Graphic Notations for ABM/S in OR/MS

ESM 2013 Tutorial

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Content

• Introduction to the Ideas of ABM/S
• Difficulties of Using ABM/S in OR/MS
• Solution: The UML Notation (e.g. State Machines)
• Building a UML State Machine: Step-by-Step Guide
• Case Studies
  – Hybrid ABM/DES Model (non synchronised)
  – Pure ABS Model (synchronised)
• Alternative: The BPMN Notation
Introduction to the Ideas of ABM/S
Heroes and Cowards Game [Wilensky and Rand 2013]

• The (very simple) rules
Heroes and Cowards Game  [Wilensky and Rand 2013]
Heroes and Cowards Game  [Wilensky and Rand 2013]
Paradigms and World Views

Process oriented world view

Process based decision making

SD (OR/MS + Business)
Theory driven; equation based

DES (OR/MS)
Data driven; UML based

Traditional DES (OR/MS)

Object Oriented DES (OR/MS)

Object oriented world view

Entity based decision making

ABM/S (Business + Social Science + Economics)
Theory driven; equation based

ABM/S (Social Science)
Data driven; equation based

Multi Agent Systems (Software Engineering)
Data driven; UML based

Agent Oriented DES (ABM + DES) (OR/MS)
Data + theory driven; UML based; non-synchronised

Object Oriented ABM/S (OR/MS)
Data + theory driven; UML based; synchronised

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
Simple SD Example
Simple DES Example
Simple ABS Example
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
Agent-Based Modelling

• Borrowing from Artificial Intelligence: From simple to complex
  – Learning Robo-Dog (SONY's AIBO)

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 thread of control
    • With their own memory
  – 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

• Validating an ABS model
  – System behaviour is an emergent property
  – Validation on a micro level
  – Experimental validation at macro level (if possible)

• Alternative (e.g. Ecology)

Grimm and Railsback (2005)
Agent-Based Simulation

• How does an agent based simulator work? [Macal 2013]
  – The **time-stepped simulation approach**: We have a time loop in which all the agents executed their behaviours at each integer time tick.
  – Each time an agent's behaviour is executed, it updates its own agent state, which possibly leads to updating the states of other agents and the environment (**synchronisation**).
  – An **event** in an ABS is the "time" at which an agent executes its behaviour and interacts with other agents and the environment. This may or may not correspond to time in the real world, only an ordered sequence of events is required to make the ABS work.
  – This is just one example algorithm: There are **many other ways** to advance time ...
Difficulties of Using ABM/S in OR/MS
Why is ABM/S still in its Infants in OR/MS?

• Some Stats:

<table>
<thead>
<tr>
<th></th>
<th>term 1</th>
<th>term 2</th>
<th>2006-2009</th>
<th>2010-2013</th>
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<td>simulation</td>
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</table>

Source: International Abstracts in Operations Research (http://www.palgrave-journals.com/iaor/)
Why is ABM/S still in its Infants in OR/MS?

- What do you think?
Why is ABM/S still in its Infants in OR/MS?

- Why don't we adopt the ABM/S approaches from other disciplines?

<table>
<thead>
<tr>
<th>Operations Research</th>
<th>Business, Economics, Social Science</th>
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<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 (2011)
Why is ABM/S still in its Infants in OR/MS?

• My hypotheses:
  – It is due to the fact that other disciplines do not use a graphical notation while in OR simulation we are used to a graphical notation
    • If a graphical notation (as in SD and DES) can be established the number of users of ABM will grow rapidly
  – It is due to the fact that it is assumed that huge computer power is required for ABMs
    • If a combined ABM/DES approach is considered as an alternative (which does not require synchronisation) usability of ABM will grow rapidly
    • If the right level of abstraction is chosen (perhaps multiple models at different levels of abstraction need to be build for solving a problem) ABM becomes feasible and the application of ABM will grow rapidly
Hybrid ABM/DES Simulation

- Communication layer
- Direct interactions
  Network activities
- Agent layer
  Let entities interact + communicate
  Active entities
  Behavioural state charts
- DES layer
  Replace passive entities by active ones
  Passive entities
  Queues
  Processes
  Resources

[Images of birds and people representing layer descriptions]
Solution: The UML Notation
Unified Modelling Language (UML)
Defining Behaviour Using State Charts  [Source: AnyLogic Help]

• State Charts
Defining Behaviour Using State Charts

• **State**
  – Represents a location of control with a particular set of reactions to conditions and/or events
  – Can be either **simple** or **composite**
    • Control always resides in one of simple states

– Example
  • Cup can be in state **full** or **empty**
  • Person can be in state **idle** or **busy**
Defining Behaviour Using State Charts

• State chart entry point
  – Indicates the initial state of the state chart
  – Each state chart has exactly one

• Initial state pointer
  – Points to the initial state within a composite state
  – Each state chart has as many as it has composite states
Defining Behaviour Using State Charts [Source: AnyLogic Help]

• **Transition**
  – Indicates that if the specified trigger event occurs and the specified guard condition is true, the state chart switches from one state to another and performs the specified action.

• **Internal transition**
  – Does not exit the enclosing state.
  – Useful for implementing simple background jobs, which do not interrupt the main activity of the composite state.
Defining Behaviour Using State Charts

- **Branch (pseudo state)**
  - Transition branching and/or connection point
  - When control passes a branch:
    - Its action is executed
    - The guards of transitions exiting the branch are evaluated

- **Final state (pseudo state)**
  - Termination point of a state chart; when control enters a final state, its action is executed, and the state chart terminates
Defining Behaviour Using State Charts  

- **History (pseudo state)**
  - A composite state may contain shallow and deep history states
  - When the control reaches history state its action is executed and the control is immediately passed to the real state referred by it

- Shallow history state is a reference to the most recently visited state on the same hierarchy level within the composite state.

- Deep history state is a reference to the most recently visited simple state within the composite state.
Typical Designs

- Centralised

- Decentralised

Please note that there are exceptions to this rule.
Building a Simple State Chart Step-by-Step

- Laptop model (considering different power states)
Building a Simple State Chart Step-by-Step

- State chart of laptop
Case Study 1
(For more details see Siebers and Aickelin 2011)

Understanding the Impact of Management Practices on Company Performance
Case Study: 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: 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: Modelling

- Conceptual model
CASE STUDY: MODELLING

**STORE**

- Entering
  - Queuing at till (for refund)
  - Being served at till (refund decision)
  - Browsing
  - Queuing at till (to buy)
  - Queuing for help
  - Being helped
  - Being served at till (refund decision)

**Leaving**

**Staff Resource Pool**
Case Study: Modelling

Customer State-Chart

- Queuing at till (for refund)
- Being served at till (refund decision)
- Seeking refund
- Browsing
- Contemplating (dummy state)
- Seeking help
- Queuing for help
- Being helped
- Being served at till (buying)

Staff State-Chart

- Serving
- Waiting

Errors:
- Identifier "UNITED KINGDOM - OHMA - MALAYSIA" is unreferenced.
- Identifier "Lancaster University Management School" is unreferenced.
Case Study: Modelling

STORE

CUSTOMERS

Customer #3 State-Chart
Customer #2 State-Chart
Customer #1 State-Chart

Staff #3 State-Chart
Staff #2 State-Chart
Staff #1 State-Chart

STEM

Customer #3

Customer #2

Customer #1

Entering

Leaving

Contemplating
(dummy state)

Serving

Waiting

Queuing at till
(for refund)

Seeking refund

Being served at till
(refund decision)

Browsing

Seeking help

Queuing for help

Being helped

Queuing at till
(to buy)

Being served at till
(buying)

Queuing at till
(for refund)

Seeking help

Contemplating
(dummy state)

Being served at till
(refund decision)

Browsing

Seeking refund

Queuing for help

Being helped

Queuing at till
(to buy)

Being served at till
(buying)
Case Study: Modelling

STORE

CUSTOMERS

Customer #1 State-Chart
- Entering
- Queuing at till (for refund)
- Seeking refund
- Seeking help
- Queuing for help
- Being served at till (refund decision)
- Browsing
- Being helped
- Being served at till (buying)
- Leaving

Customer #2 State-Chart
- Entering
- Queuing at till (to buy)
- Seeking help
- Queuing for help
- Being served at till (buying)

Customer #3 State-Chart
- Entering
- Queuing at till (dummy state)
- Leaving

STAFF

Staff #1 State-Chart
- Entering
- Serving
- Waiting
- Evaluating (system state)
- Invite

Staff #2 State-Chart
- Entering
- Want to buy
- Want help
- Want refund

Staff #3 State-Chart
- Entering
- Want to buy
- Want help
- Want refund

SIGNALS
*** = Initialisation state
Case Study: Implementation

- **Software:** AnyLogic v5 (later translated into v6)
  - Multi-method simulation software (SD, DES, ABS, DS)
  - State charts + Java code
Case Study: 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: Implementation

- Implementation of customer types

<table>
<thead>
<tr>
<th>Customer type</th>
<th>Likelihood to</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>buy</td>
</tr>
<tr>
<td>Shopping enthusiast</td>
<td>high</td>
</tr>
<tr>
<td>Solution demander</td>
<td>high</td>
</tr>
<tr>
<td>Service seeker</td>
<td>moderate</td>
</tr>
<tr>
<td>Disinterested shopper</td>
<td>low</td>
</tr>
<tr>
<td>Internet shopper</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: 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: 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
    • ...
**Department: Audio & TV (A&TV)  Sunday: Shop open for 8 hours**

Red: cashier  Green: normal staff member  Blue: expert staff member  Magenta: section manager  Yellow: department manager  Cyan: advisor  Lighter colours: free  Darker colours: serving  Very dark colours: supporting (expert advice)

<table>
<thead>
<tr>
<th></th>
<th>real</th>
<th>planned</th>
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</thead>
<tbody>
<tr>
<td>Average arrival rate per hour:</td>
<td>73</td>
<td>(73)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>years</th>
<th>weeks</th>
<th>days</th>
<th>hours</th>
<th>minutes</th>
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<tbody>
<tr>
<td>Runtime:</td>
<td>0</td>
<td>21</td>
<td>0</td>
<td>5</td>
<td>52</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Current customer population:</th>
<th>60000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transactions:</td>
<td>29101</td>
</tr>
<tr>
<td></td>
<td>Av. Transaction [k]:</td>
<td>149.7</td>
</tr>
<tr>
<td></td>
<td>Sales [E]:</td>
<td>4,356,420</td>
</tr>
<tr>
<td></td>
<td>Missed [E]:</td>
<td>8,351,912</td>
</tr>
</tbody>
</table>

|                      | Overall customers: | 86228 |
|                      | 477406 |

|                      | Customers left: | 86228 |
|                      | 477406 |

|                      | Till queue length: mean: 3.78; max: 17.0 |
|                      | Normal help queue length: mean: 1.25; max: 14.0 |
|                      | Expert help queue length: mean: 0.08; max: 4.0 |

|                      | Overall Satisfaction Level Index: | 477406 |
|                      | shopping: | 477406 |

|                      | Overall decisions by authorised person: | 0 |

|                      | Important parameters: | |
|                      | Replication number: | 3 |
|                      | Empowerment level of cashier for refunds: | 0.7 |
|                      | Probability that refund is granted by cashier: | 0.8 |
|                      | Probability that refund is granted by authoriser: | 0.7 |
|                      | Probability that staff stay with customer: | 0 |
|                      | Points required to become an expert: | 100000 |
|                      | Word of mouth adoption fraction: | 0.5 |
|                      | Word of mouth contact rate: | 0 |

|                      | testimonials: | |
|                      | 1 served 255 |
|                      | 2 served 455 |
|                      | 3 served 265 |
|                      | 4 served 164 |
|                      | 5 served 74 |
|                      | 6 served 47 |
|                      | 7 served 25 |
|                      | 8 served 17 |
|                      | 9 served 10 |
|                      | 10 served 11 |
|                      | 11 served 0 |

|                      | Finite population: | |
|                      | shopping enthusiasts: | 400 |
|                      | solution demanders: | 3200 |
|                      | service seekers: | 3200 |
|                      | disinterested shoppers: | 400 |
|                      | internet shoppers: | 800 |
|                      | intNumproactiveOpportunity: | 0 |
|                      | intSumProactiveOpportunity: | 30741 |
|                      | intSumCustomersPickedProactively: | 3740 |
Case Study 2
(For more details see Zhang et al 2010)

Office Building Energy Consumption
Case Study: 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: 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: 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: 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 \( C_{f1} \ldots C_{fn} = \) maximum electricity consumption of each flexible appliance
    • and \( \beta_1 \ldots \beta_n = \) 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: 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: Modelling

- Conceptual model
Case Study: Modelling

- Energy user agent
  - Proactive
Case Study: Modelling

- Computer agent  
  - passive

- Light agent  
  - passive

- Office agent  
  - passive
Case Study: Implementation
Alternative: The BPMN Notation
(For more details see Onggo 2012 and Onggo 2013)
Why BPMN?

• A standard designed for business users
• Supported by influential vendors
• Designed for process modelling, but
  – Agent in ABS model ≈ BPMN participant (pool)
    • BPMN pool provides graphical representation
  – Agent’s autonomy ≈ BPMN pool’s domain control
  – Agent’s attributes ≈ BPMN data annotations
  – Agent’s behaviour ≈ BPMN flow and connecting objects
  – Communication via message passing
## BPMN Core Components

<table>
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<tr>
<th>Element</th>
<th>Notation</th>
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<tbody>
<tr>
<td>Event</td>
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<tr>
<td>Activity</td>
<td>![Activity symbol]</td>
</tr>
<tr>
<td>Gateway</td>
<td>![Gateway symbol]</td>
</tr>
<tr>
<td>Sequence flow</td>
<td>![Sequence flow]</td>
</tr>
<tr>
<td>Message flow</td>
<td>![Message flow]</td>
</tr>
<tr>
<td>Association</td>
<td>![Association]</td>
</tr>
<tr>
<td>Data association</td>
<td>![Data association]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element</th>
<th>Notation</th>
</tr>
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<tbody>
<tr>
<td>Pool</td>
<td>![Pool symbol]</td>
</tr>
<tr>
<td>Lane</td>
<td>![Lane symbol]</td>
</tr>
<tr>
<td>Data object, Data input, Data output</td>
<td>![Data object, Data input, Data output]</td>
</tr>
<tr>
<td>Data store</td>
<td>![Data store]</td>
</tr>
<tr>
<td>Group</td>
<td>![Group]</td>
</tr>
<tr>
<td>Text annotation</td>
<td>![Text annotation]</td>
</tr>
</tbody>
</table>
BPMN Collaboration and Conversation Diagram

Collaboration:
- Distributor:
  - Receive inventory request
  - Send inventory status
- Inventory request
- Inventory status

Conversation:
- Trader:
  - Receive order
  - Check inventory status
  - Send order status
- Order
- Order status

- Customer:
  - Send order
  - Receive order status

Customer → Trader → Distributor
BPMN Pattern for a Generic Agent
Example: SugarScape - Person

- Enquire sugar from visible grids
- Select grid with highest sugar
- intention to enter
- Select the next best grid
- granted?
  - more grid?
  - Consume sugar
  - sugar > 0?
    - No
    - person died
  - No
  - age < max age?
    - Yes
    - Enquire sugar
    - harvest request
    - Add to own sugar
    - amount harvested
    - intention to leave
  - Declined
Example: SugarScape - Grid

Max capacity?

No

Grow sugar

1 time unit

Grow

Respond to sugar enquiry

Get sugar info

sugar info

sugar enquiry

Respond to intention to enter

Check availability

No

granted

Set to occupied

harvest request

Get sugar info

amount harvested

Reset sugar

declined

intention to enter

available?

Respond to intention to leave

Validate sender

Yes

Set to available

valid sender?
Example: SugarScape - Conversation

Sugar Person

Sugar Grid

sugar enquiry  sugar info  intention to enter  granted  declined  harvest request  amount harvested  intention to leave
Questions / Comments

For slides and models of our short course "Simulation for Decision Support" have a look at www.cs.nott.ac.uk/~pos/biss2013
References

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