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

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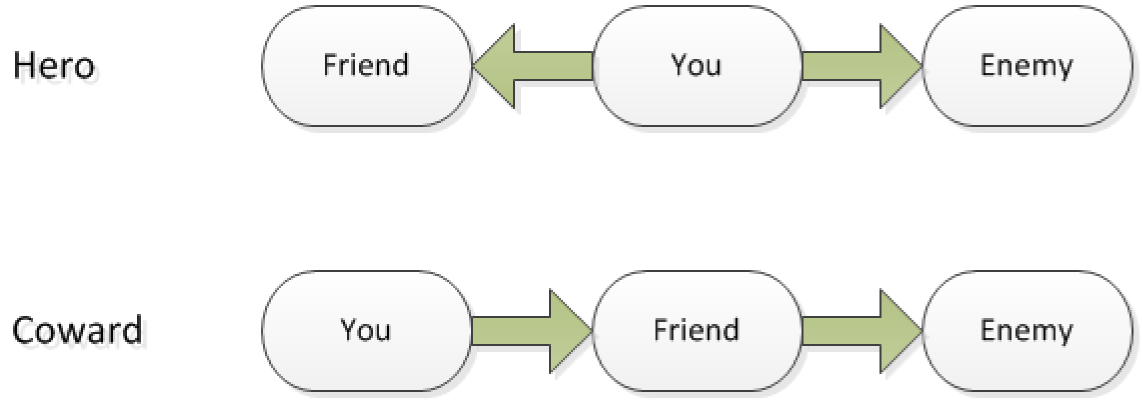
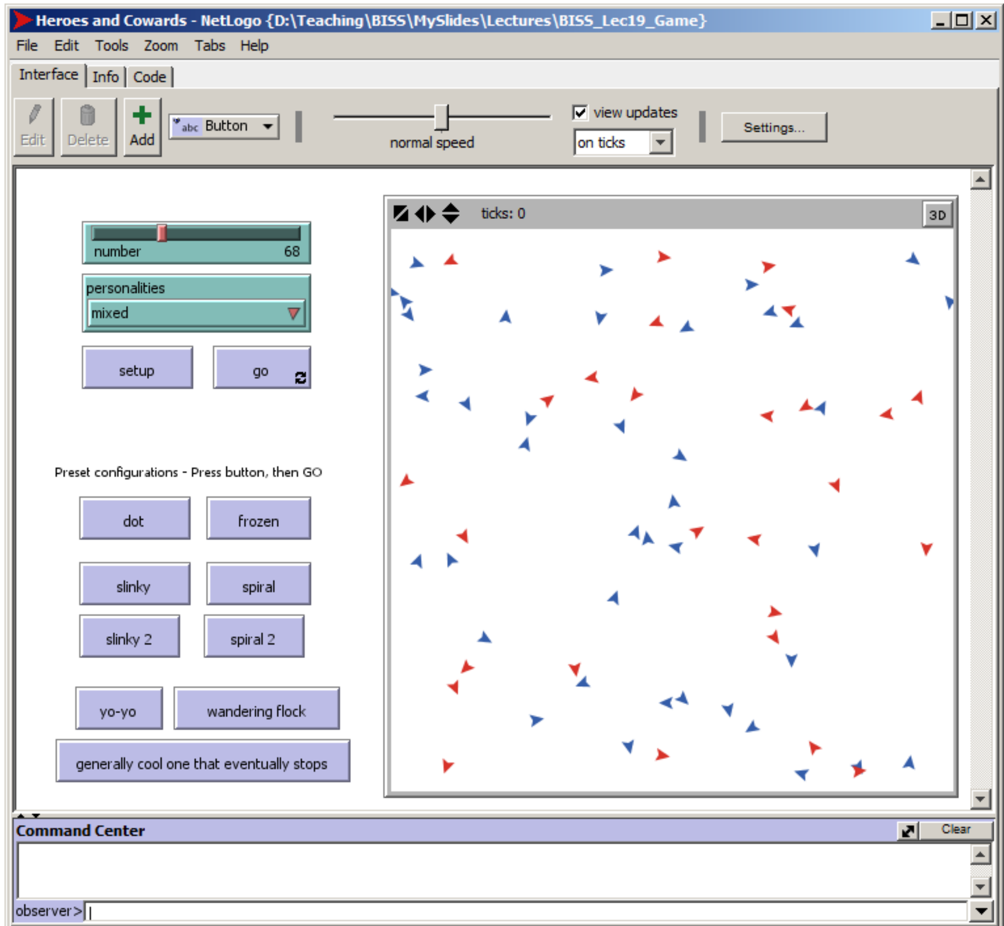
Heroes and Cowards Game [Wilensky and Rand 2013]

- The (very simple) rules



Heroes and Cowards Game [Wilensky and Rand 2013]



Heroes and Cowards Game [Wilensky and Rand 2013]

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

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; See Info tab for full copyright and license.
```
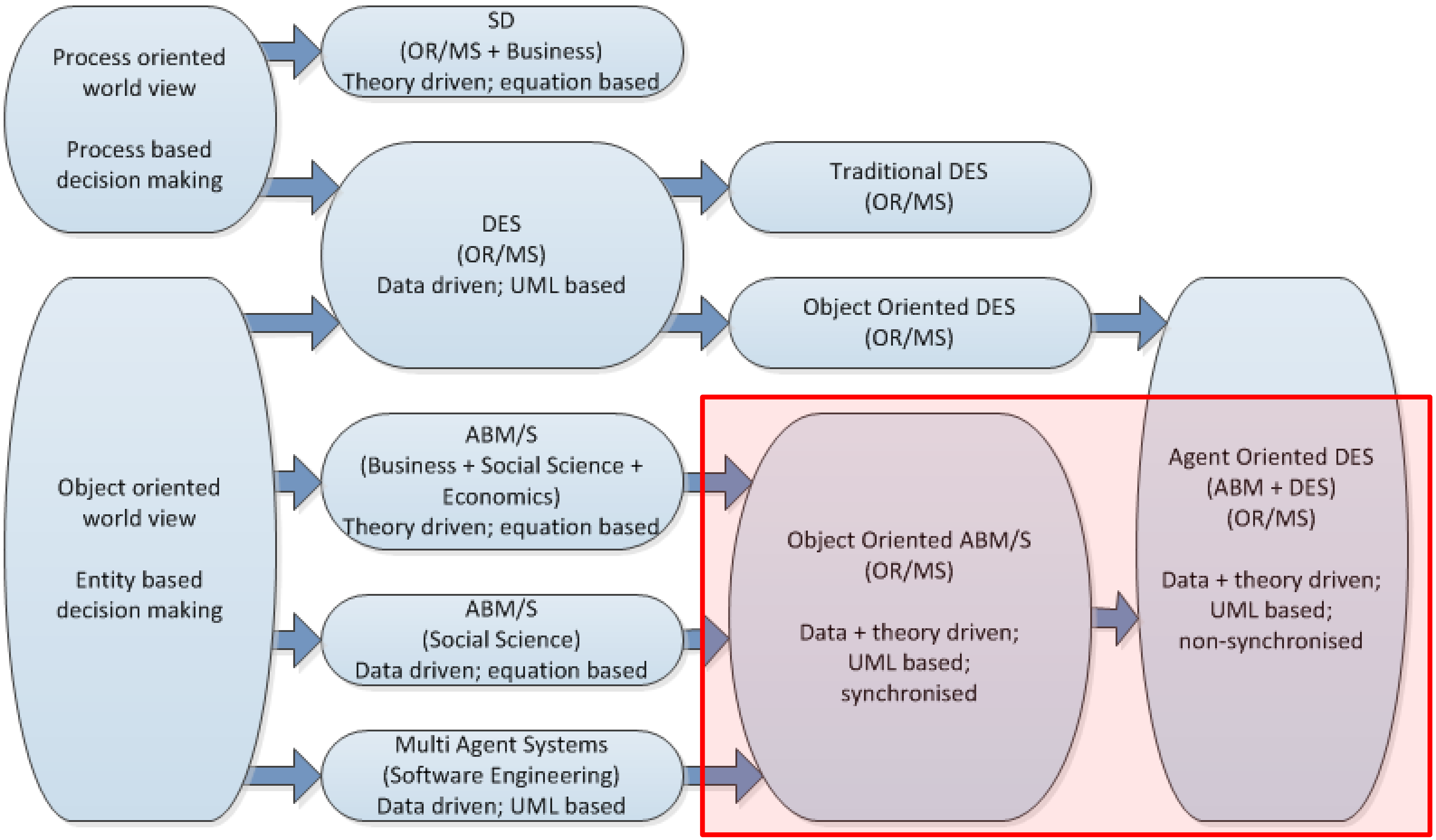
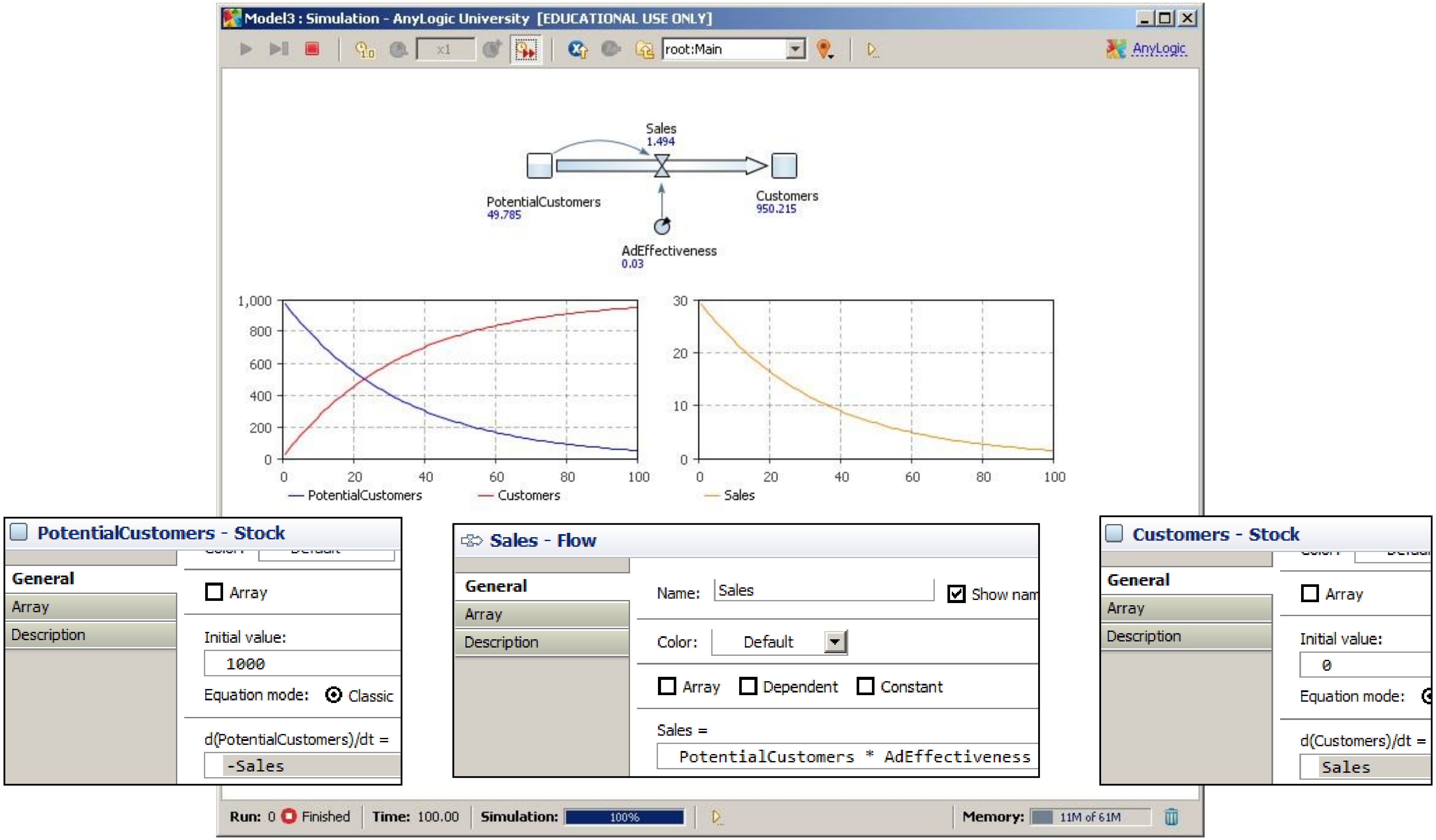

Paradigms and World Views

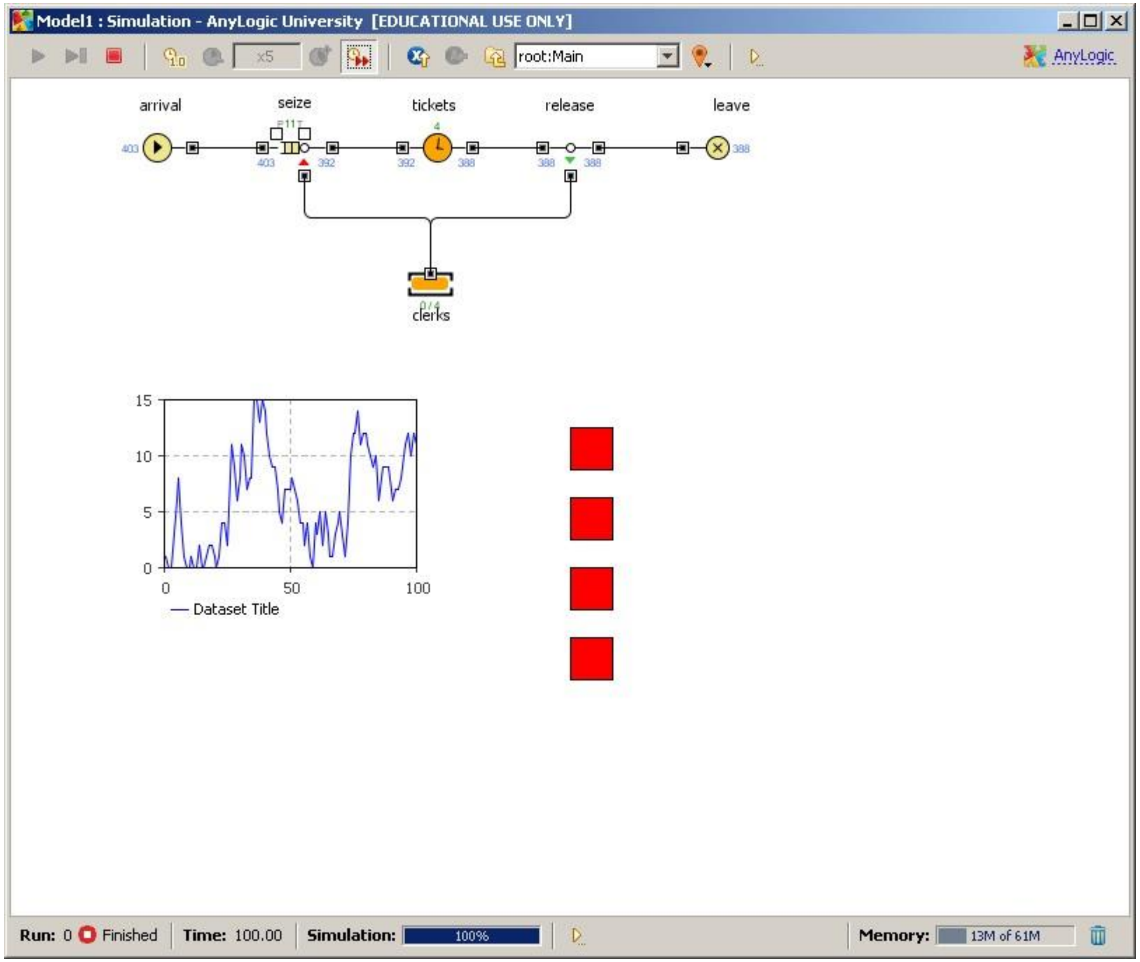


Data driven: Data for model formulation (in Social Sciences can be quantitative and qualitative); data for model validation
Theory driven: Theories for model formulation; data for model validation

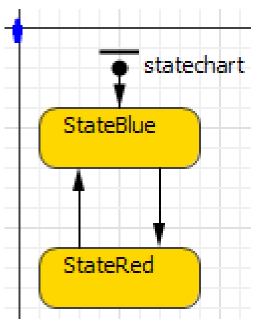
Simple SD Example

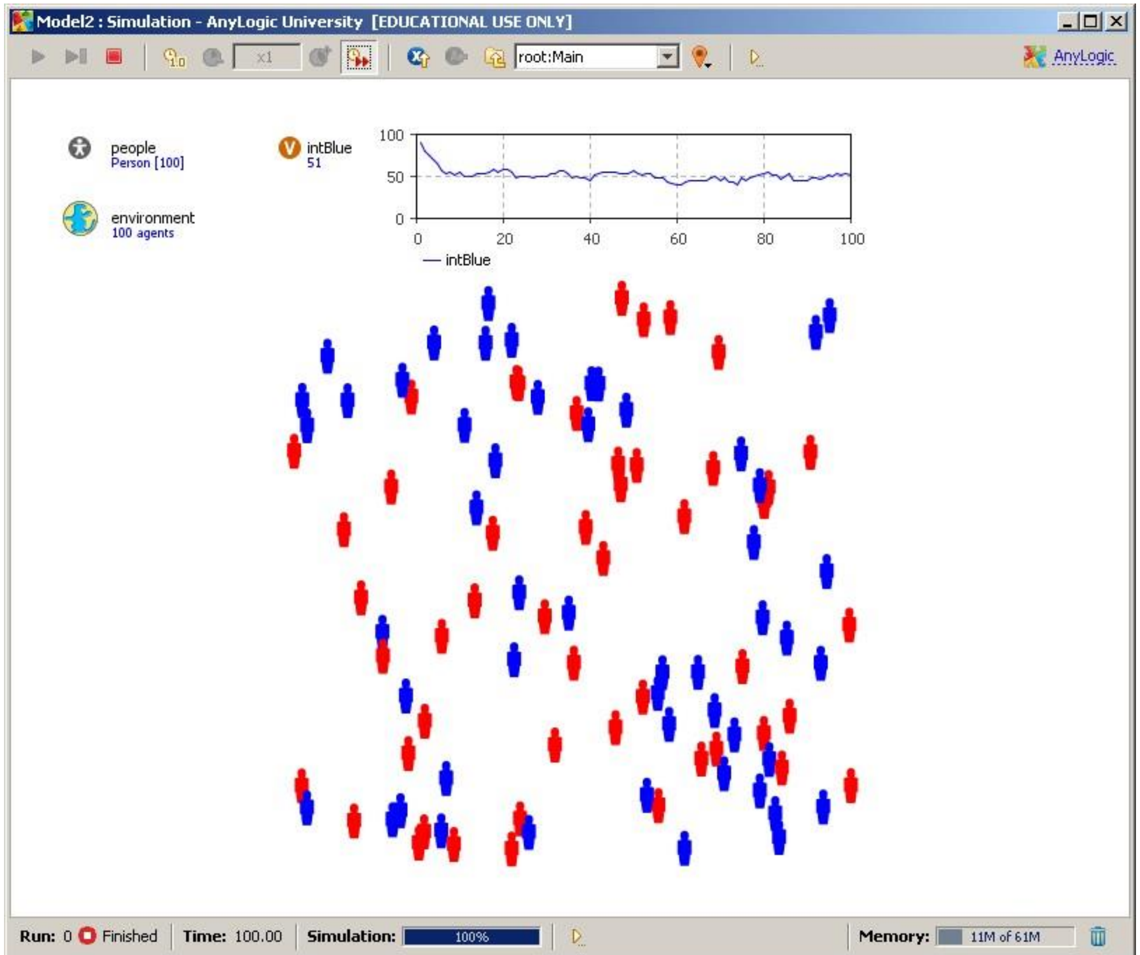


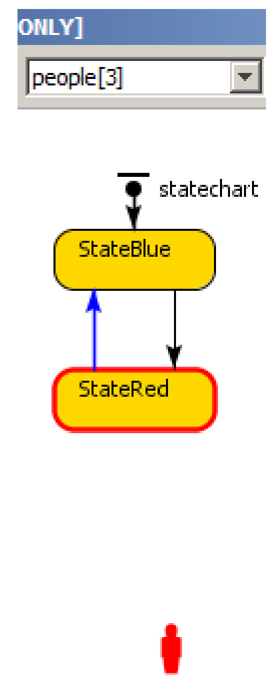
Simple DES Example



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**.

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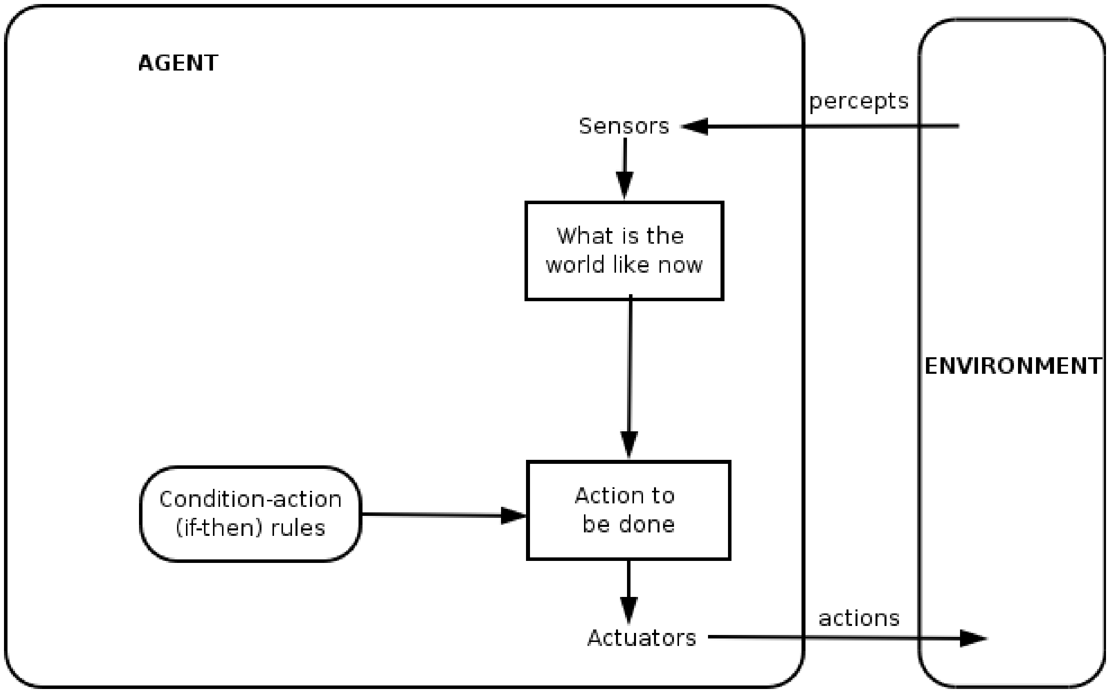
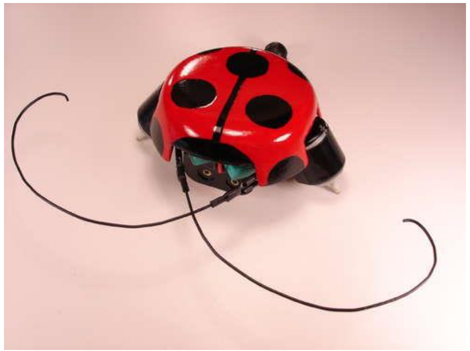
Agent-Based Modelling

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

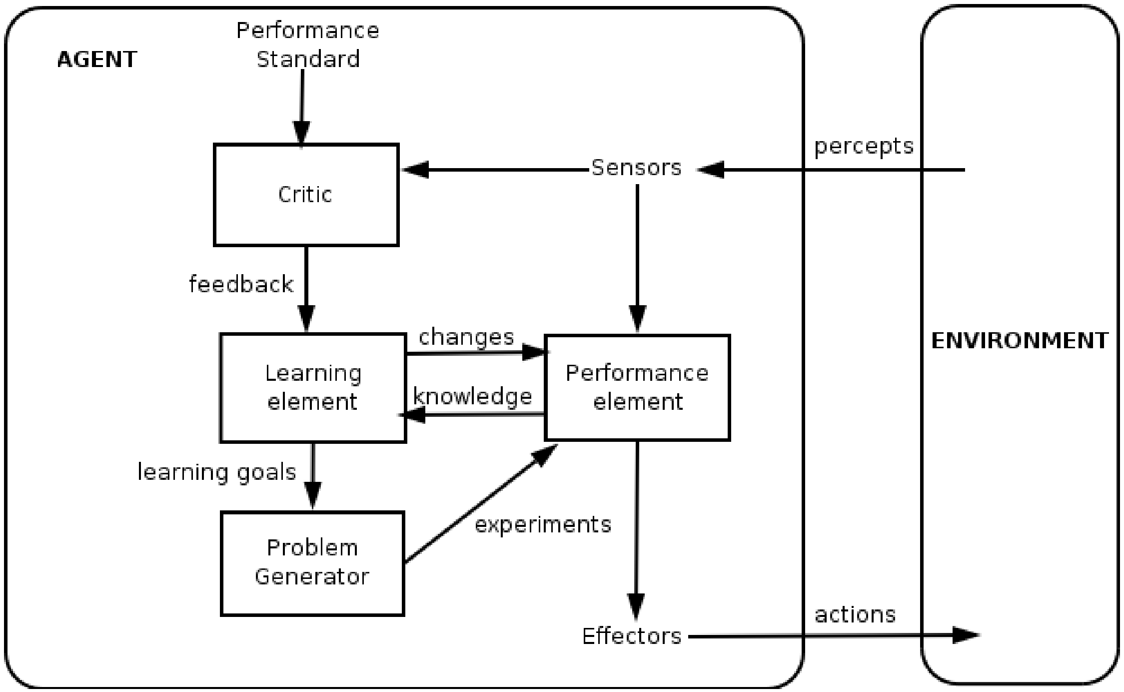




Russell and Norvig (2003)

Agent-Based Modelling

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

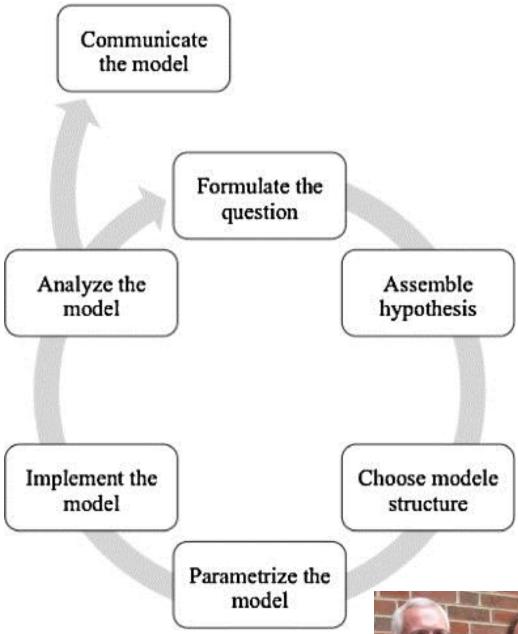
- The Sims: Interactive Organisational Agent-Based Simulation

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:

term 1	term 2	2006-2009	2010-2013
	simulation	1298	2049
system dynamics	simulation	73	128
discrete event	simulation	119	93
agent based	simulation	47	85
uml	simulation	2	5
agent based	uml	0	0
	social simulation	38	83
agent based	social simulation	3	12

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?

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 (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

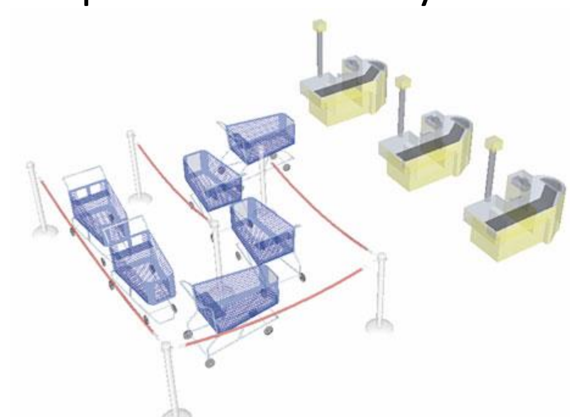
Let entities interact + communicate

Agent layer

Active entities
Behavioural state charts

Replace passive entities by active ones

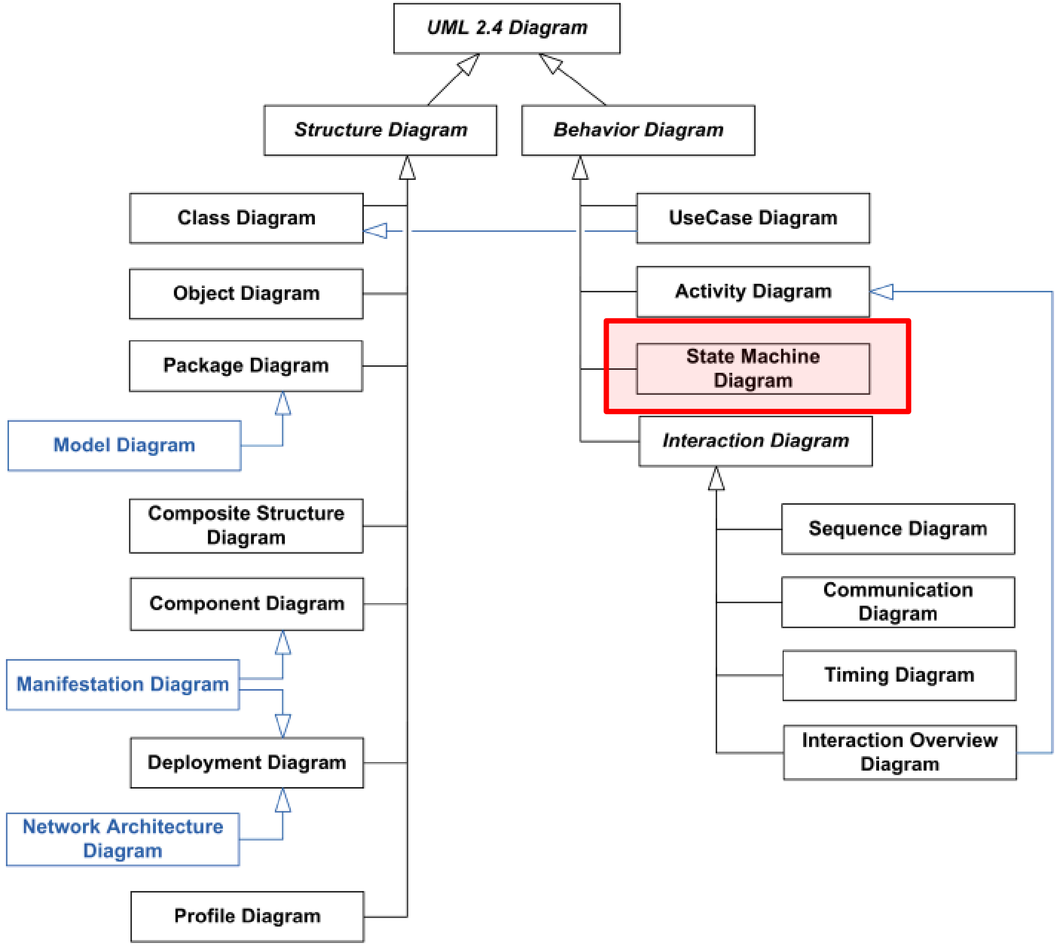
DES layer



Passive entities
Queues
Processes
Resources

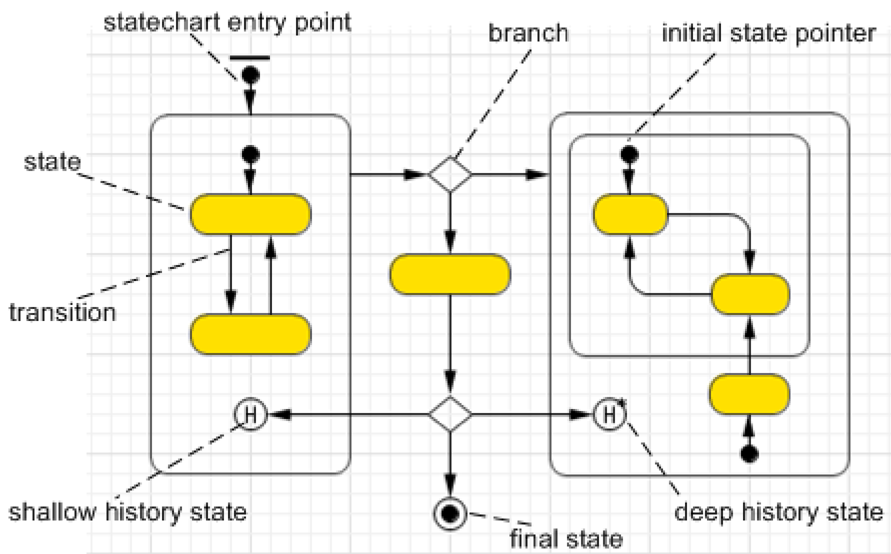
Solution: The UML Notation

Unified Modelling Language (UML)



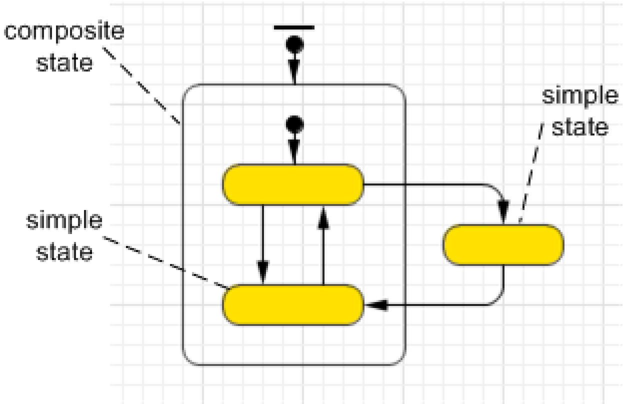
Defining Behaviour Using State Charts [Source: AnyLogic Help]

- State Charts



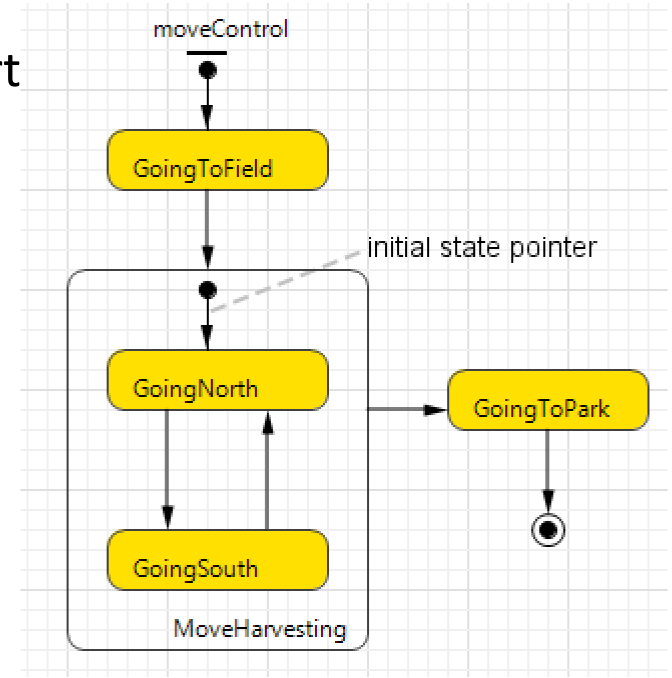
Defining Behaviour Using State Charts [Source: AnyLogic Help]

- 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**



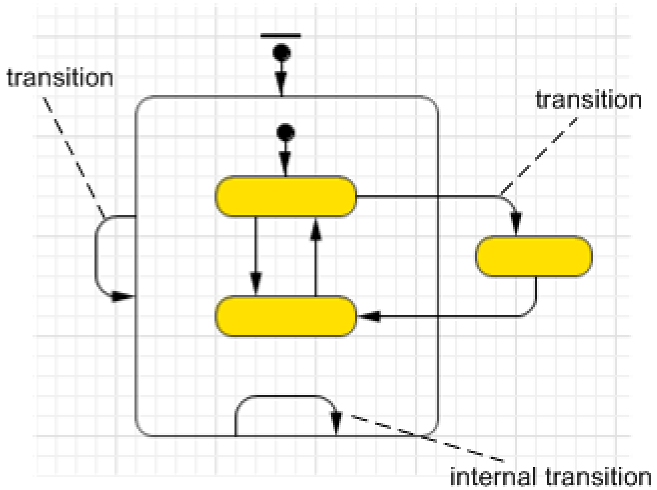
Defining Behaviour Using State Charts [Source: AnyLogic Help]

- 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

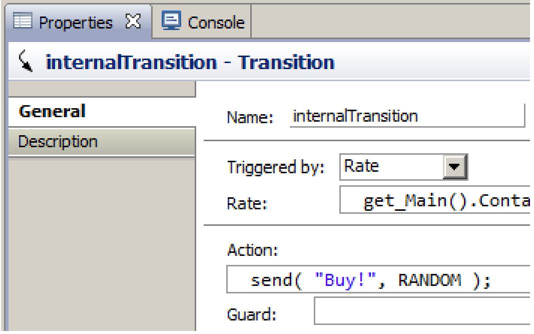


Defining Behaviour Using State Charts [Source: AnyLogic Help]

- 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

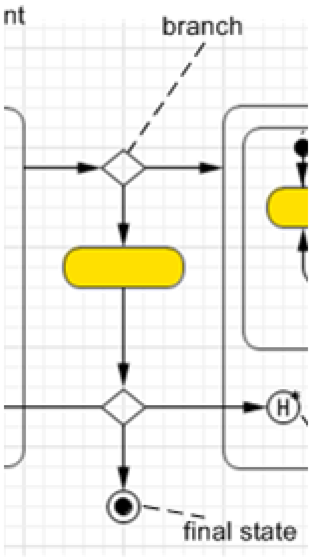


- Internal transition
  - Does not exit the enclosing state
  - Useful for implementing simple background jobs, which do not interrupt the main activity of the composite state.



Defining Behaviour Using State Charts [Source: AnyLogic Help]

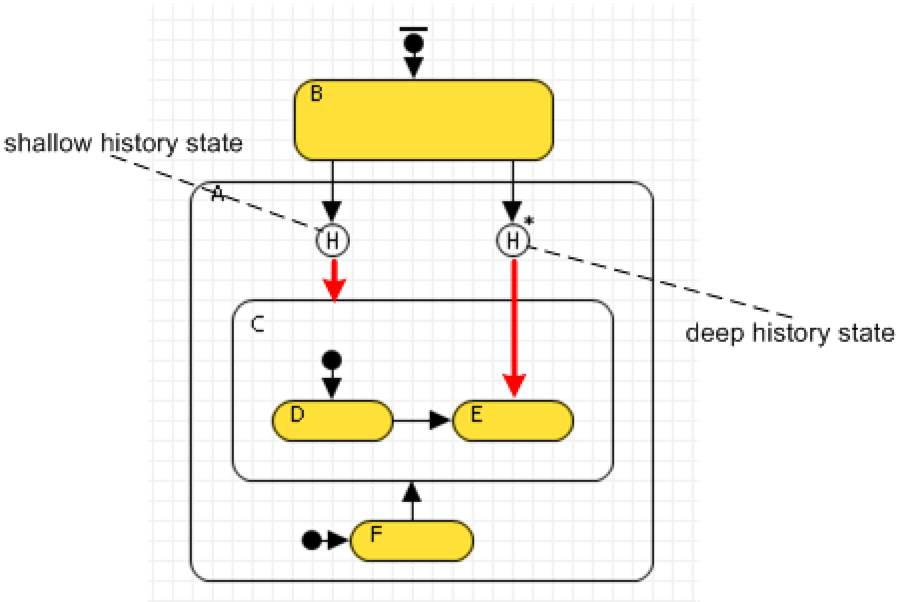
- Branch (pseudo state)
  - Transition branching and/or connection point
  - When control passes a branch:
    - Its action is executed
    - The guards of transitions exiting the branch are evaluated



- 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 [Source: AnyLogic Help]

- 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

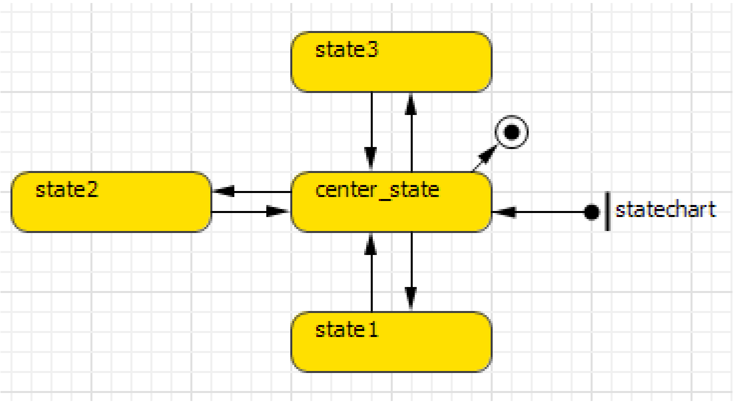


- Shallow history state is a reference to the most recently visited state on the same hierarchy level within the composite state.

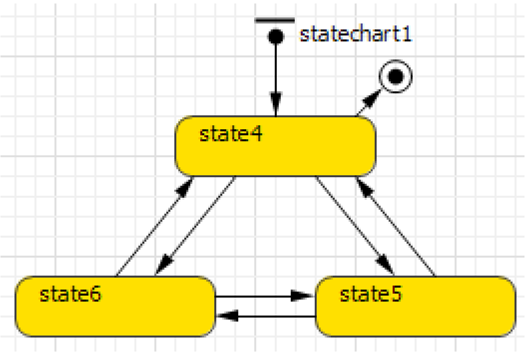
- Deep history state is a reference to the most recently visited simple state within the composite state.

Typical Designs

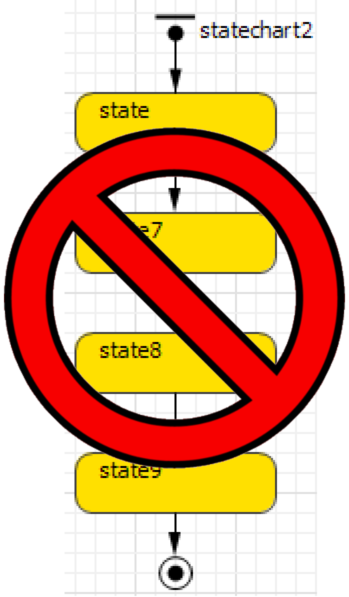
- Centralised



- Decentralised



- Flow



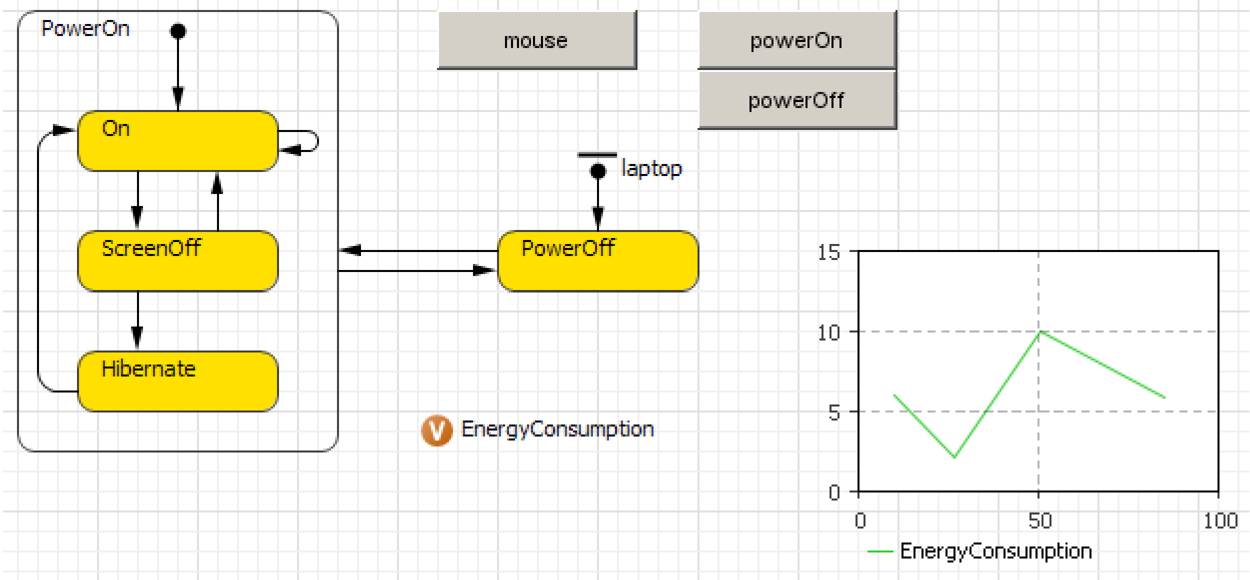
Please note that there are exceptions to this rule

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

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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?

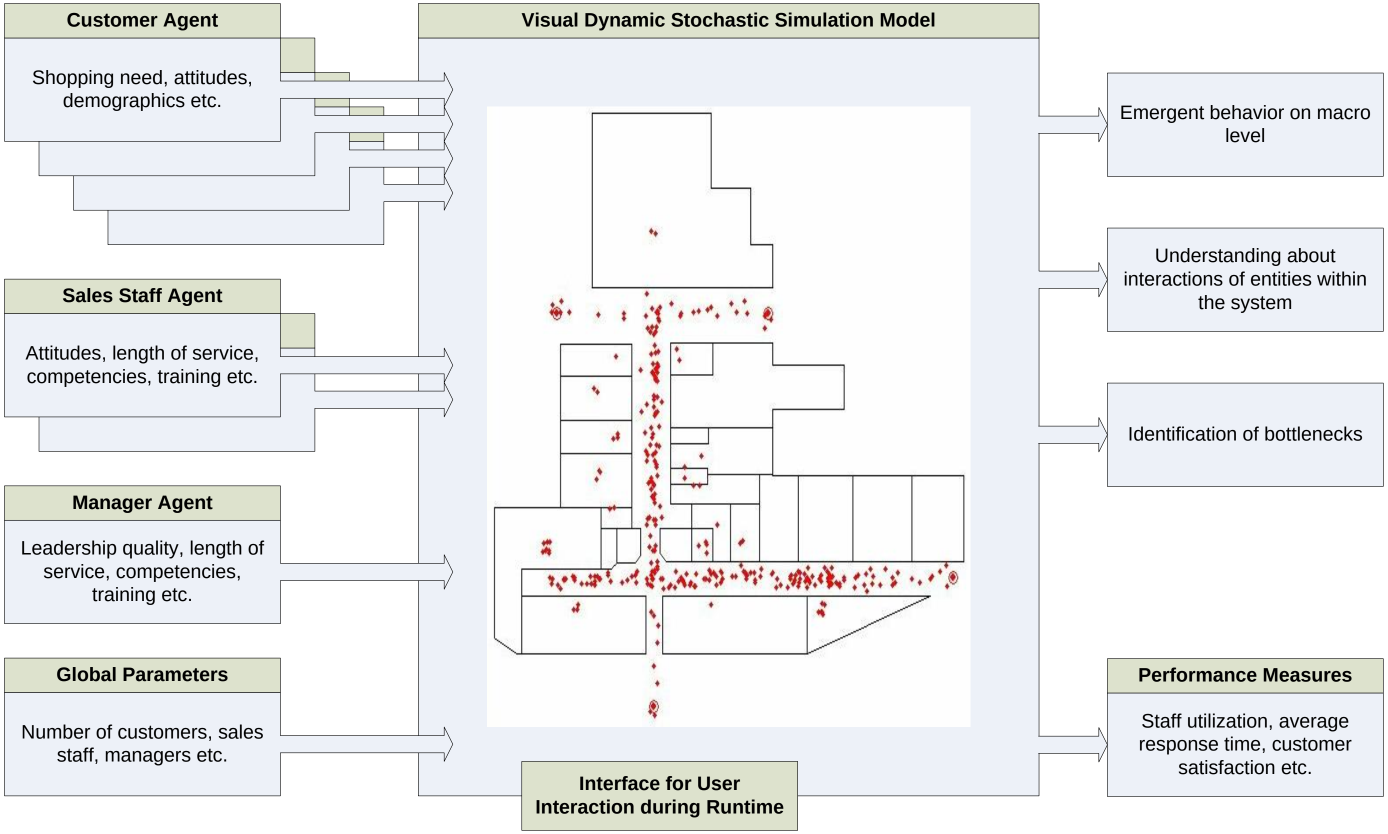
Case Study: Modelling

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

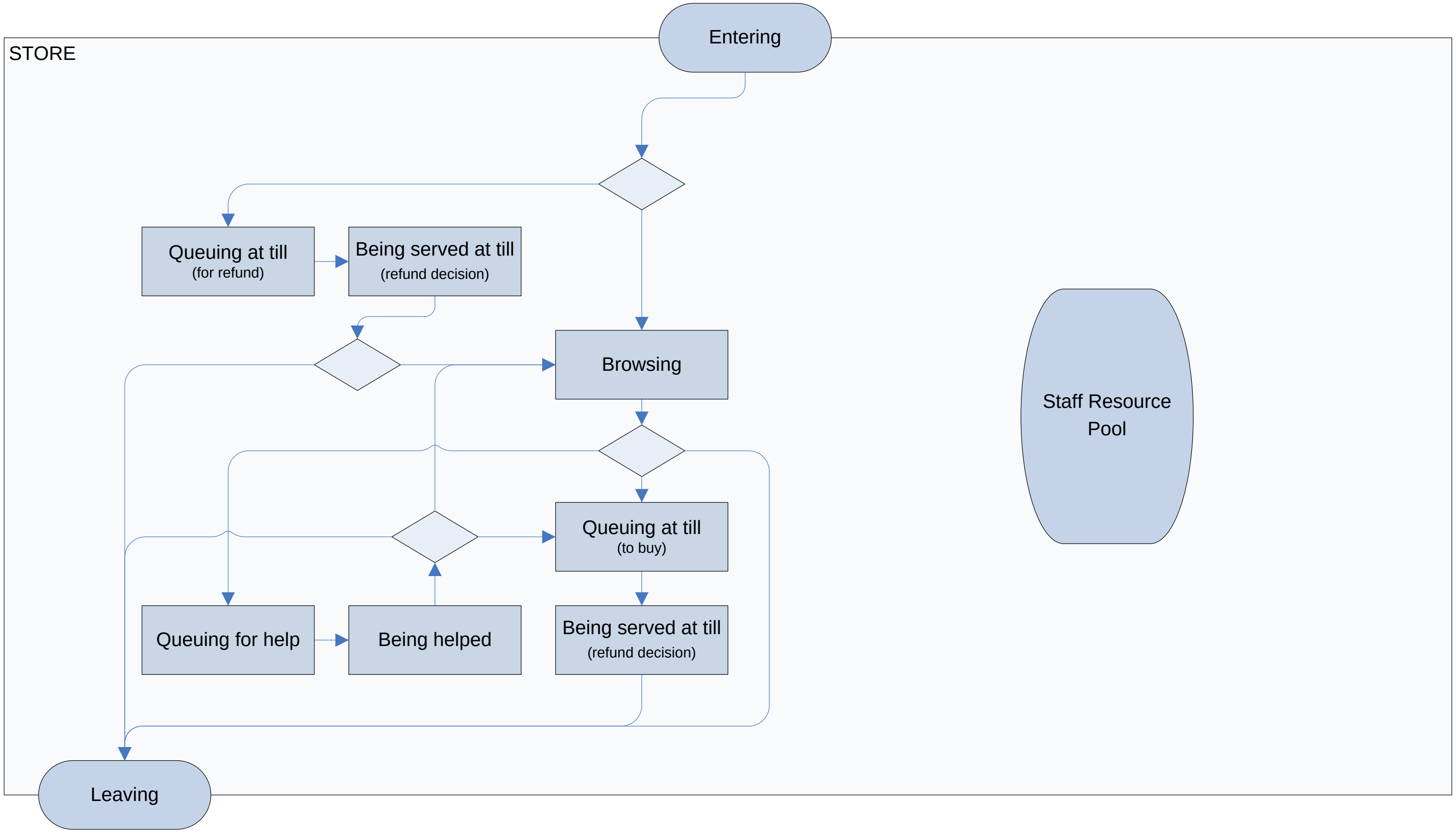
- Knowledge gathering
  - Informal participant observations
  - Staff interviews
  - Informational sources internal to the case study organisation

Case Study: Modelling

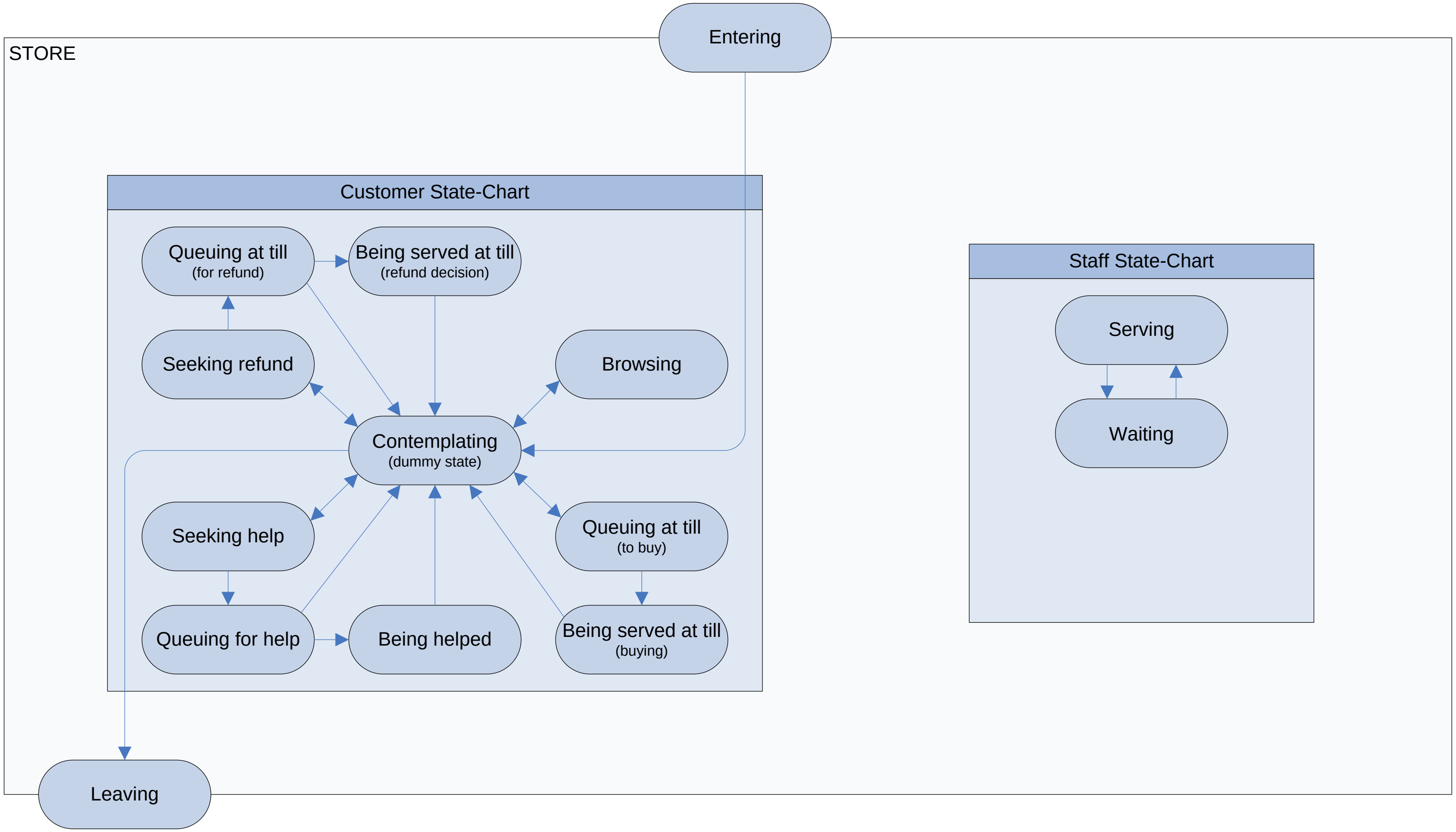
- Conceptual model



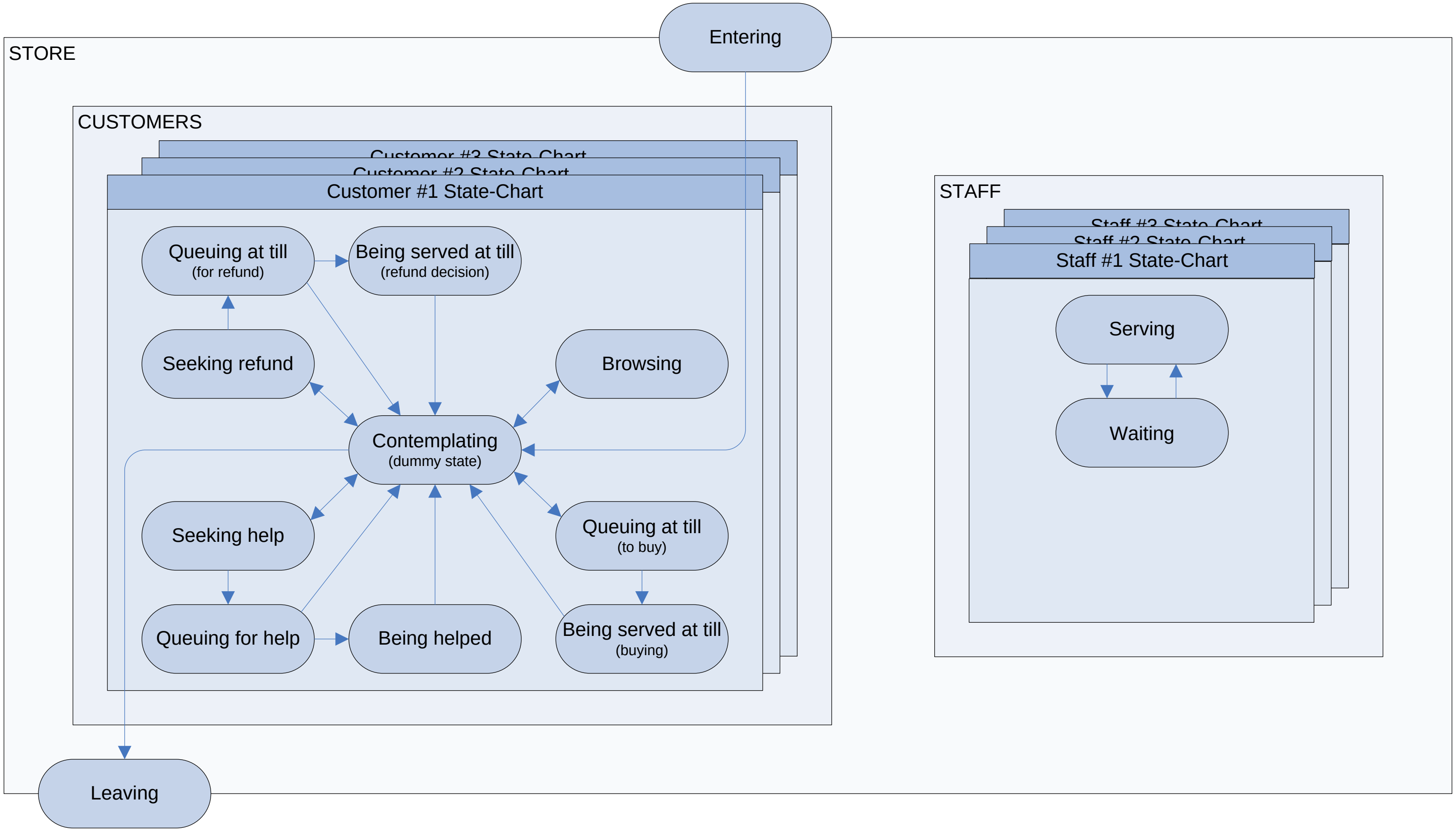
Case Study: Modelling



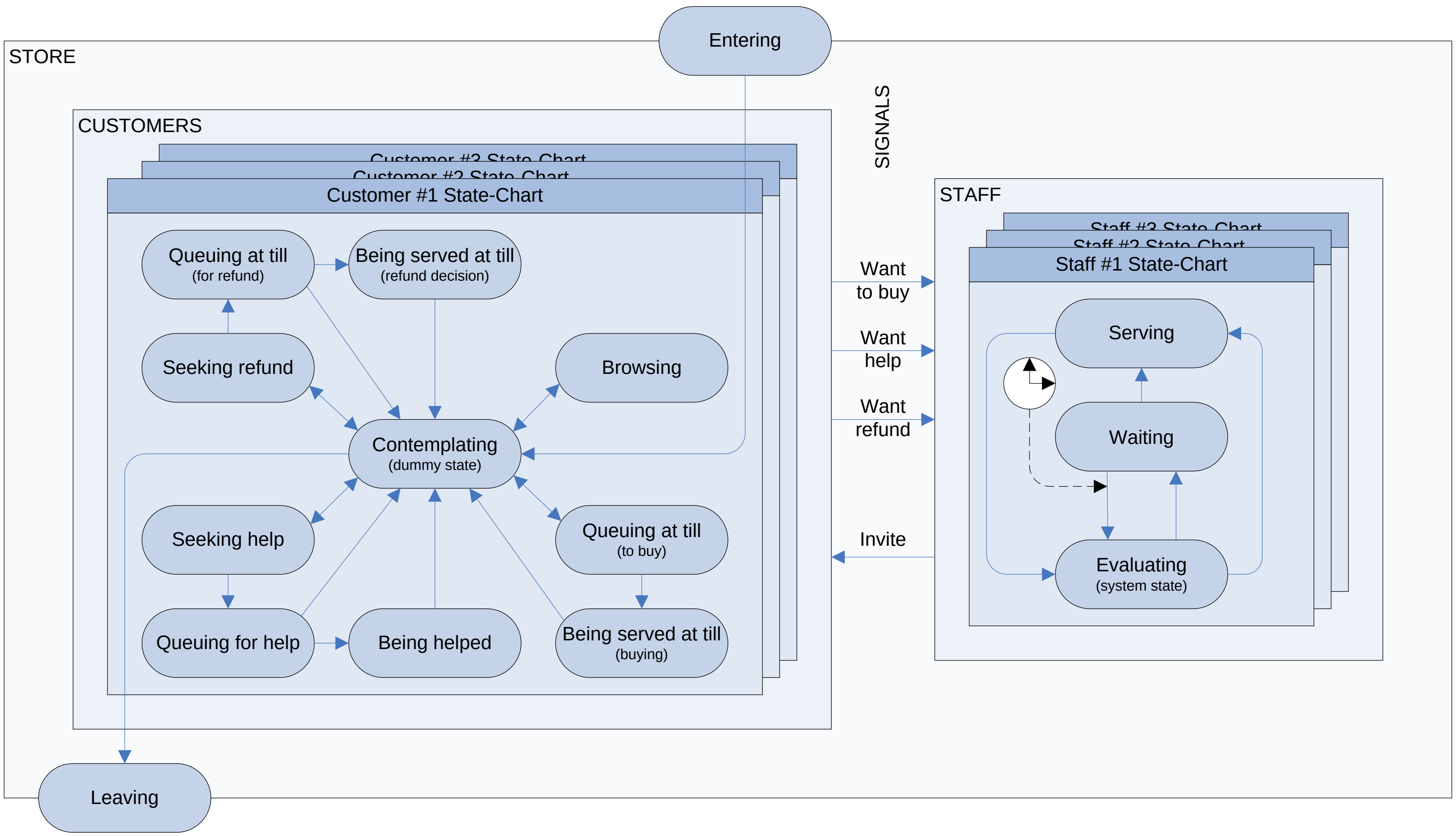
Case Study: Modelling

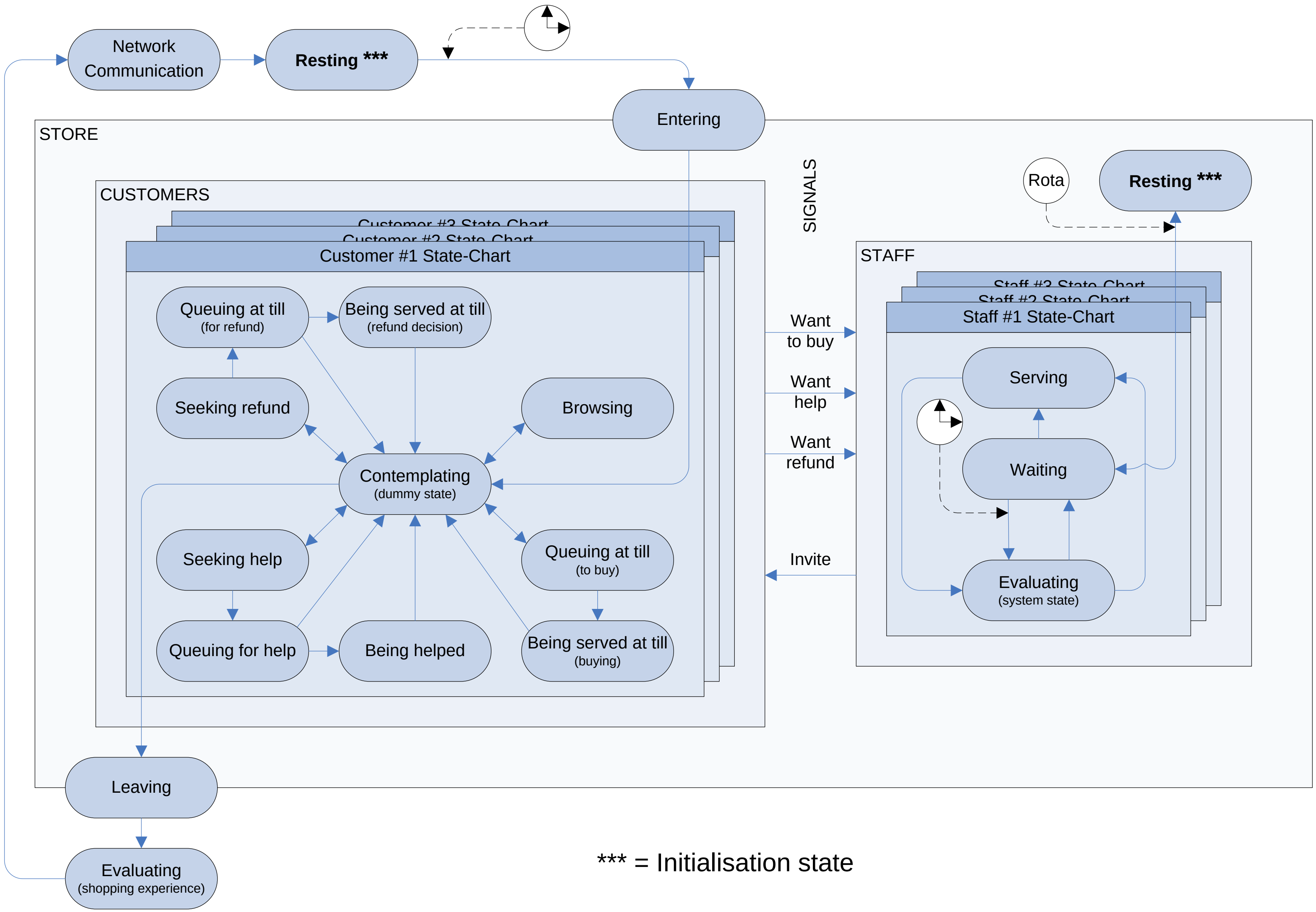


Case Study: Modelling



Case Study: Modelling

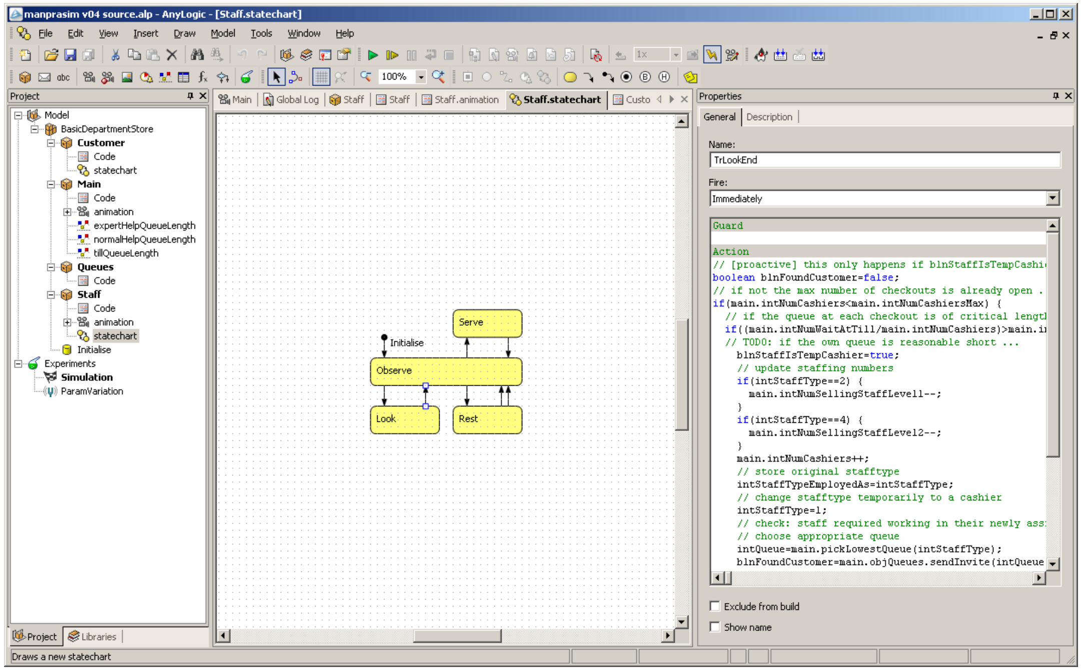




*** = Initialisation state

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

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

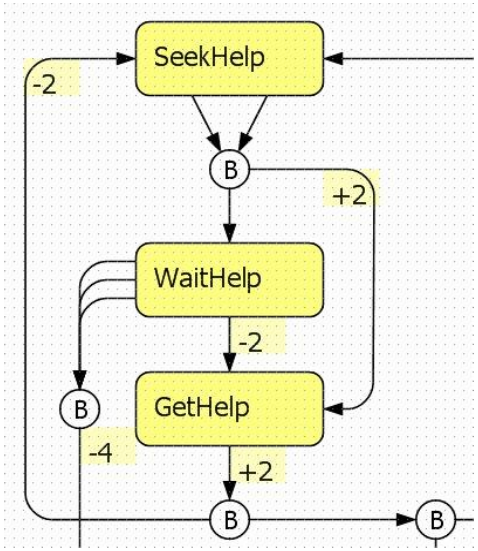
```
for (each threshold to be corrected) do  {
   if (OT < 0.5) limit = OT/2 else limit = (1-OT)/2
   if (likelihood = 0) CT = OT – limit
   if (likelihood = 1) CT = OT
   if (likelihood = 2) CT = OT + limit
}
where:      OT = original threshold
            CT = corrected threshold
            likelihood: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

Case Study: 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
    - ...

Model Animation

1/5 1/2 x1 x2 x5 VT

technologies

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)

F F F F F F F F F F

*1 = number of people queueing for this service
*2 = % of those leaving the queue
*3 = considering accumulated history [number]
*4 = considering accumulated history [satisfaction growth]
*5 = experience per visit [number]
*6 = experience per visit [satisfaction growth]

	real	planned
Average arrival rate per hour:	73	(73)

	years	weeks	days	hours	minutes
Runtime:	0	21	0	5	52

Current customer population: 8000

Customers in store:	27	
- browsing:	9	
- seeking help:	0	
- queuing for help:	0	
- standard:		0
- expert:		0
- refund author.:		0
- getting help:	7	
- standard:		7
- expert:		0
- refund author.:		0
- wait at till:	8	
- to pay:		8
- for refund:		0
- served at till:	3	
- to pay:		3
- for refund:		0

			*1	*2
Overall customers:	86255	100 %		
- leave happy (transaction or refund):	29101	34 %		
- leave not waiting for normal help:	2464	3 %	19921	12 %
- leave not waiting for expert help:	826	1 %	1907	43 %
- leave not waiting to pay:	10855	13 %	39001	28 %
- leave without finding anything:	42982	50 %		
- leave unhappy (no refund):	0	0 %		

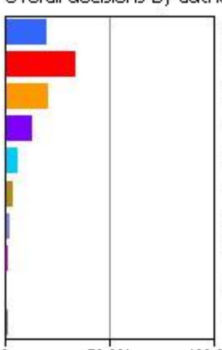
Till queue length: mean: 3.78; max: 17.0
Normal help queue length: mean: 1.25; max: 14.0
Expert help queue length: mean: 0.08; max: 4.0

Overall Satisfaction Level Index:	477406
- shopping:	477406
- refund:	0

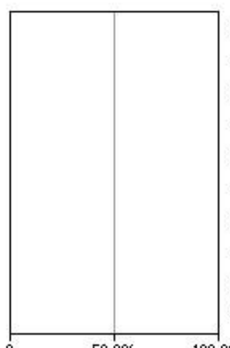
Transactions:	29101
Av. Transaction [£]:	149.7
Sales [£]:	4,356,420
Missed [£]:	8,551,912

	*3		*4	*5		*6
Customers left:	86228	100 %	477406		100 %	
- satisfied (> 0):	61697	72 %	518960	35188	41 %	101567
- don't know (= 0):	10574	12 %		40652	47 %	
- not satisfied (< 0):	13957	16 %	-41554	10388	12 %	-26726

			*1	*2
Overall refunds:	0	100 %		
- refunds accepted:	0	0 %		
- refunds denied:	0	0 %		
- leave not waiting for refund decision:	0	0 %	0	0 %
- leave not waiting for author. decision:	0	0 %	0	0 %
Overall decisions by cashier:	0			
Overall decisions by authorised person:	0			



1 served	255
2 served	435
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
12 served	0
13 served	0
14 served	0
15 served	0
16 served	0
17 served	0
18 served	0
19 served	0
20 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

Important parameters:

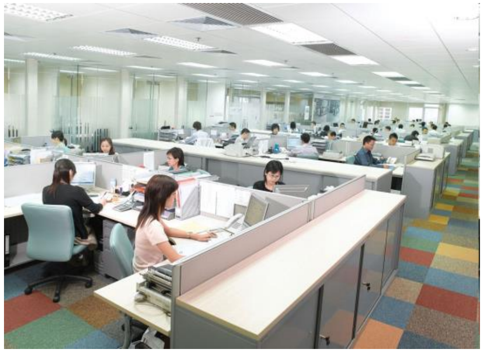
- Replication number:	3
- Empowerment level of cashier for refunds:	0.7
- Probability that refund is granted by cashier:	0.8
- Probability that refund is granted by authoriser:	0.7
- Probability that staff stay with customer:	0
- Points required to become an expert:	100000
- Word of mouth adoption fraction: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

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
  - 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)

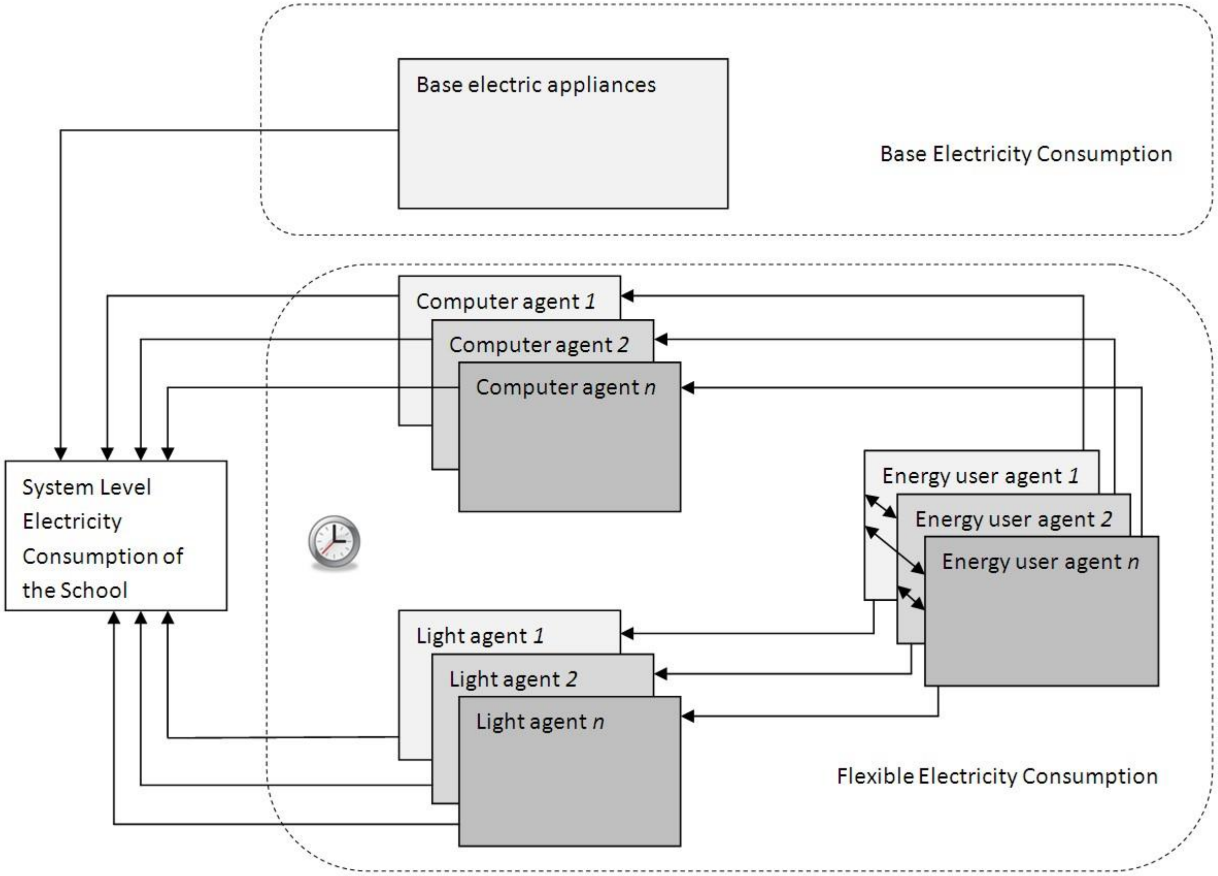
Case Study: Modelling

- 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

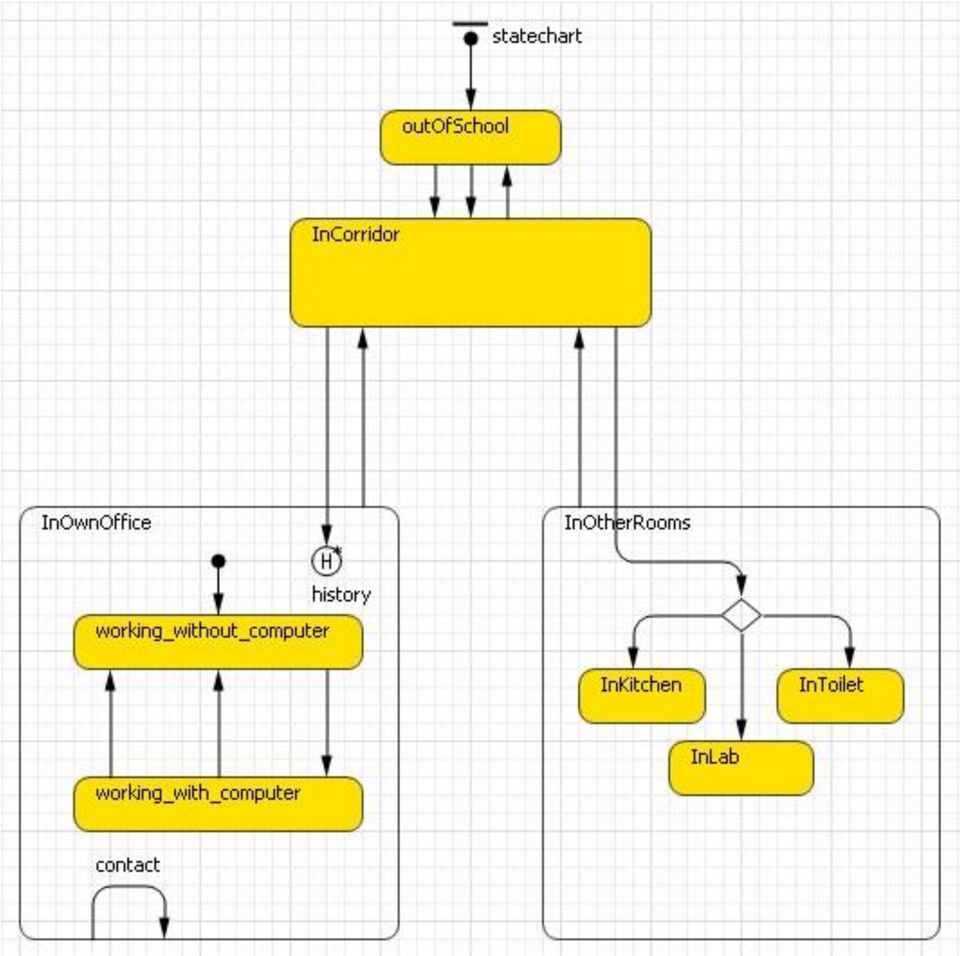
Case Study: Modelling

- Conceptual model



Case Study: Modelling

- Energy user agent
  - Proactive



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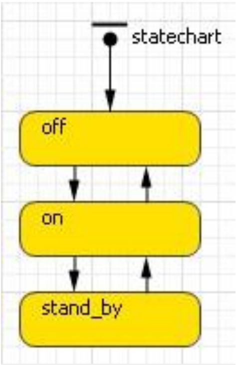
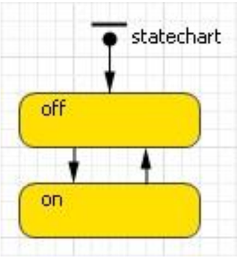
Case Study: Modelling

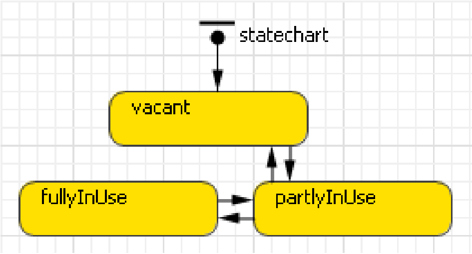
- Computer agent
  - passive



- Light agent
  - passive



- Office agent
  - passive



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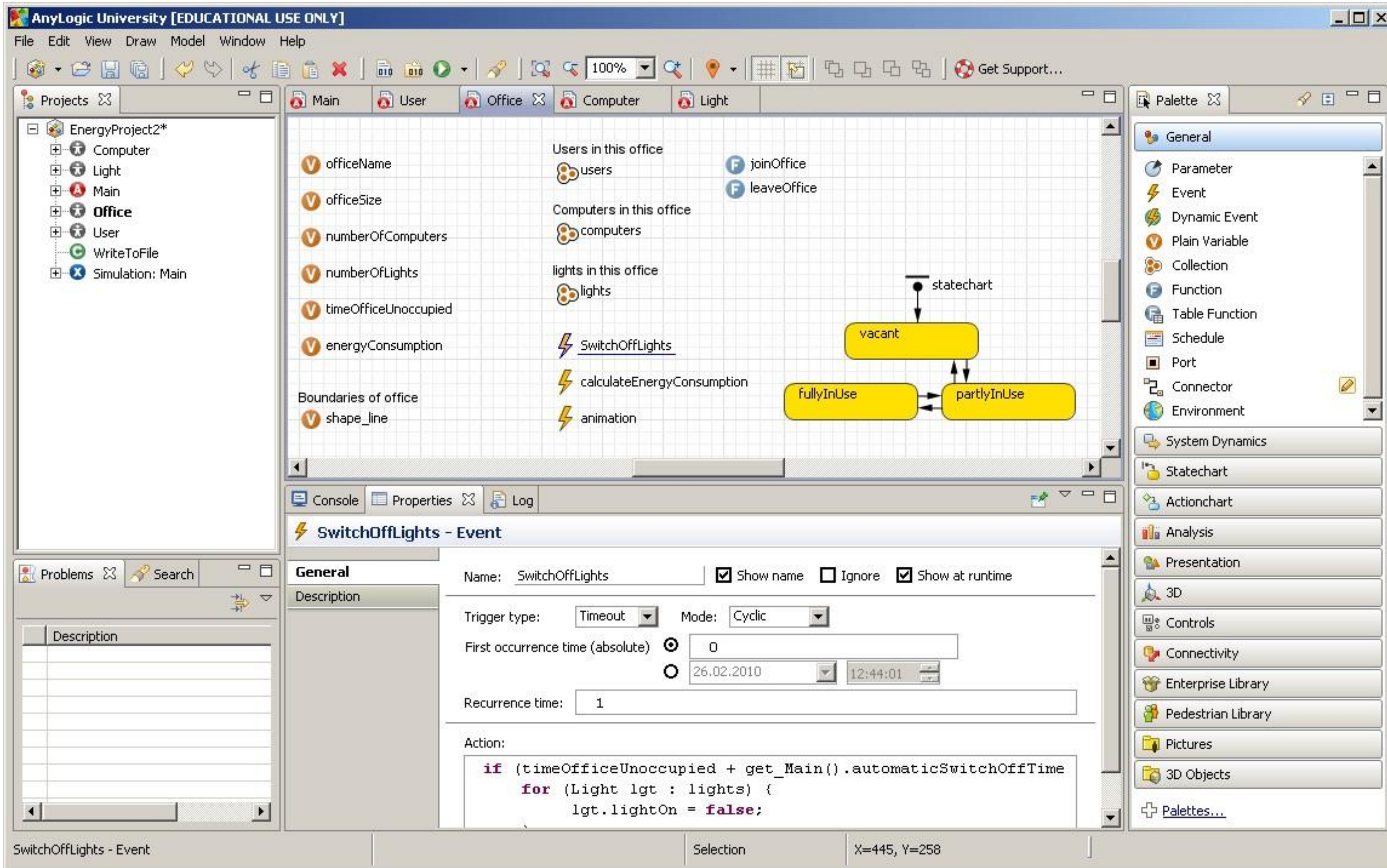
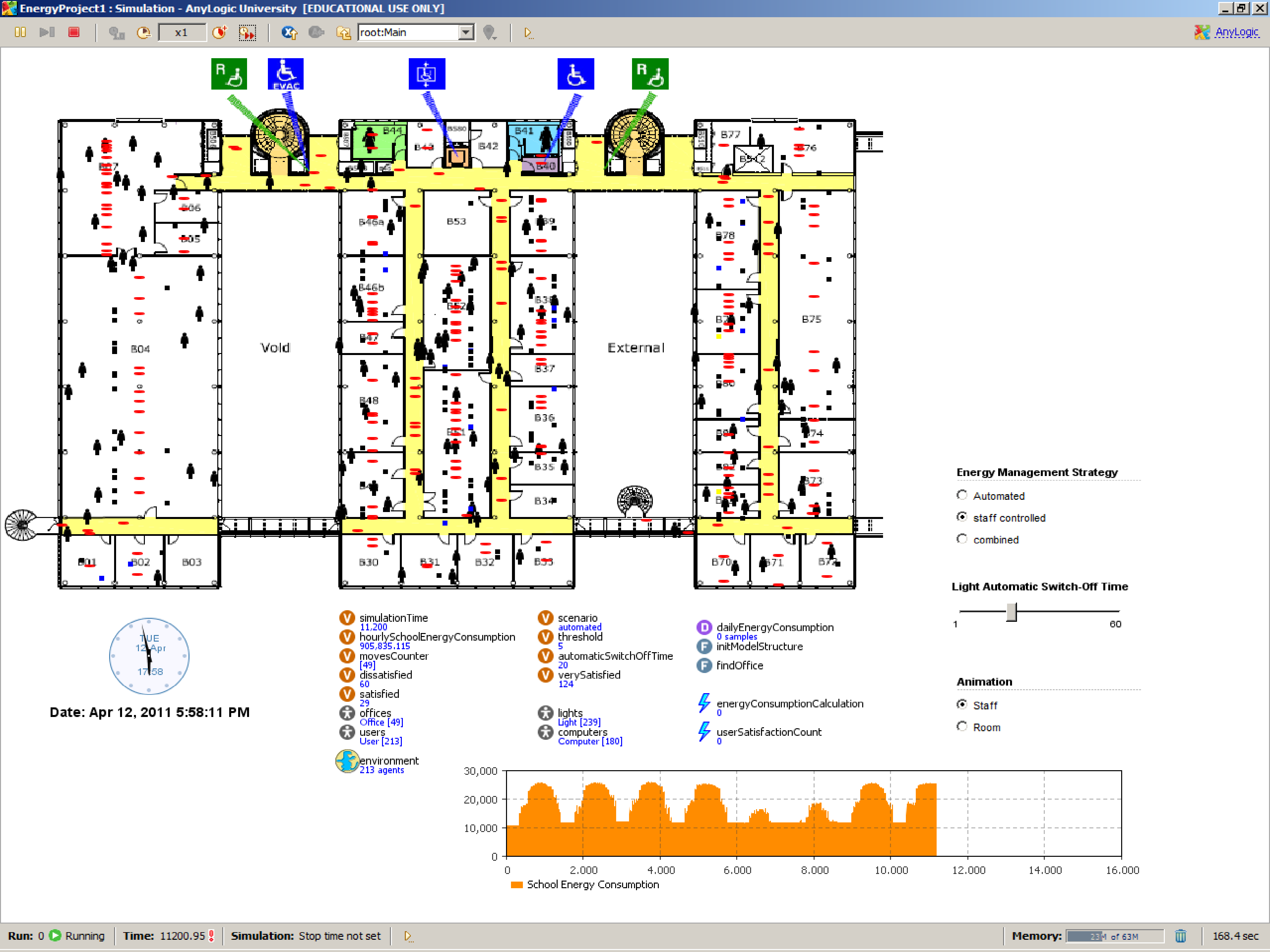
Case Study: Implementation





EnergyProject1 : Simulation - AnyLogic University [EDUCATIONAL USE ONLY]
x1
root:Main
AnyLogic
Void
External
Energy Management Strategy
Automated
staff controlled
combined
Light Automatic Switch-Off Time
1
60
Animation
Staff
Room
Date: Apr 12, 2011 5:58:11 PM
simulationTime
11,200
hourlySchoolEnergyConsumption
905,835.115
movesCounter
[49]
dissatisfied
60
satisfied
29
offices
Office [49]
users
User [213]
environment
213 agents
scenario
automated
threshold
5
automaticSwitchOffTime
20
verySatisfied
124
lights
Light [239]
computers
Computer [180]
dailyEnergyConsumption
0 samples
initModelStructure
findOffice
energyConsumptionCalculation
0
userSatisfactionCount
0
30,000
20,000
10,000
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
School Energy Consumption
Run: 0 Running
Time: 11200.95
Simulation: Stop time not set
Memory:
168.4 sec

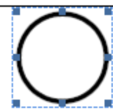
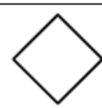
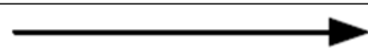
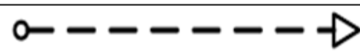
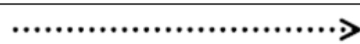
Alternative: The BPMN Notation

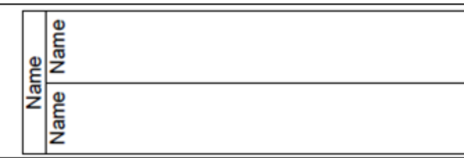
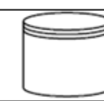
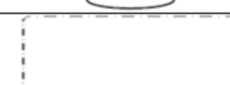
(For more details see Onggo 2012 and Onggo 2013)

Why BPMN?

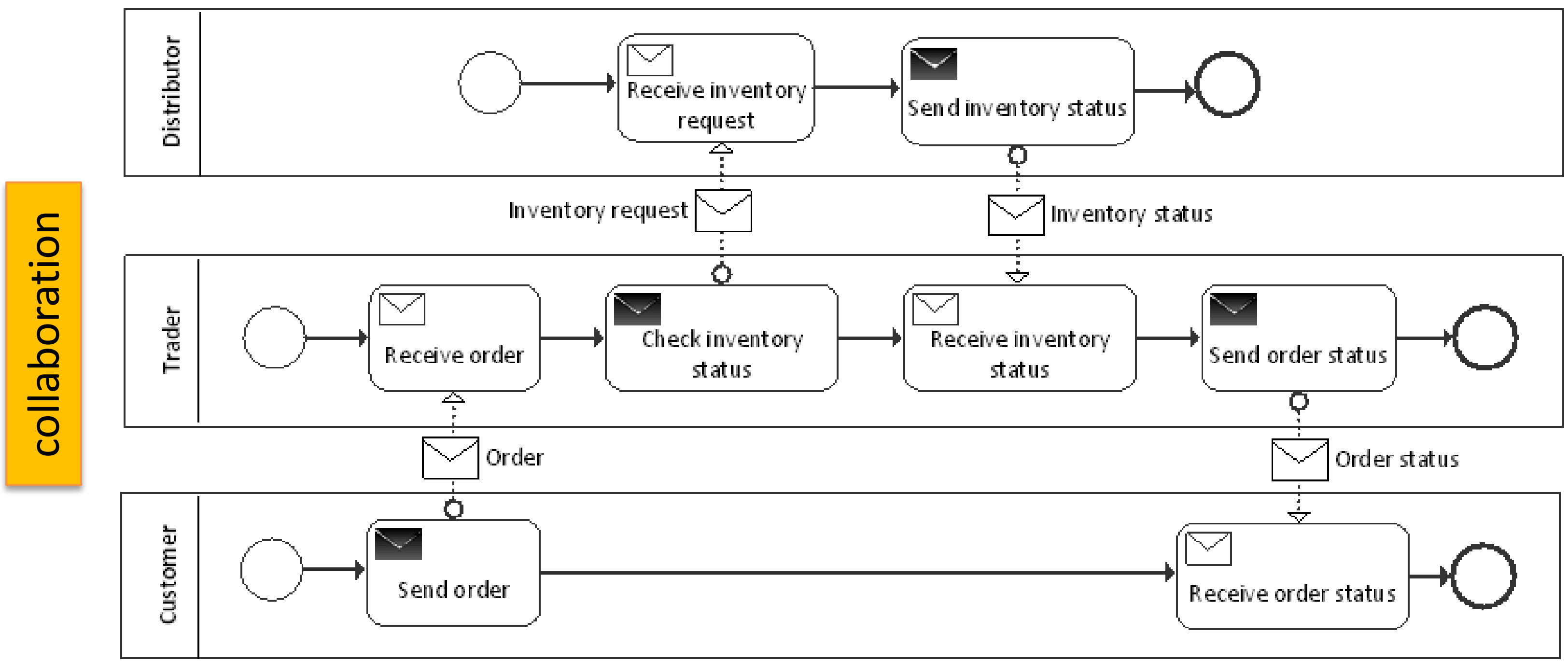
- A standard designed for business users
- Supported by influential vendors
- Designed for process modelling, but
  - Agent in ABS model ≈ BPMN participant (pool)
    - BPMN pool provides graphical representation
  - Agent's autonomy ≈ BPMN pool's domain control
  - Agent's attributes ≈ BPMN data annotations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

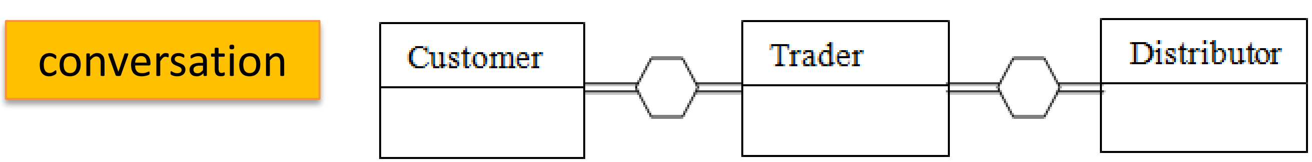
BPMN Core Components

Element	Notation
Event	
Activity	
Gateway	
Sequence flow	
Message flow	
Association	
Data association	

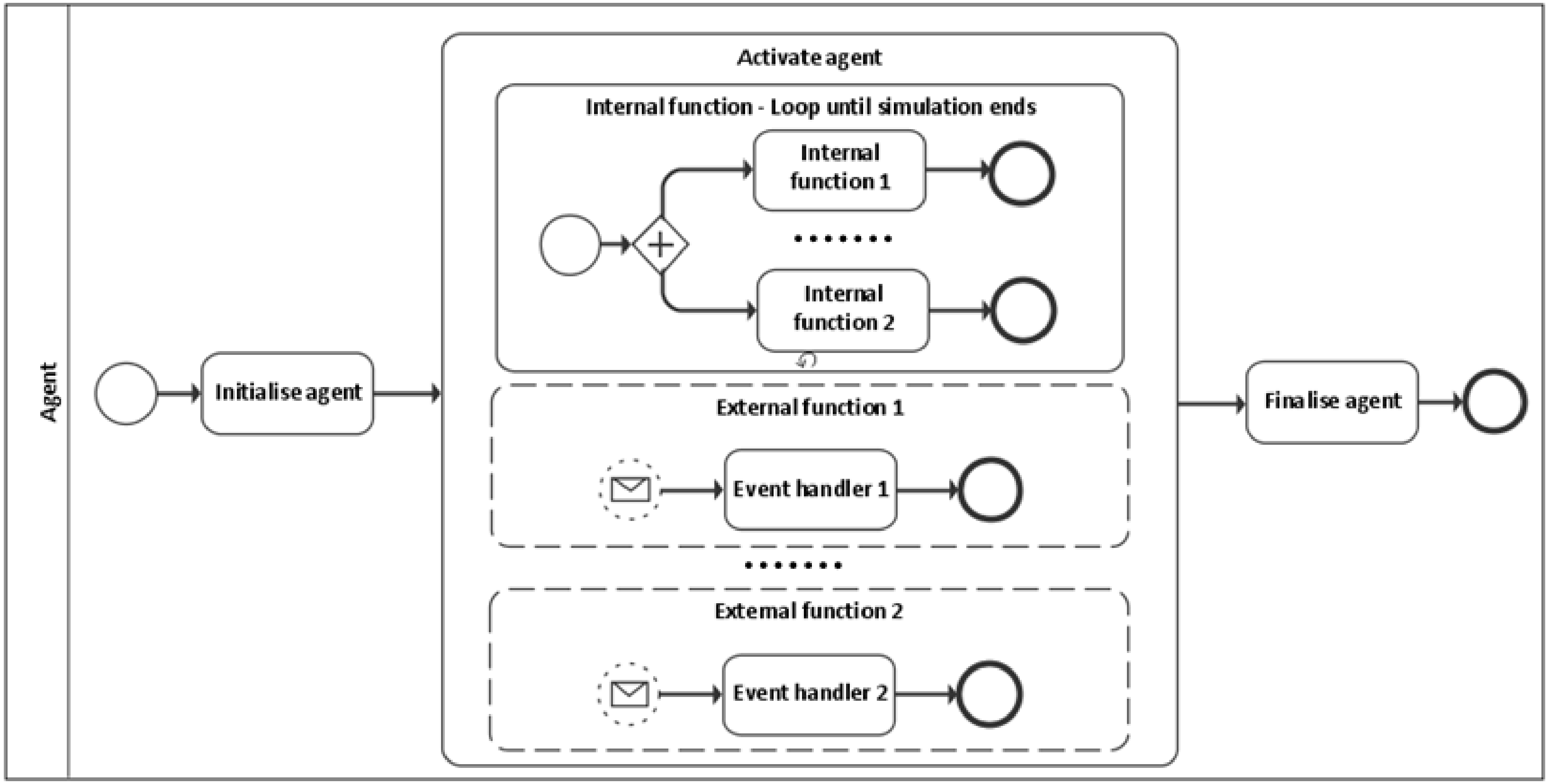
Element	Notation
Pool	
Lane	
Data object, Data input, Data output	
Data store	
Group	
Text annotation	

BPMN Collaboration and Conversation Diagram





BPMN Pattern for a Generic Agent



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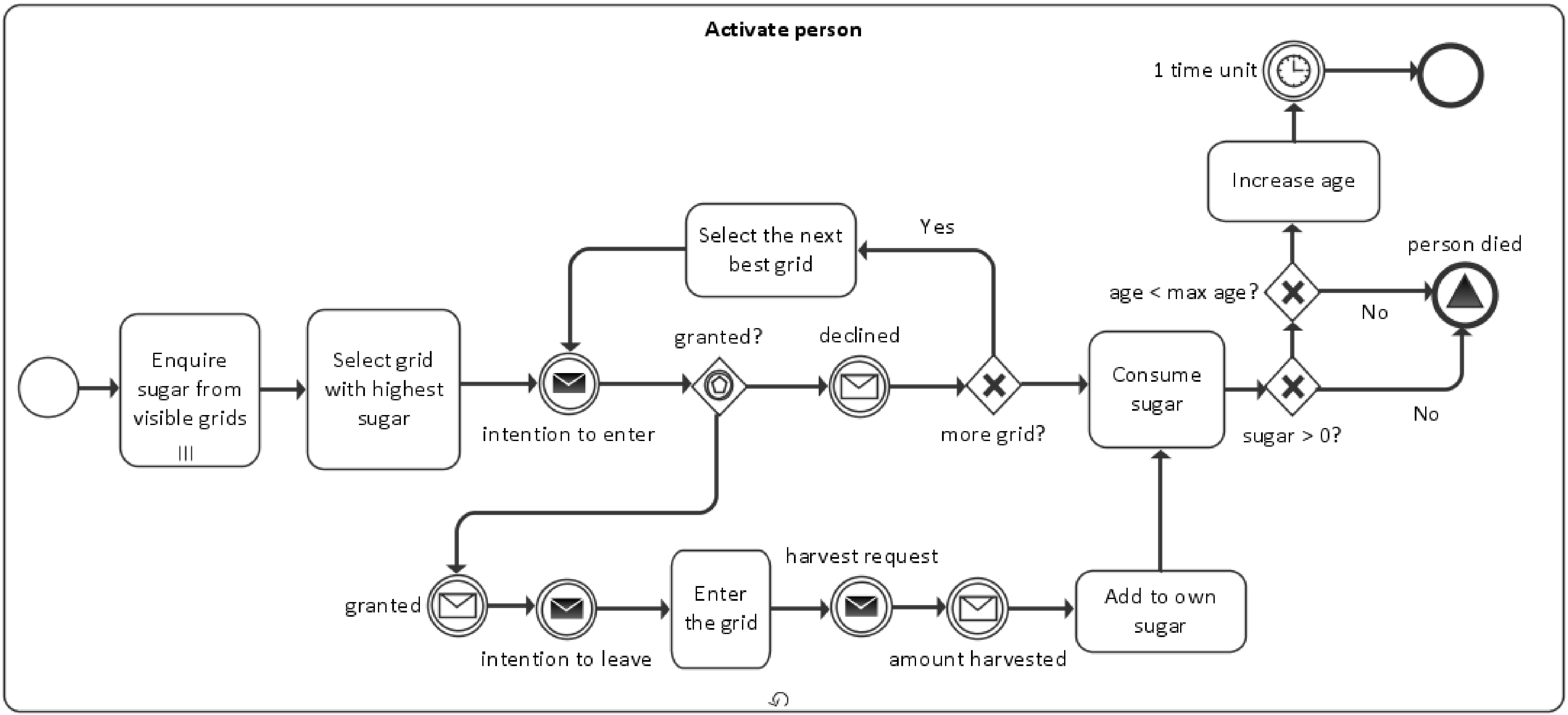
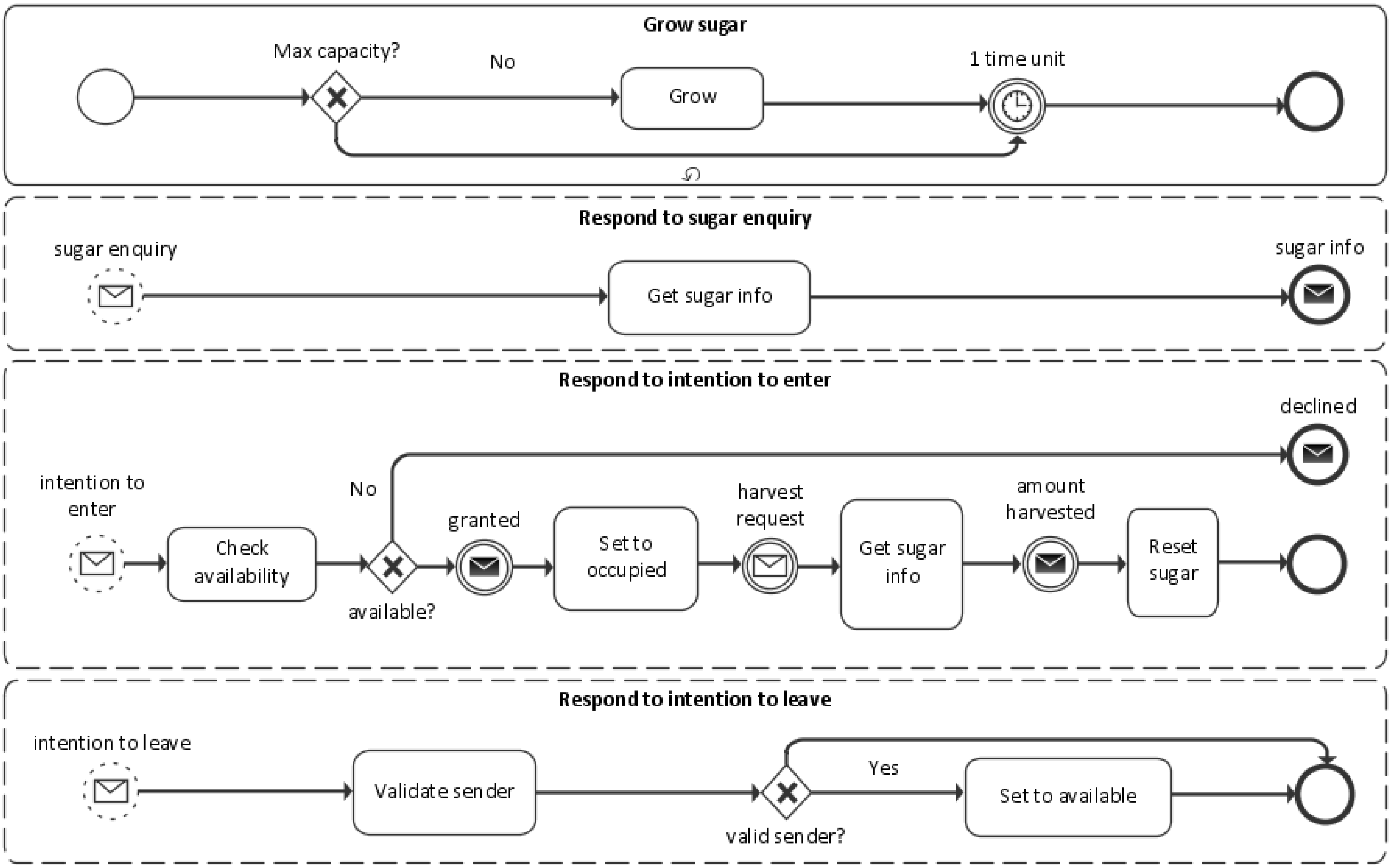
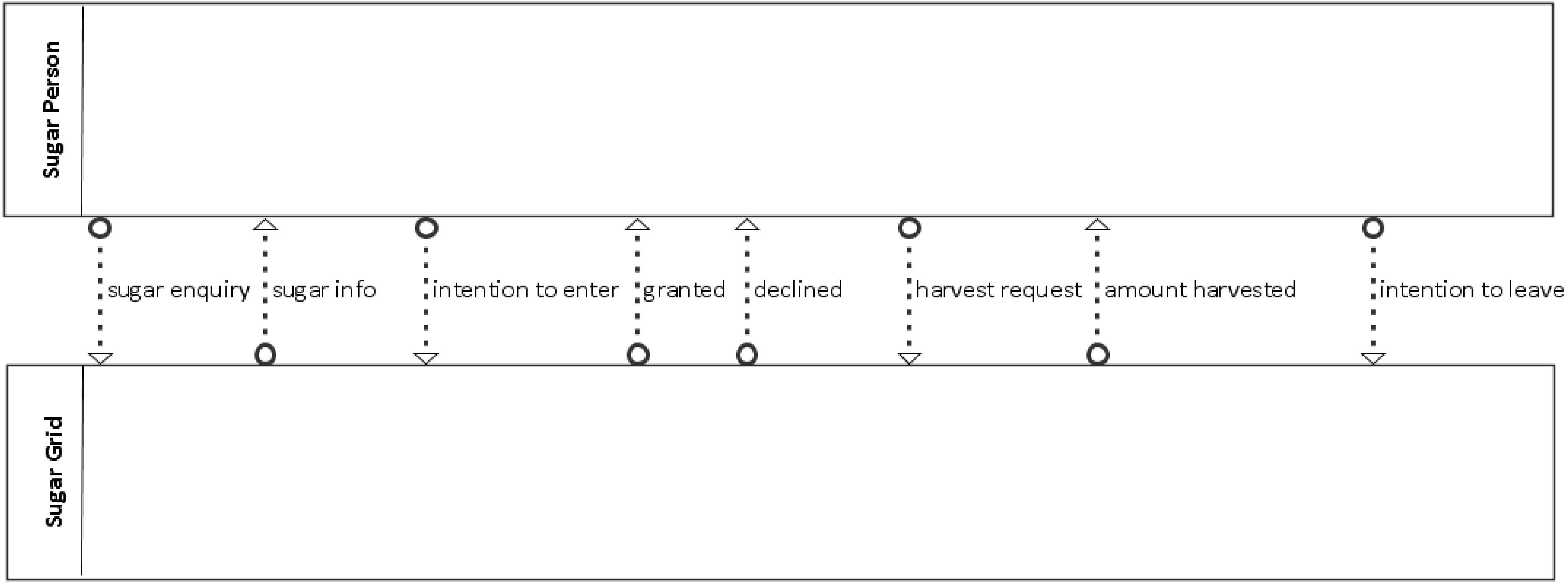
Example: SugarScape - Person

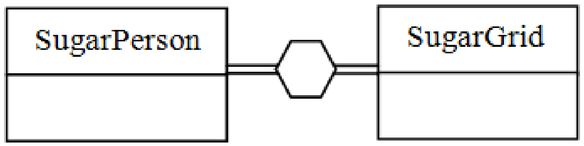


Example: SugarScape - Grid



Example: SugarScape - Conversation





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

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