Agent-Oriented Modelling and Simulation of Human Centric Systems

Southampton Seminar
8 July 2014

Peer-Olaf Siebers

pos@cs.nott.ac.uk
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
Personal Introduction

• Technical aspects

- Energy Users
  - Consumers
    - Archetyping
  - Travellers
  - Personnel
- ABM Design Patterns
- Energy Users
- Development
- Agent templates
- Specific agents
- Multi-agent systems

- Agent-Based Modelling (ABM)

- Framework for agent-based model development
- Framework for combined ABM/DES
  - Defining the differences between agents in the different fields
  - New measures for ABM (how to turn subjective measures into objective ones)

- Comparing different approaches to ABM/S
- Comparing different approaches to modelling decision making in ABM/S

Southampton Seminar 2014
Personal Introduction

Southampton Seminar 2014
Personal Introduction

- Applications
Personal Introduction
Personal Introduction

• Related topics

- Mathematical Modelling
- System Dynamics (SD)
- Agent-Based Modelling (ABM)
- Translating mathematical models into ABMs
- Making sense of outliers
- Cost-Benefit Analysis (CBA)
- Multi-Criteria Decision Analysis (MCDA)
- Using MCDA together with Simulation
- Rare Event Modelling
Simulation Modelling Approaches
Simulation Modelling Approaches

- Process Oriented (PO) world view
  - Process based decision making
- Object Oriented (OO) world view
  - Entity based decision making
  - Multi Agent Systems (Software Engineering)
    - Data Driven
  - Agent-Based Modelling (Business + Social Science + Economics)
    - Theory Driven
  - System Dynamics Modelling (OR/MS + Business)
    - Theory Driven
- Process Flow Modelling (OR/MS)
  - Data Driven
- Other Hybrid Modelling
- AO Process Flow Modelling (OR/MS)
  - Data + Theory Driven
- OO Process Flow Modelling (OR/MS)
  - Data Driven
- OO Agent-Based Modelling (OR/MS + B + SS + E)
  - Data + Theory Driven

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
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]
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 decentralized; 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
  – ...

Southampton Seminar 2014
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

Grimm and Railsback (2005)

• Alternative (e.g. Ecology)
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
Agent-Based Simulation in OR/MS

- Simulation facts in different disciplines

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

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

Let entities interact + communicate

Agent layer

Replace passive entities by active ones

DES layer

Direct interactions
Network activities

Active entities
Behavioural state charts

Passive entities
Queues
Processes
Resources

Southampton Seminar 2014
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

<table>
<thead>
<tr>
<th>Situation</th>
<th>Min.</th>
<th>Mode</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leave browse state after ...</td>
<td>1</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td>Leave help state after ...</td>
<td>3</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Leave pay queue (no patience) after ...</td>
<td>5</td>
<td>12</td>
<td>20</td>
</tr>
</tbody>
</table>

- Probability distributions to represent decisions made

<table>
<thead>
<tr>
<th>Event</th>
<th>Probability of event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Someone makes a purchase after browsing</td>
<td>0.37</td>
</tr>
<tr>
<td>Someone requires help</td>
<td>0.38</td>
</tr>
<tr>
<td>Someone makes a purchase after getting help</td>
<td>0.56</td>
</tr>
</tbody>
</table>
Case Study 1: Implementation

- Implementation of customer archetypes

<table>
<thead>
<tr>
<th>Customer type</th>
<th>Likelihood to</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>buy</td>
<td>wait</td>
<td>ask for help</td>
<td>ask for refund</td>
</tr>
<tr>
<td>Shopping enthusiast</td>
<td>high</td>
<td>moderate</td>
<td>moderate</td>
<td>low</td>
</tr>
<tr>
<td>Solution demander</td>
<td>high</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Service seeker</td>
<td>moderate</td>
<td>high</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Disinterested shopper</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Internet shopper</td>
<td>low</td>
<td>high</td>
<td>high</td>
<td>low</td>
</tr>
</tbody>
</table>

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 one's 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

<table>
<thead>
<tr>
<th>Department: Audio &amp; TV (A&amp;TV)</th>
<th>Sunday: Shop open for 8 hours</th>
</tr>
</thead>
</table>

- **Customers in store:**
  - 27
  - 6
  - 6
  - 0
  - 0
  - 8
  - 3
  - 3

- **Average arrival rate per hour:**
  - Planned: 73

- **Overall satisfaction level index:**
  - 477405

- **Important parameters:**
  - 3

- **Transactions:**
  - 29701
  - 1974

- **Sales:**
  - 4256420

- **Customer complaints:**
  - 86326
  - 477405

- **Customer satisfaction:**
  - 3
  - 100%

Southampton Seminar 2014
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
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
  – \( C_{\text{total}} = C_{\text{base}} + C_{\text{flexible}} \)
    • where \( C_{\text{flexible}} = \beta_1 C_{f1} + \beta_2 C_{f2} + \ldots + \beta_n C_{fn} \)
    • and \( C_{f1} \ldots C_{fn} = \text{maximum electricity consumption of each flexible appliance} \)
    • and \( \beta_1 \ldots \beta_n = \text{parameters reflecting the behaviour of the electricity user} \)
      – \( \beta \) close to 0 = electricity user switches flexible appliances always off
      – \( \beta \) close to 1 = electricity user leaves flexible appliances always on
  – \( C_{\text{total}} = C_{\text{base}} + (\beta_1 C_{f1} + \beta_2 C_{f2} + \ldots + \beta_n C_{fn}) \)
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*

![Graph showing electricity consumption over the week for automated operation: Base scenario (simulation) and Empirical data.](chart.png)
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](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]
References

- AnyLogic Help (2013). Help file accessible from within the AnyLogic Software
- Aristotle (BC). Aristotle quotes [url]
- OpenABM.org. "Updating Information" [url]
Questions / Comments