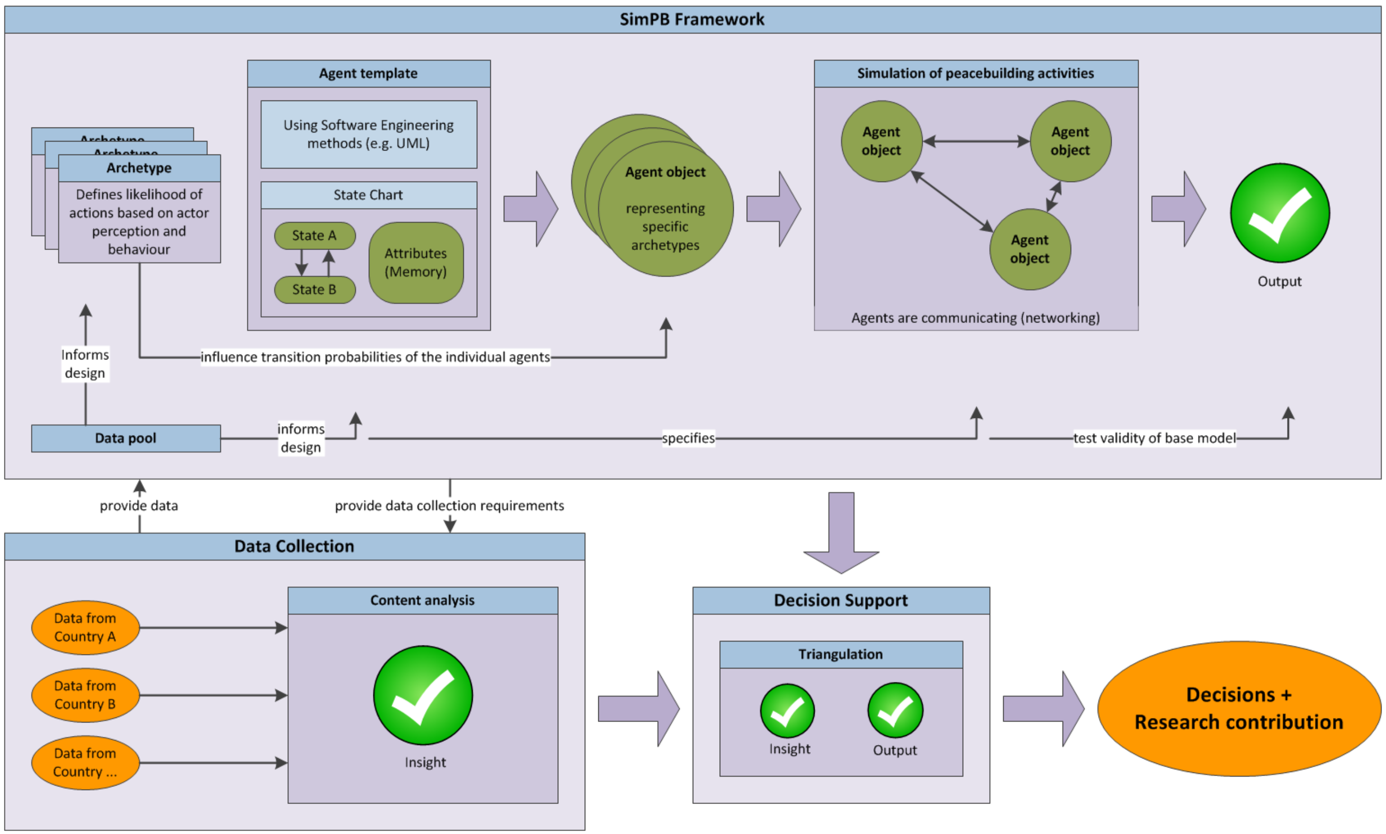
- Scenario #1
  - Comparing **automated** and **manual operation** (low user interaction)



Outlook

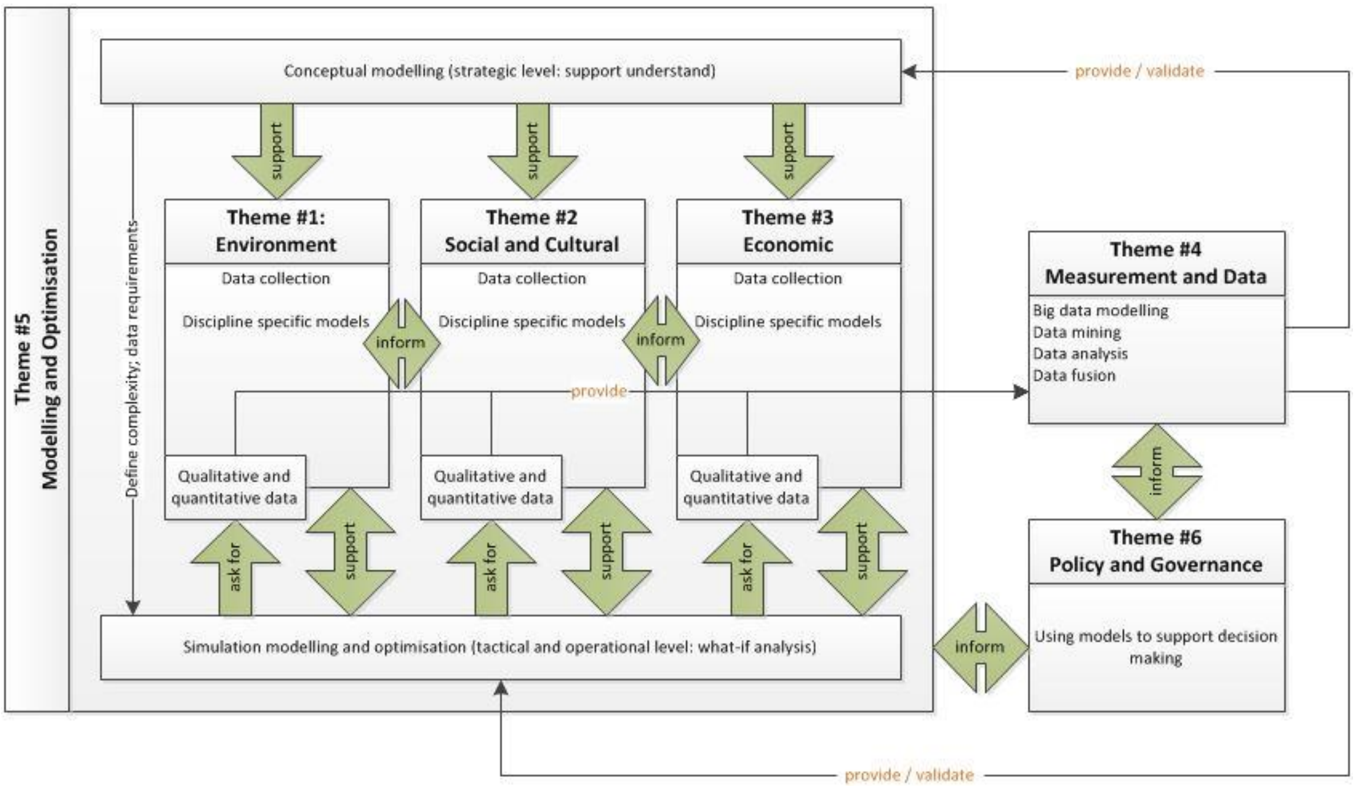
SimPB – Simulating Peace Building in Africa

- For more information see: http://www.cs.nott.ac.uk/~pos/research.html



Sustaining Urban Habitats

- For more information see: http://www.cs.nott.ac.uk/~pos/research.html



Recommended reading

- Discussion
  - Discrete-event simulation is dead, long live agent-based simulation! [url]
  - Discrete-event simulation is alive and kicking [url]
- HowTo
  - From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools [url]
  - Graphical Representation of Agent-Based Models in Operational Research and Management Science using UML [url]
  - JASSS Article: UML for ABM [url]
- Simulation Course
  - RWTH Aachen Summer Simulation Seminar 2014 [url]
  - ESSA Summer School [url]

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Questions / Comments