A Young OR Guide to ...

Everything you always wanted to know about Agent-Based Modelling and Simulation

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- Simulation Paradigms
- ABMS in General Terms
- ABMS from an OR Perspective
- Case Study I: Queuing System
- Case Study II: Non-Queuing System
- Conclusions

Simulation Paradigms

- System Dynamics Simulation (continuous, deterministic)
  - Aggregate view; differential equations
- Discrete Event Simulation (discrete, stochastic)
  - Process oriented (top down); one thread of control; passive objects
- Agent Based Simulation (discrete, stochastic)
  - Individual centric (bottom up); each agent has its own thread of control; active objects
- Multi-Method Simulation (linked or integrated)

ABMS in General Terms

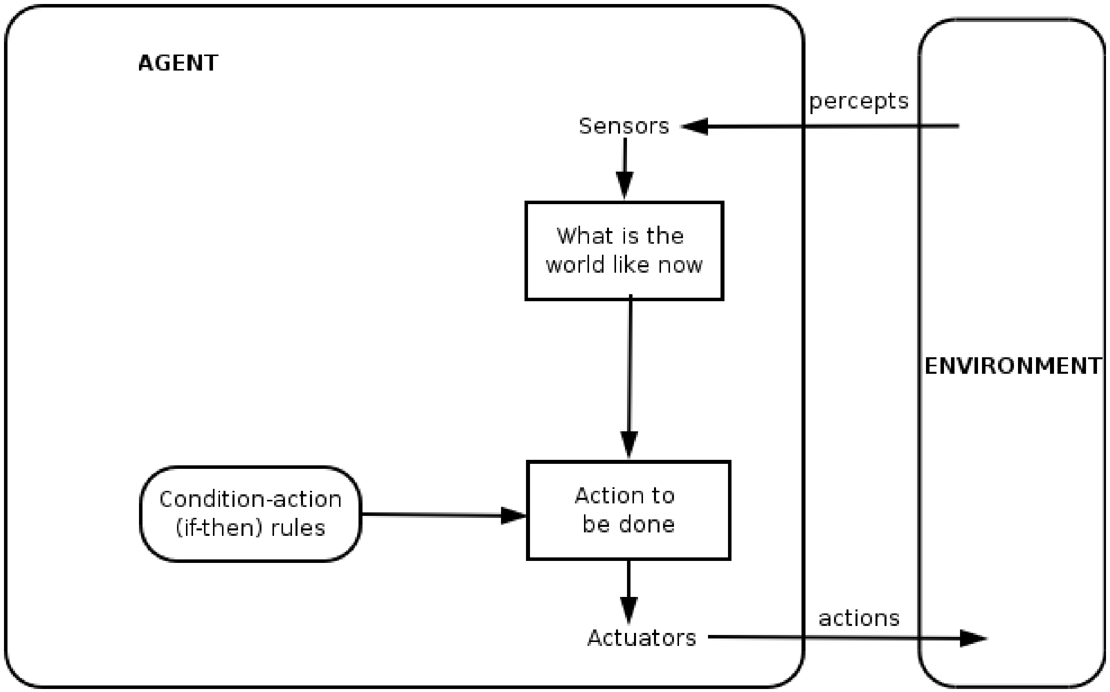
- In Agent-Based Modelling (ABM), a system is modelled as a collection of autonomous decision-making entities called agents

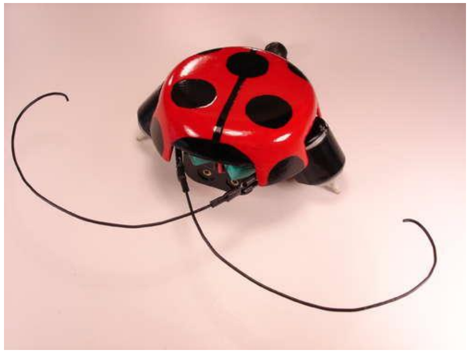
- ABM is a mindset more than a technology; the ABM mindset consists of describing a system from the perspective of its constituent units [Bonabeau, 2002]

- ABM is well suited to modelling systems with heterogeneous, autonomous and proactive entities, such as human-centred systems

ABMS in General Terms

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

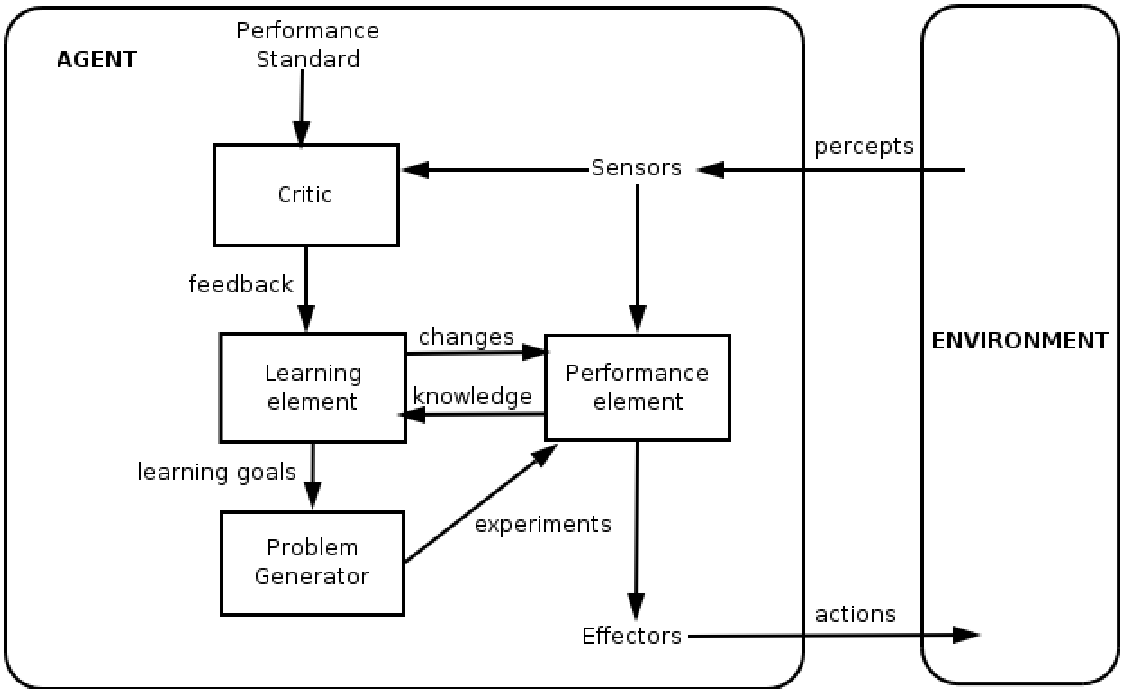




Russell and Norvig (2003)

ABMS in General Terms

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



Russell and Norvig (2003)

ABMS in General Terms

- Two main multi-agent system 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

ABMS in General Terms

- Examples of multi-agent simulation systems

Field	Application Examples
Social Science	Insect societies, group dynamics in fights, growth and decline of ancient societies, group learning, spread of epidemics, civil disobedience
Economics	Stock market, self organising markets, trade networks, consumer behaviour, deregulated electric power markets
Ecology	Population dynamics of salmon and trout, land use dynamics, flocking behaviour in fish and birds, rain forest growth, pollution
Political Sciences	Water rights in developing countries, party competition, origins and patterns of political violence, power sharing in multicultural states
Systems Biology	Virtual plant growth, immune system modelling, cancer cells, infectious diseases
Operational Research	???

- Domains employing ABM [http://www.swarm.org]
  - Economics; Political Science; Culture/Anthropology/Archeology; Agent-Based Models in Social Science; Ecology; Biology and Medicine; Physics; Geography; Computer Science; Business/Industry ; Military

ABMS in General Terms

- Classification: Empirical embeddedness [Boero and Squazzoni, 2005]
  - Case-based (specific circumscribed empirical phenomena)
    - Example: Evolutionary studies of prehistoric societies
  - Typification (specific classes of empirical phenomena)
    - Example: Simulating issues related to land use management
  - Theoretical abstractions (pure theoretical models)
    - Example: Flocks of boids; Schelling's segregation model

ABMS in General Terms

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

- Properties:
  - Discrete entities
    - With their own goals and behaviours
    - With their own thread of control
  - Autonomous
    - Capable to adapt
    - Capable to modify their behaviour
  - Proactive
    - Actions depending on motivations generated from their internal state

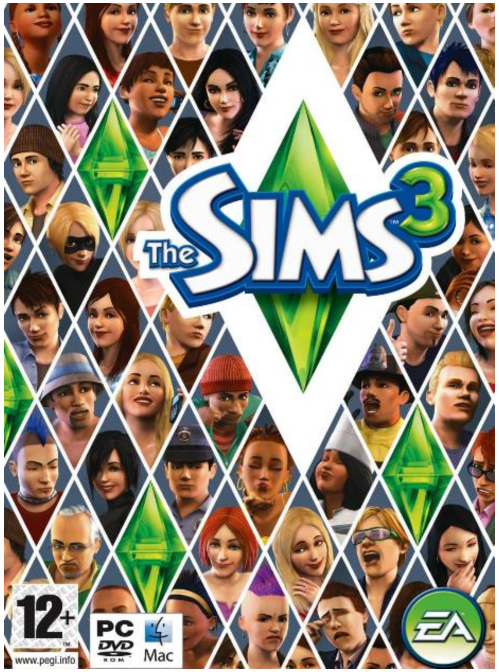
ABMS in General Terms

- The agents can represent individuals, households, organisations, companies, nations, …

- Typical 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.

ABMS in General Terms

- The Sims: Interactive Organisational Agent-Based Simulation



ABMS in General Terms

- 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 because of the interactions between the parts.
  - An emergent phenomenon can have properties that are decoupled from the properties of the part.

ABMS in General Terms

- Agent-Based Simulation (ABS)
  - Often Object Oriented Discrete Event Simulation (DES) is used for implementing ABMs
  - Some good literature on the topic: "Object Oriented Simulation: A Modeling and Programming Perspective" [Garrido 2009]

ABMS in General Terms

- Resources
  - Simulation for the Social Scientist [Gilbert and Troitzsch 2005]
  - Journal of Artificial Societies and Social Simulation [http://jasss.soc.surrey.ac.uk/]
  - Winter Simulation Conference ABM Tutorials [Macal and North 2010]
  - Introduction to Multi-Agent Simulation [Siebers and Aickelin 2008]

ABMS in General Terms

- Software (see also http://en.wikipedia.org/wiki/Comparison_of_agent-based_modeling_software)
  - NetLogo [http://ccl.northwestern.edu/netlogo/]
  - Repast [http://repast.sourceforge.net/]
  - AnyLogic [http://www.xjtek.com/]
  - Simio [http://www.simio.com/index.html]
  - Simul8 [http://www.simul8.com/]

ABMS from an OR Perspective

- Comparing attributes of traditional DES with ABS [Siebers et al. 2010]

DES models	ABS models
Process oriented; focus is on modelling the system in detail, not the entities	Individual based; focus is on modelling the entities and interactions between them
Top down modelling approach	Bottom up modelling approach
One thread of control (centralised)	Each agent has its own thread of control (decentralised)
Passive entities, i.e. something is done to the entities while they move trough the system; intelligence (e.g. decision making) is modelled as part in the system	Active entities, i.e. the entities themselves can take on the initiative to do something; intelligence is represented within each individual entity
Queues are a key element	No concept of queues
Flow of entities through a system; macro behaviour is modelled	No concept of flows; macro behaviour is not modelled, it emerges from the micro decisions of the individual agents
Input distributions are often based on collect/measured (objective) data	Input distributions are often based on theories or subjective data

ABMS from an OR Perspective

- Getting Practical: Simulating Service Systems
  - Using a combined DES/ABS approach

- Mapping real world processes
  - Often we have a system where customers have to queue for services (requires process oriented modelling)
  - Often we have a heterogeneous population of autonomous individuals (requires individual based modelling)

Communication layer

Direct interactions
Network activities

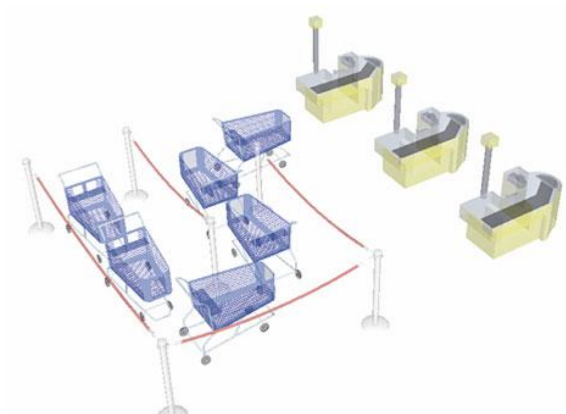
Let entities interact + communicate

Agent layer

Active entities
Behavioural state charts

Replace passive entities by active ones

DES layer



Passive entities
Queues
Processes
Resources

Case Study I

(For more details see Siebers and Aickelin 2011)

A queuing system

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 encountered:
  - When using real staffing rota we could not produce the transaction values of the real system; we had to use some optimised data instead
  - Can we solve this problem by adding proactive behaviour?
  - How can we add proactive behaviour?

Context

- Modelling proactive service behaviour in OR type models
  - The OR literature does not provide any guidance
  - Management literature defines proactive customer service as self started, long term oriented, and persistent service behaviour that goes beyond explicitly prescribed requirements
  - Artificial intelligence literature states that proactive behaviour can be modelled in terms of goals that the agents pursue
  - Business rules: Short waiting times are key to high service quality

- A staff agent goal is to provide best service by proactively balancing the different queues that appear in the department store.

Modelling

- Our modelling process
  - Identify active entities (agents)
  - Define their states and behaviour
  - Put them in an environment
  - Establish connections
  - Test the model
  - Validate model at micro and macro level

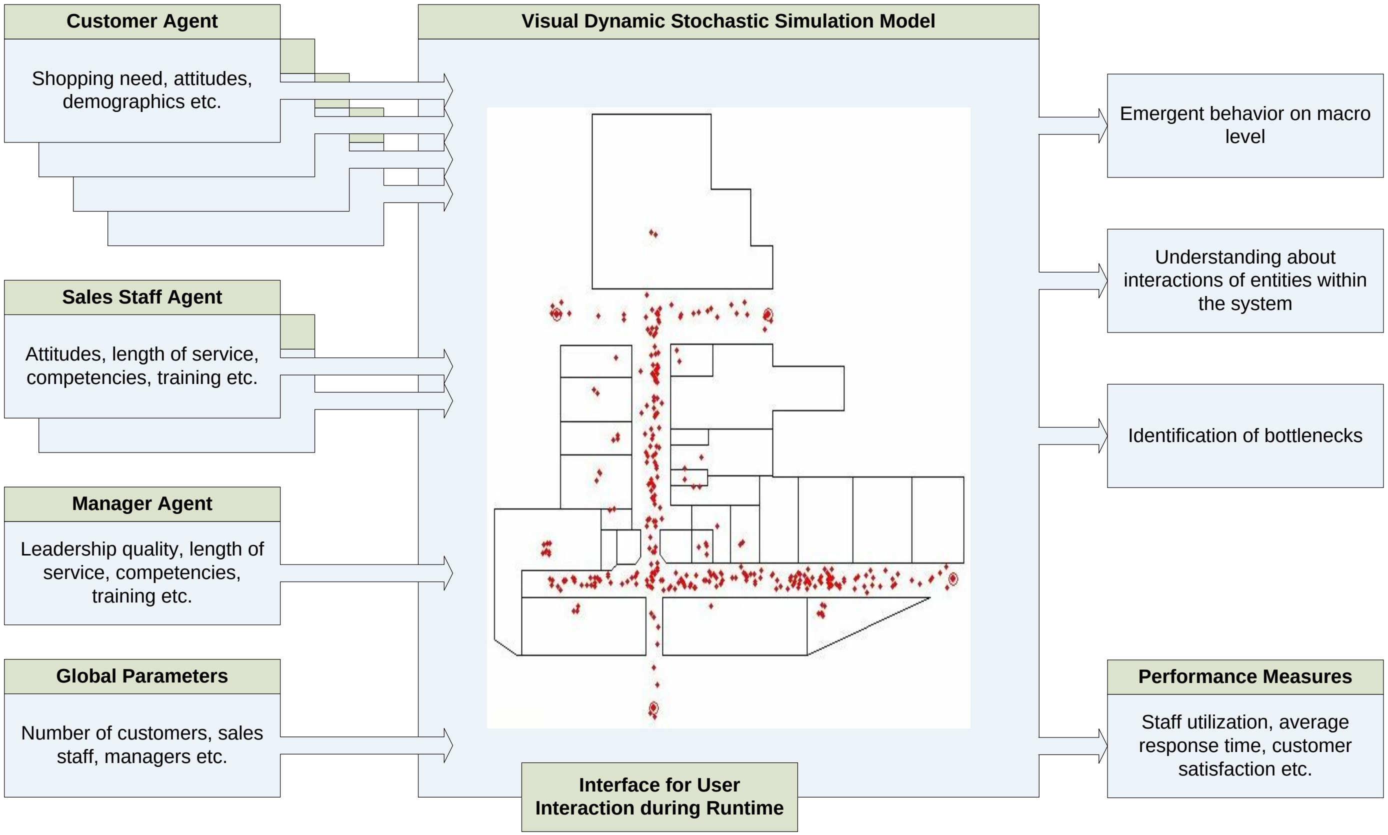
Modelling

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

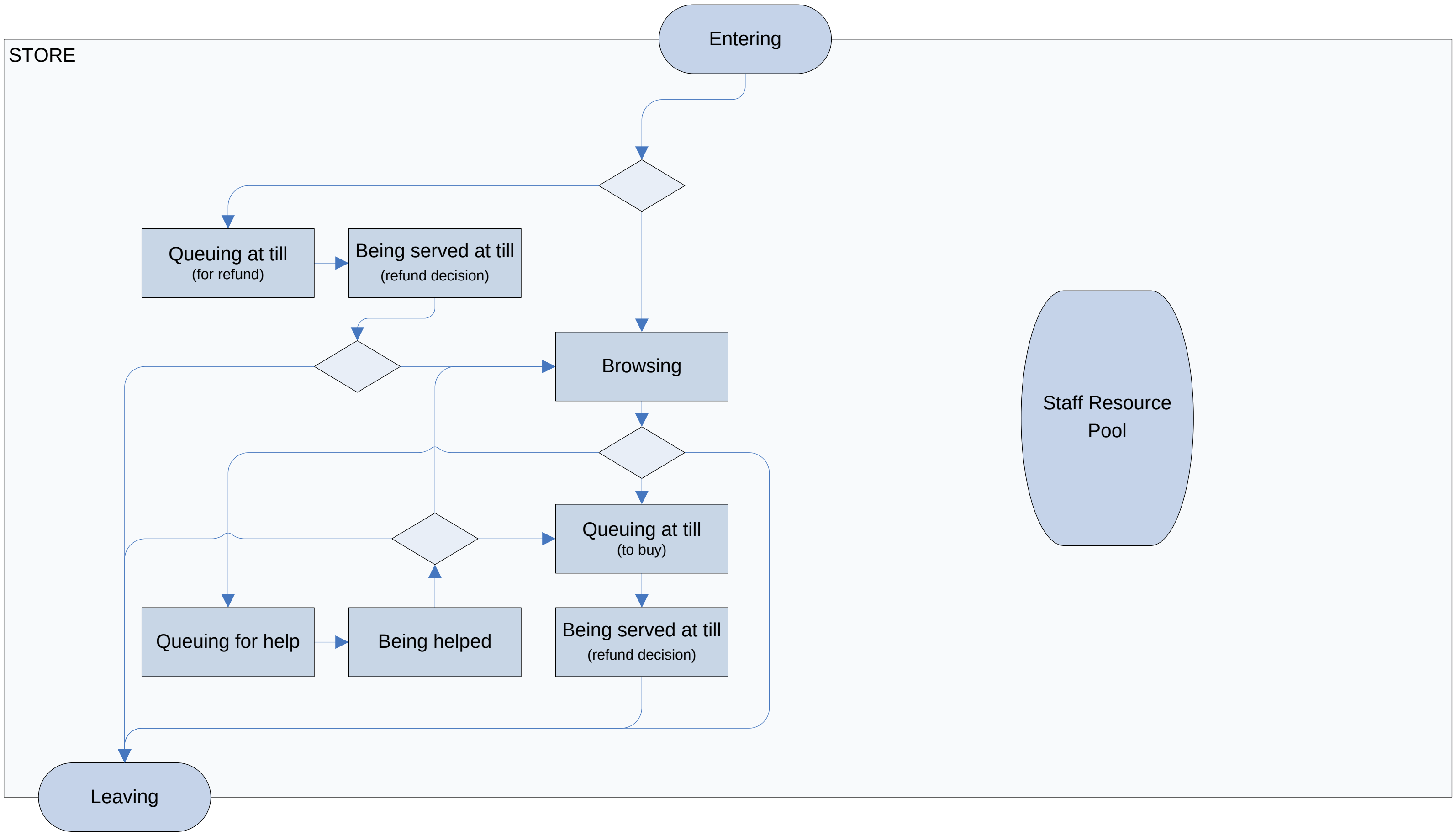
- Knowledge gathering
  - Informal participant observations
  - Staff interviews
  - Informational sources internal to the case study organisation

Modelling

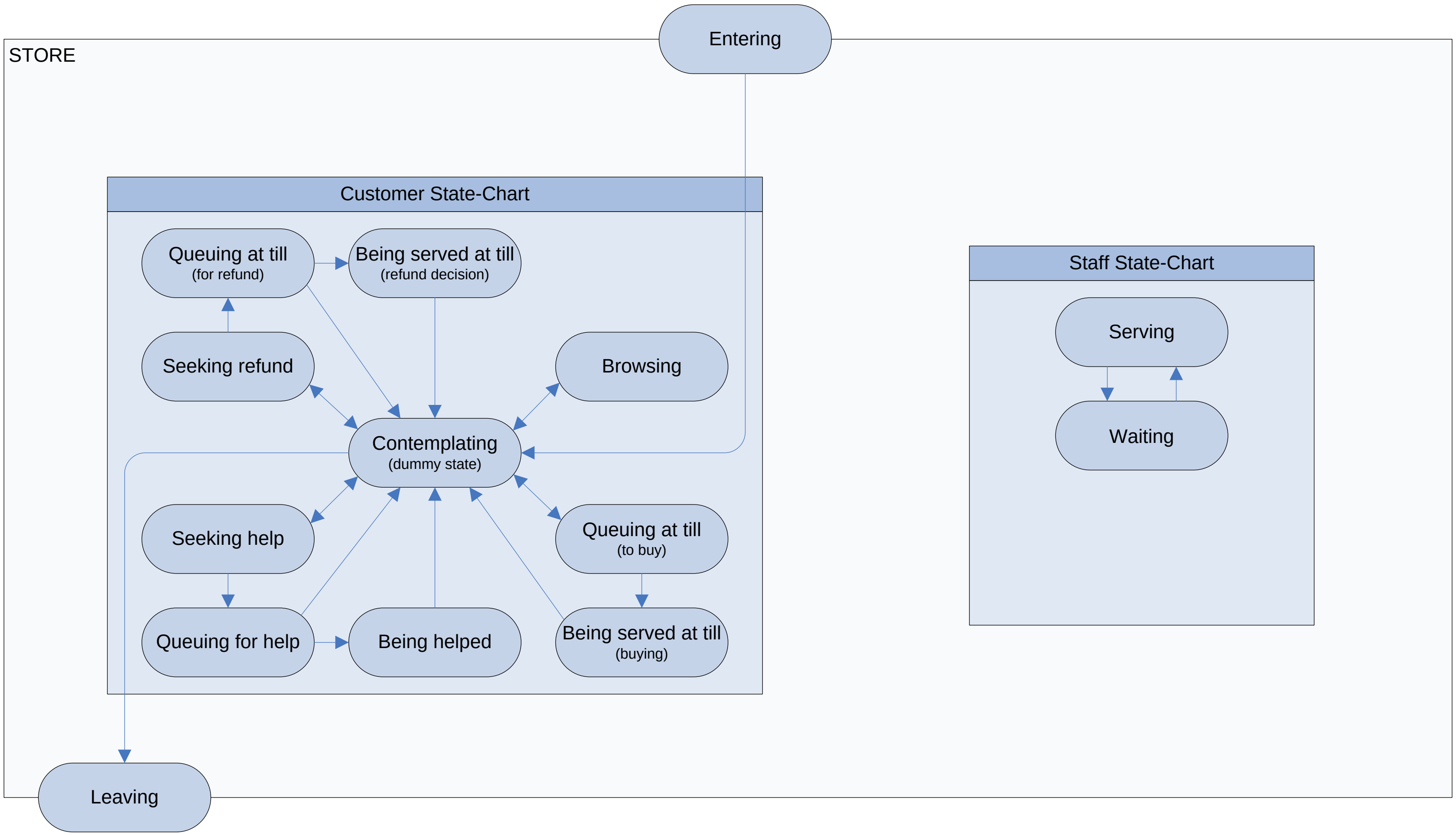
- Conceptual model



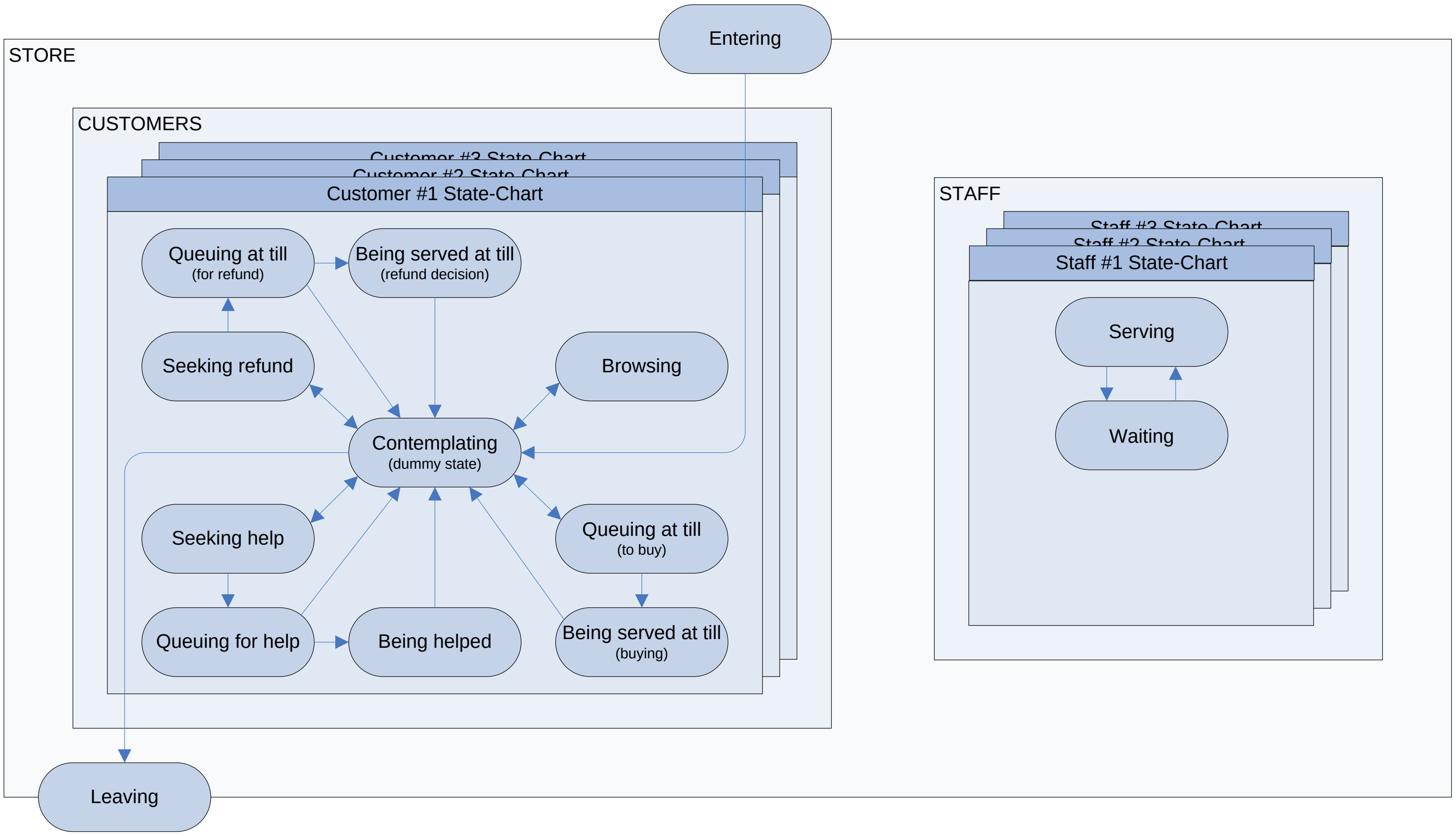
Modelling


Entering
STORE
Queuing at till
(for refund)
Being served at till
(refund decision)
Browsing
Staff Resource
Pool
Queuing at till
(to buy)
Queuing for help
Being helped
Being served at till
(refund decision)
Leaving

Modelling

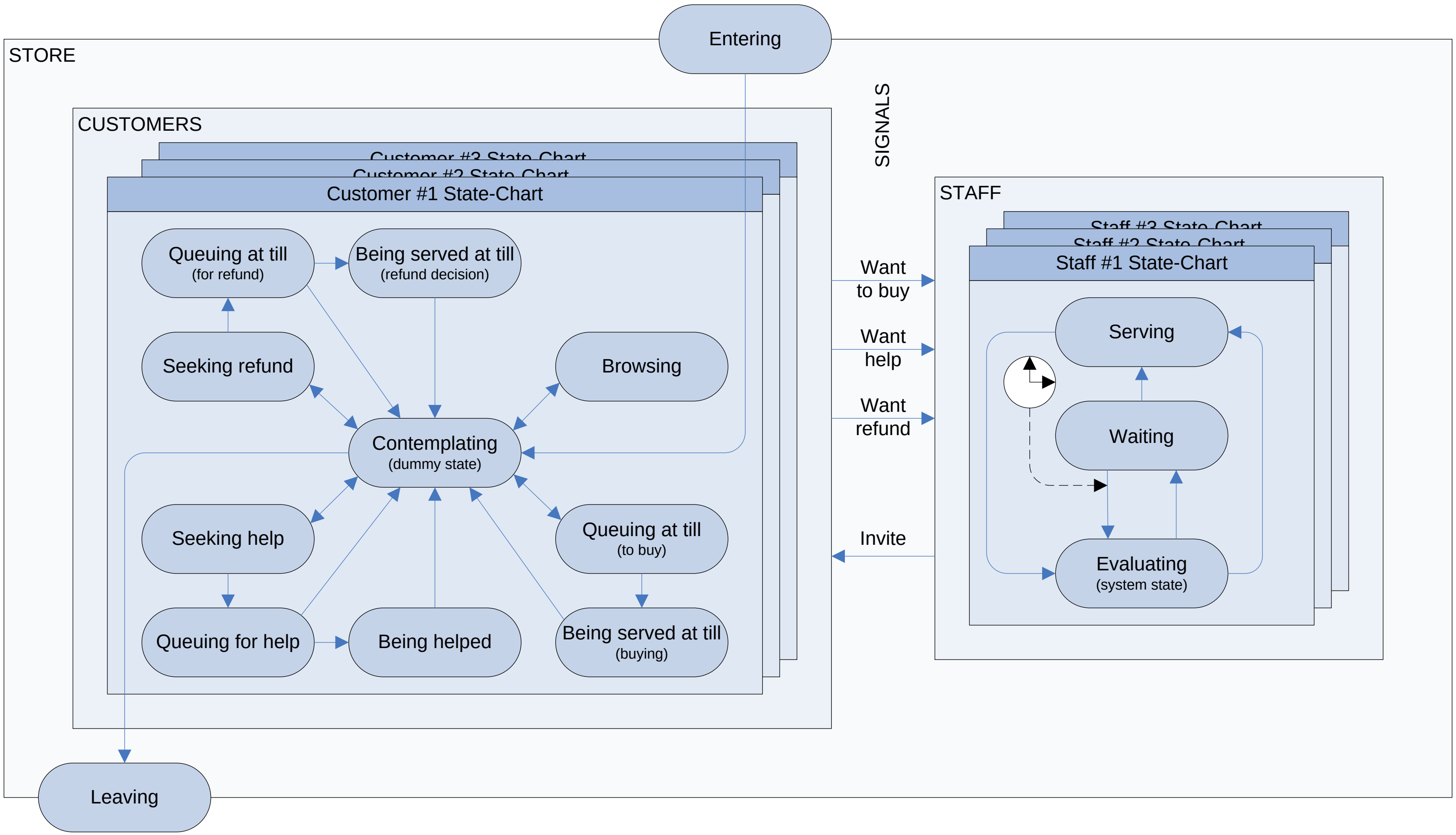

Entering
STORE
Customer State-Chart
Queuing at till
(for refund)
Being served at till
(refund decision)
Seeking refund
Browsing
Contemplating
(dummy state)
Seeking help
Queuing at till
(to buy)
Queuing for help
Being helped
Being served at till
(buying)
Staff State-Chart
Serving
Waiting
Leaving

Modelling



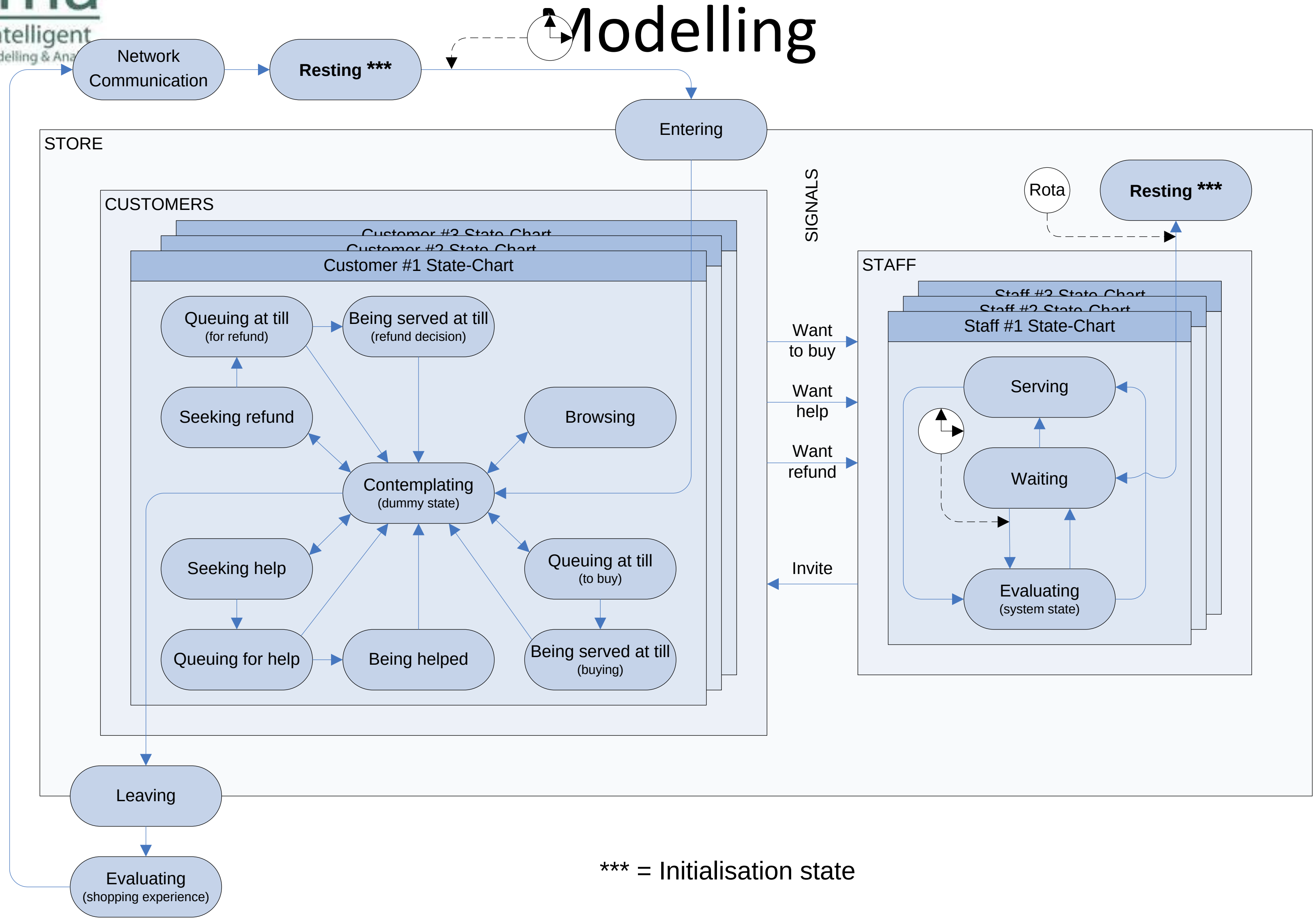
Entering
STORE
CUSTOMERS
Customer #3 State-Chart
Customer #2 State-Chart
Customer #1 State-Chart
Queuing at till
(for refund)
Being served at till
(refund decision)
Seeking refund
Browsing
Contemplating
(dummy state)
Seeking help
Queuing at till
(to buy)
Queuing for help
Being helped
Being served at till
(buying)
STAFF
Staff #3 State-Chart
Staff #2 State-Chart
Staff #1 State-Chart
Serving
Waiting
Leaving

Modelling



Entering
STORE
SIGNALS
CUSTOMERS
Customer #3 State-Chart
Customer #2 State-Chart
Customer #1 State-Chart
Queuing at till
(for refund)
Being served at till
(refund decision)
Seeking refund
Browsing
Contemplating
(dummy state)
Seeking help
Queuing at till
(to buy)
Queuing for help
Being helped
Being served at till
(buying)
Want
to buy
Want
help
Want
refund
Invite
STAFF
Staff #3 State-Chart
Staff #2 State-Chart
Staff #1 State-Chart
Serving
Waiting
Evaluating
(system state)
Leaving

Modelling



*** = Initialisation state

Implementation

- Software: AnyLogic v5.5
  - Multi-method simulation software (SD, DES, ABS, DS)
  - State charts + Java code

- The model is available from the OpenABM.org website
  [http://www.openabm.org/model/2441/]

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

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

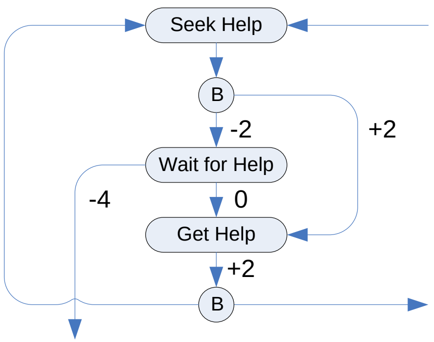
```
for (each threshold to be corrected) do  {
   if (OT < 0.5) limit = OT/2 else limit = (1-OT)/2
   if (likelihood = 0) CT = OT – limit
   if (likelihood = 1) CT = OT
   if (likelihood = 2) CT = OT + limit
}
where:      OT = original threshold
            CT = corrected threshold
            likelihood: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

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)

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

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 %		

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

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

	*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			

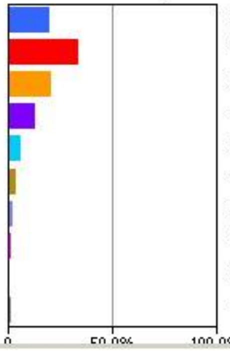
Important parameters:

- 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

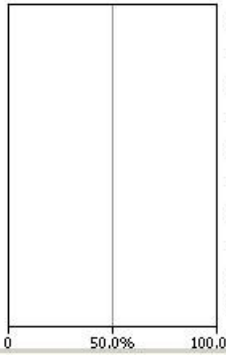
Finite population:

- shopping enthusiasts:	400
- solution demanders:	3200
- service seekers:	3200
- disinterested shoppers:	400
- internet shoppers:	800

intNumProactiveOpportunity: 0
intSumProactiveOpportunity 30741
intSumCustomersPickedProactively: 3740



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

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 II

(For more details see Zhang et al 2010)

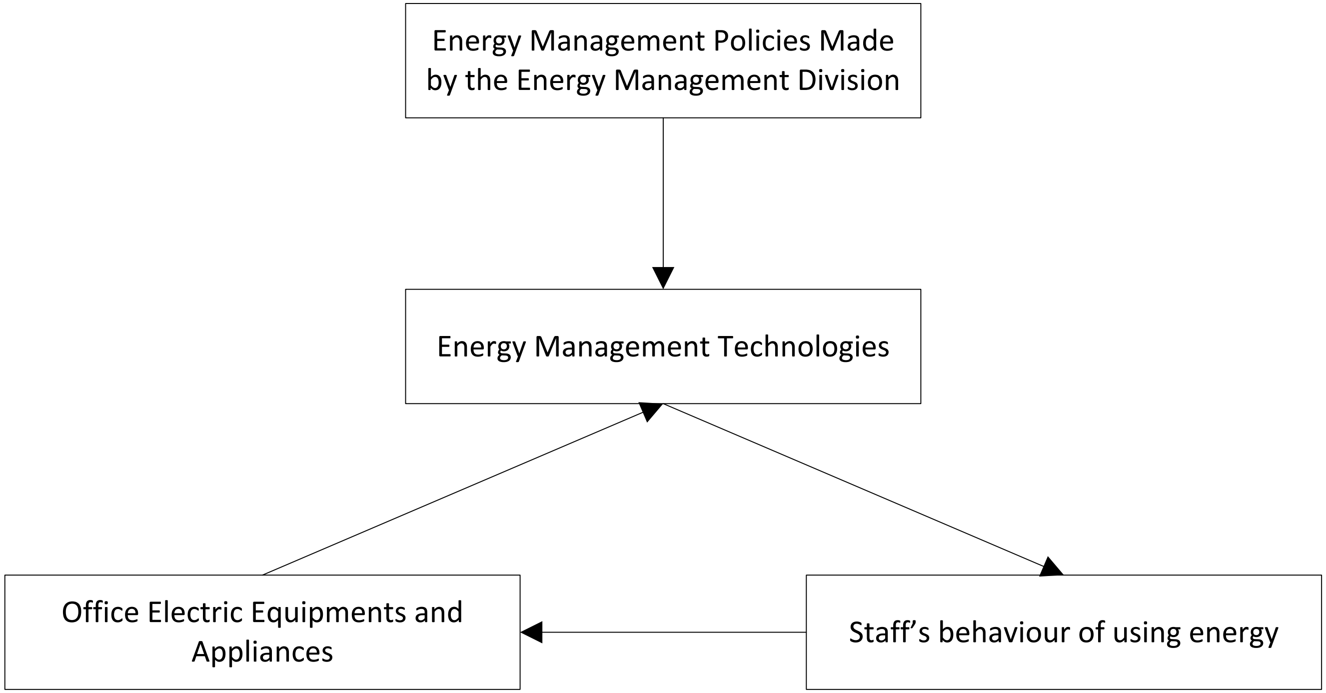
A non-queuing system

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

Context

- Four elements of office energy consumption:



Modelling

- We distinguishing base appliances and flexible appliance
  - Examples for **base appliances**: Security cameras, information displays and computer servers, refrigerators
  - Examples for **flexible appliances**: Lights, desktop computers, printers

- The mathematical model
  - $C_{total} = C_{base} + C_{flexible}$

    where $C_{flexible} = \beta_1 * C_{f1} + \beta_2 * C_{f2} + \ldots + \beta_n * C_{fn}$

    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

    β close to 0 = electricity user switches flexible appliances always off

    β close to 1 = electricity user leaves flexible appliances always on
  - $C_{total} = C_{base} + (\beta_1 * C_{f1} + \beta_2 * C_{f2} + \ldots + \beta_n * C_{fn})$

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

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

Modelling

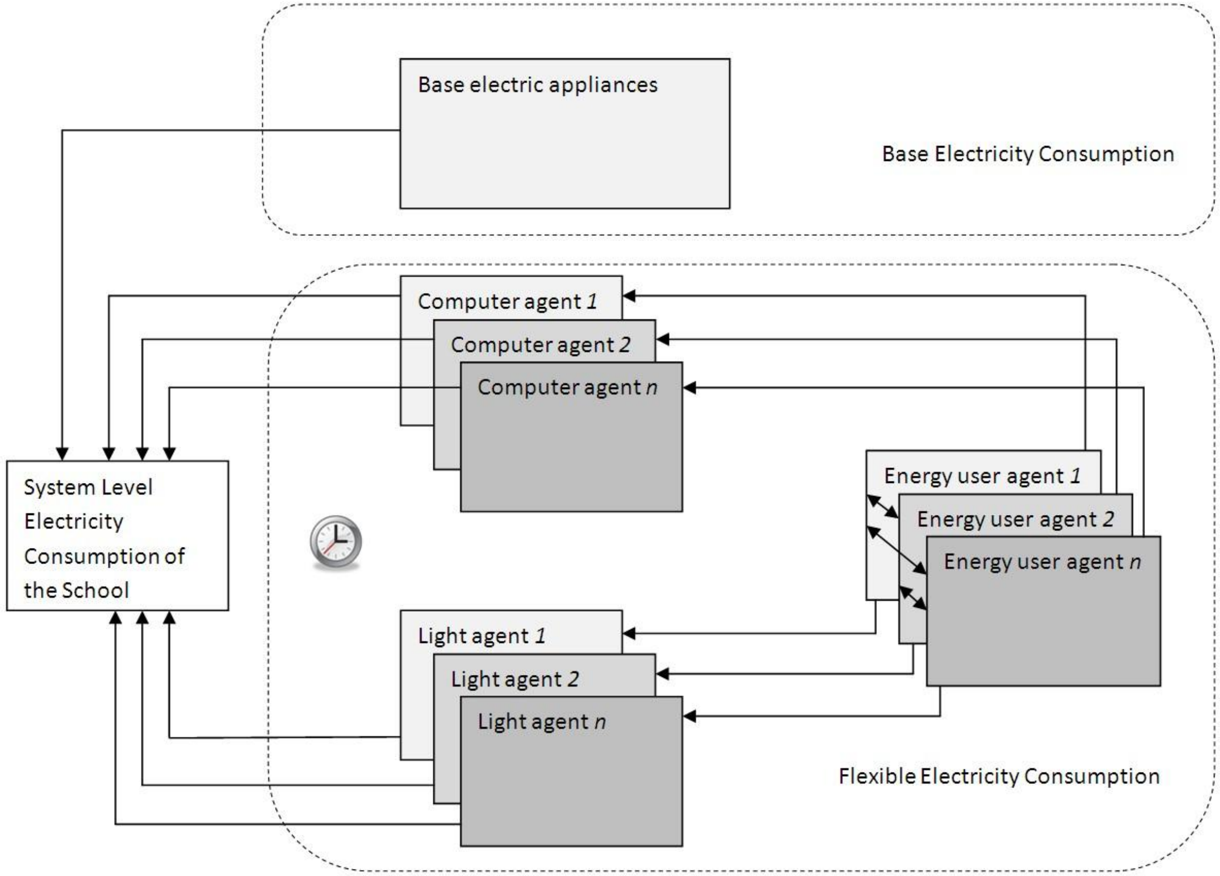
- Details of rooms and electric equipment

Item	Number
Rooms	47
Lights	239
Computers	180
Printers	24
Information Displays	2
Maximum Number of Energy Users	213

- Entities to be considered
  - Energy user agent (proactive)
  - Computer agent (passive)
  - Light agent (passive)
  - Office agent (passive)

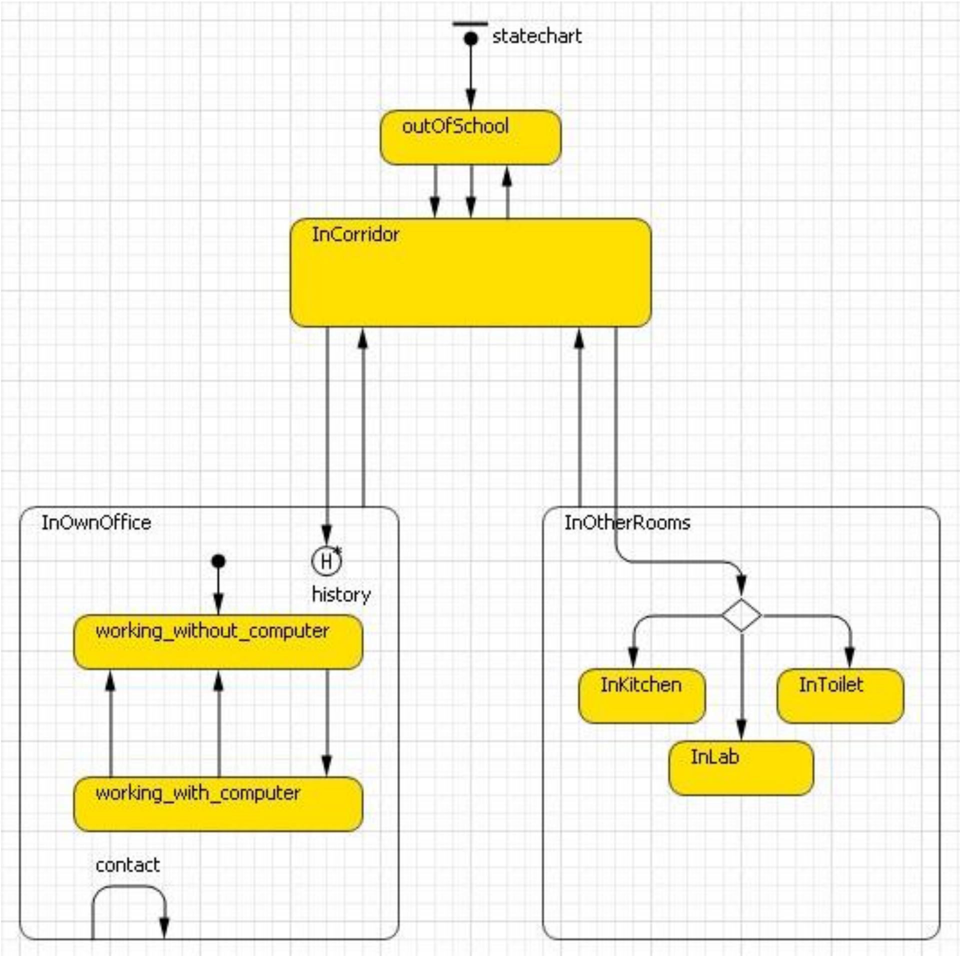
Modelling

- Conceptual model



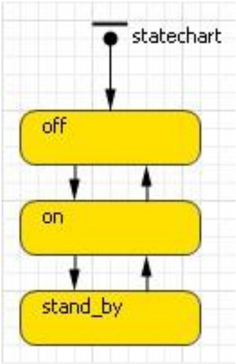
Modelling

- Energy user agent
  - Proactive

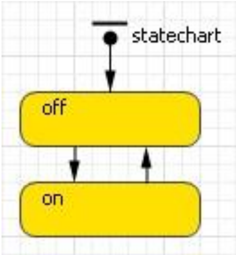


Modelling

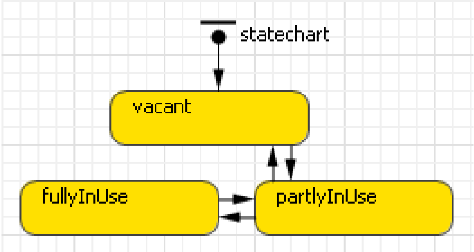
- Computer agent
  - passive



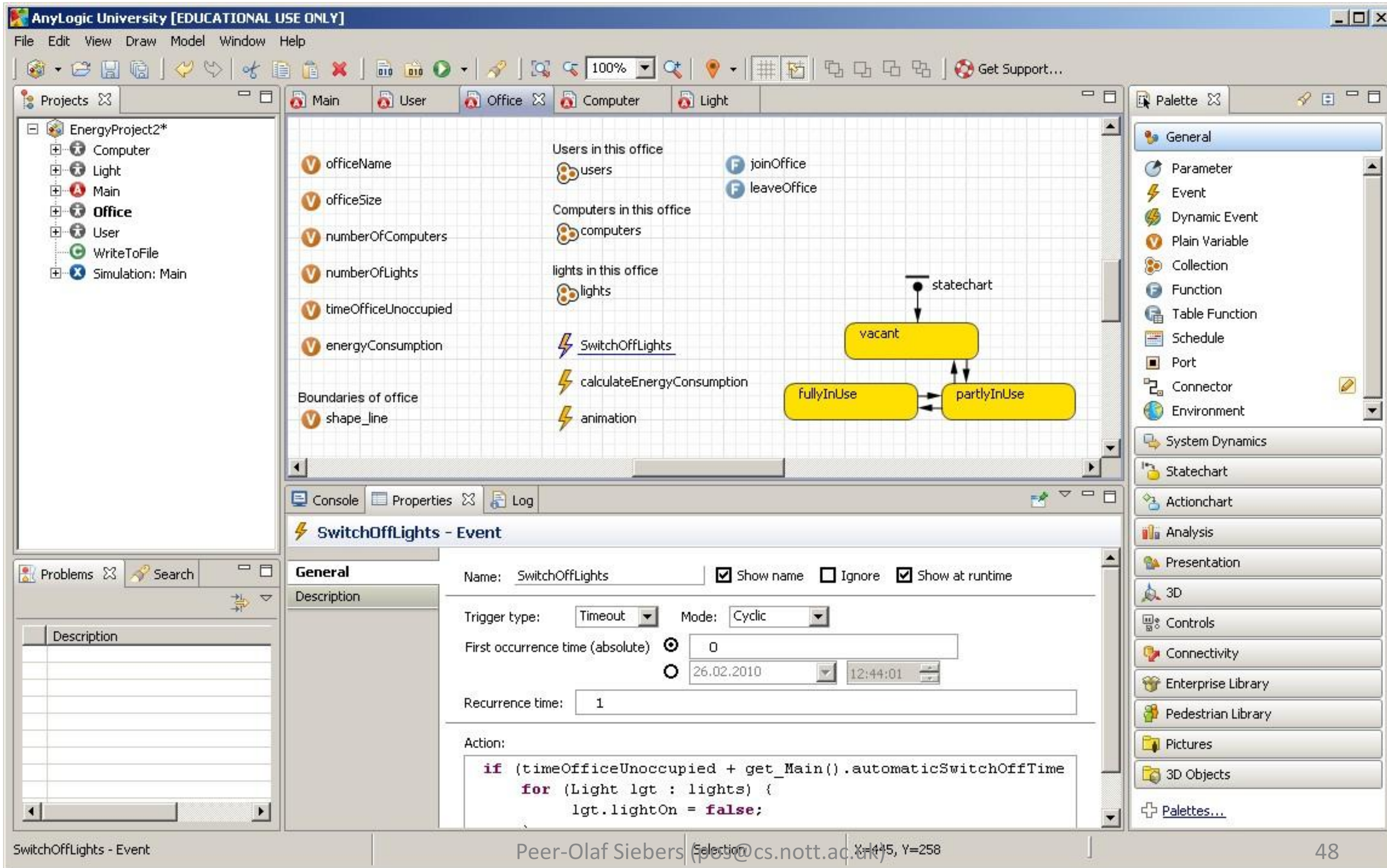
- Light agent
  - passive

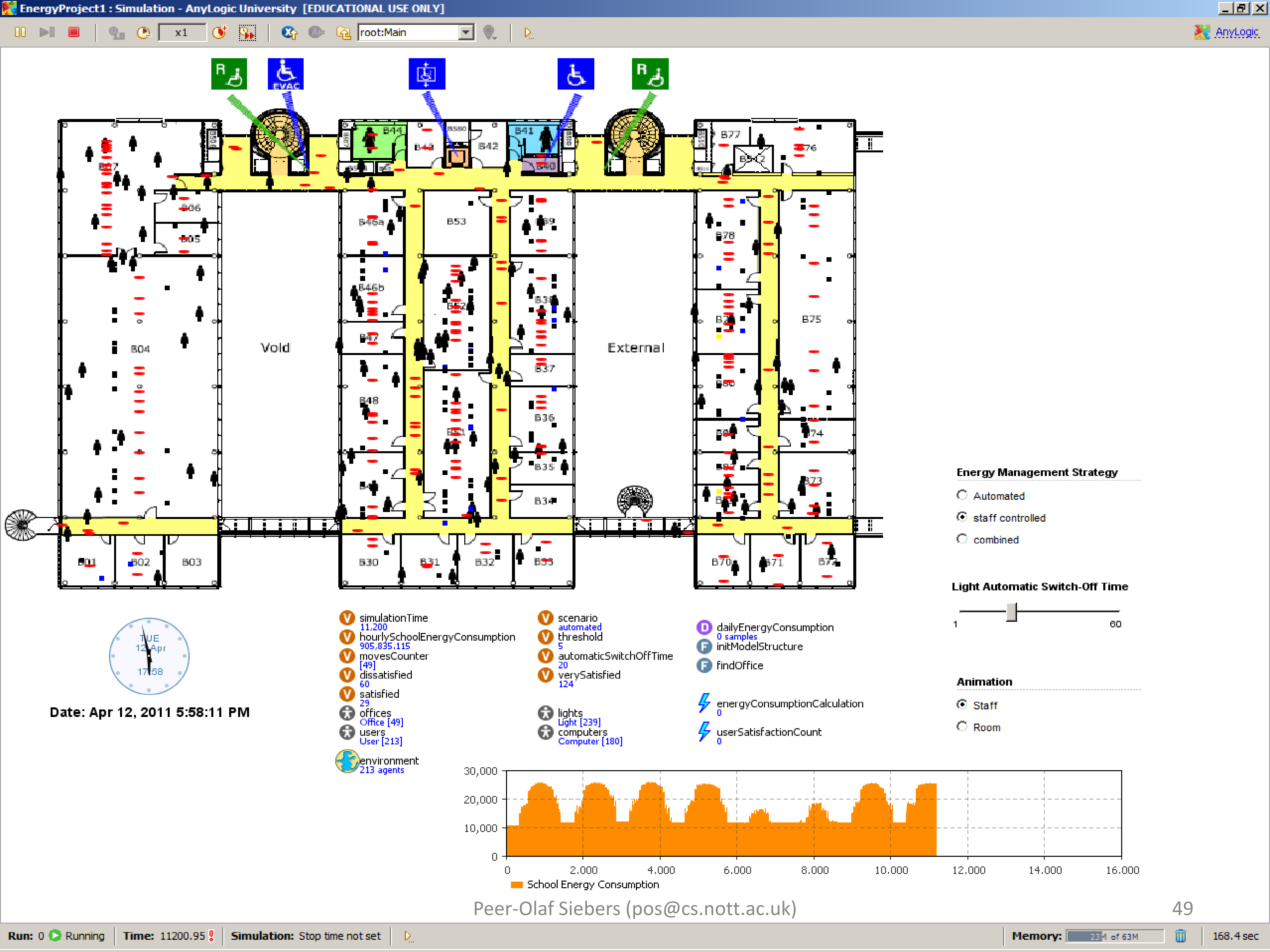


- Office agent
  - passive



Implementation




EnergyProject1 : Simulation - AnyLogic University [EDUCATIONAL USE ONLY]
x1
root:Main
AnyLogic
Void
External
B04
B06
B05
B01
B02
B03
B30
B31
B32
B33
B44
B43
B42
B41
B40
B46a
B46b
B47
B48
B53
B39
B38
B37
B36
B35
B34
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B76
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B70
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satisfied
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scenario
automated
threshold
5
automaticSwitchOffTime
20
verySatisfied
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lights
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computers
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0 samples
initModelStructure
findOffice
energyConsumptionCalculation
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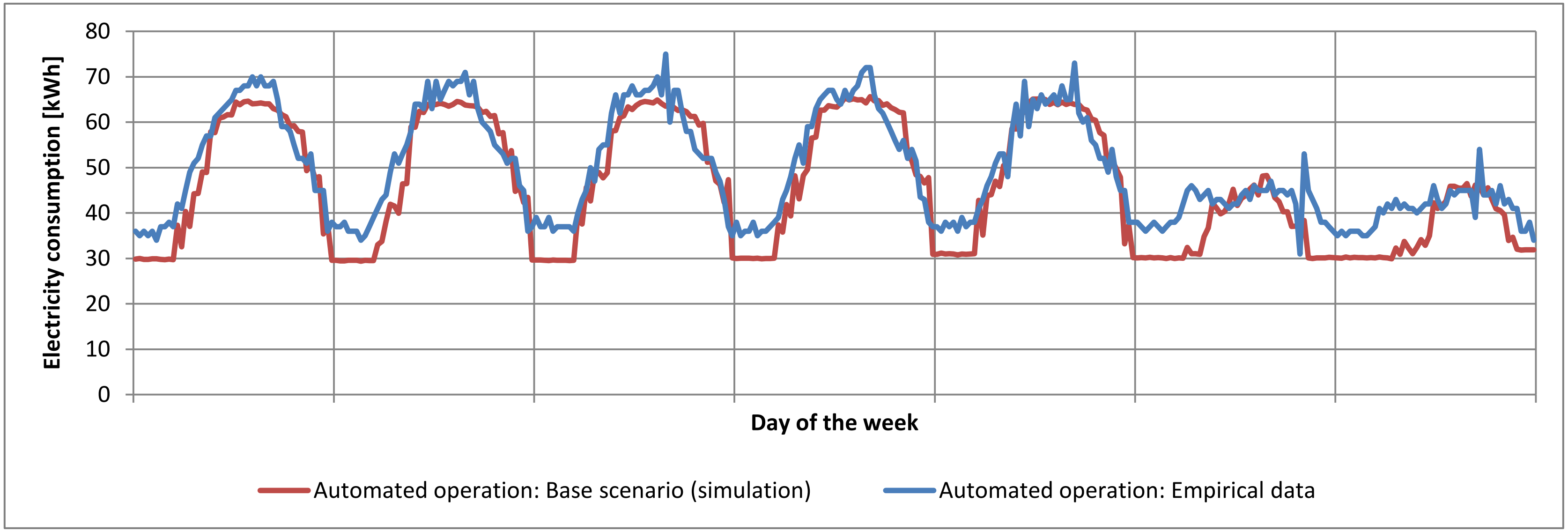
userSatisfactionCount
0
TUE
12 Apr
17:58
Date: Apr 12, 2011 5:58:11 PM
Energy Management Strategy
Automated
staff controlled
combined
Light Automatic Switch-Off Time
1
60
Animation
Staff
Room
30,000
20,000
10,000
0
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
School Energy Consumption
Run: 0
Running
Time: 11200.95
Simulation: Stop time not set
Memory:
23M of 63M
168.4 sec

Experimentation

- Experiment 1
  - Validation (comparison of **simulation** and **empirical results**)

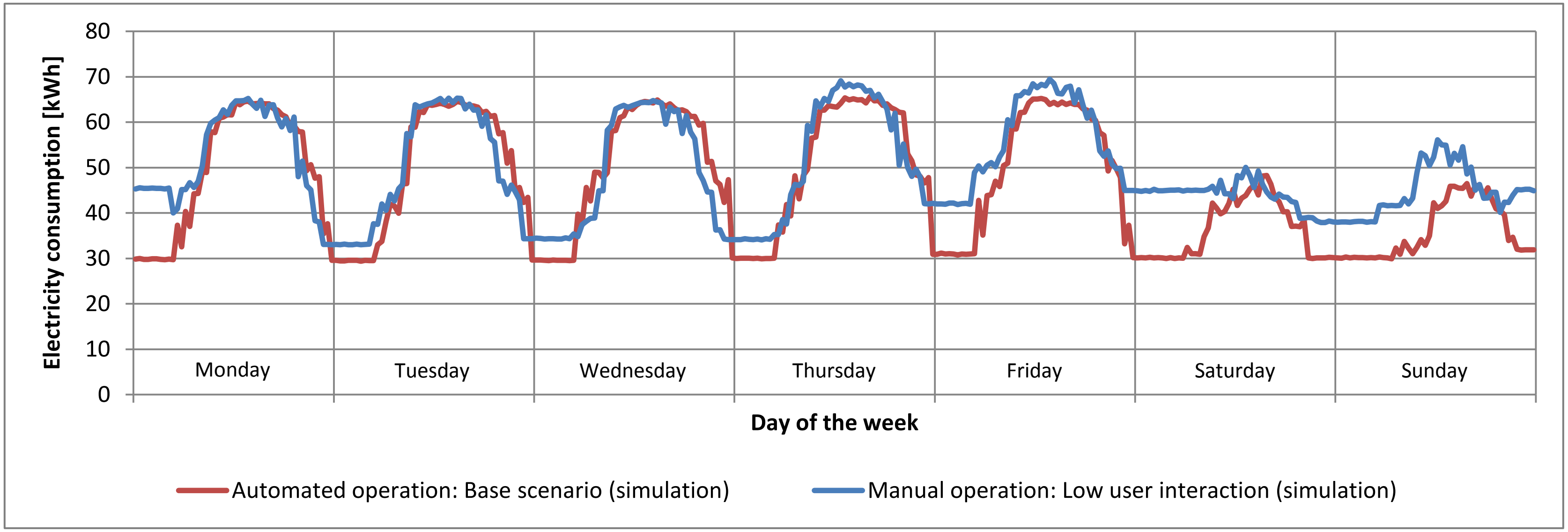


Experimentation

- Experiment 2
  - Comparison of two different lighting management strategies
    - Automated lighting management strategy: Lights in an office are off 20 minutes after the last occupying electricity user agent leaves
    - Staff-controlled lighting management strategy: Lights in an office might be switched off by the last occupying user (based on a probability)
      - Depends on the user energy saving awareness
      - Depends on the level of interaction between users

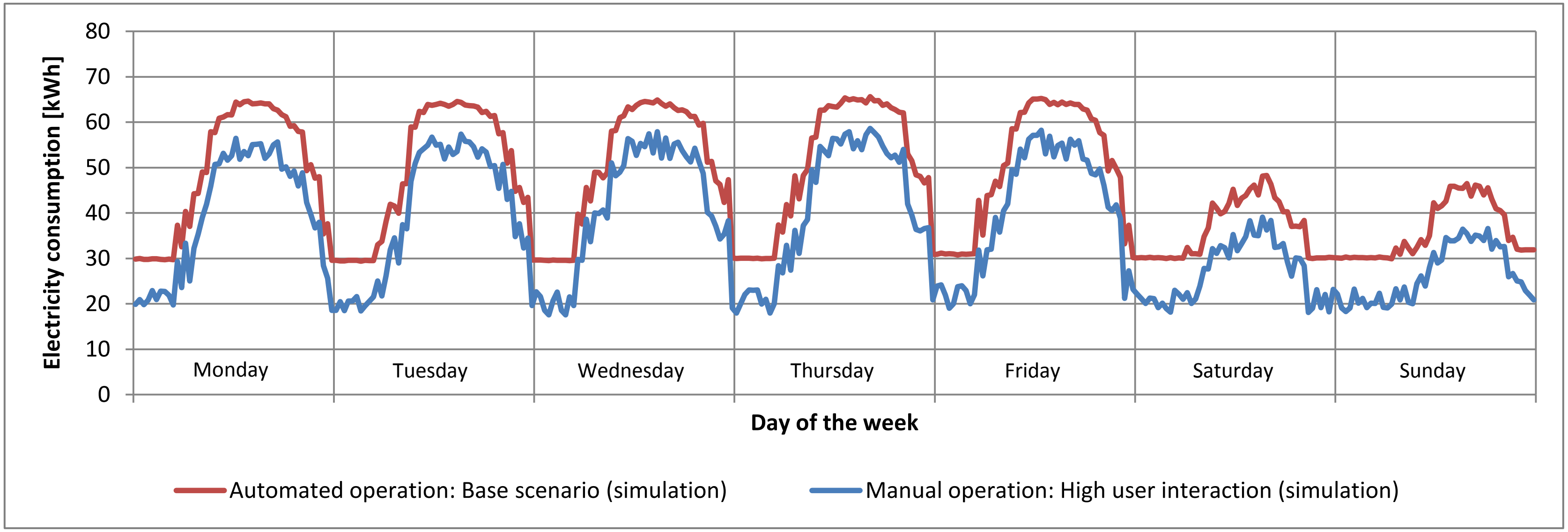
Experimentation

- Experiment 2
  - Automated vs. staff controlled lighting management with **low level of electricity user interaction**



Experimentation

- Experiment 2
  - Automated vs. staff controlled lighting management with **high level of electricity user interaction**



Conclusions

- Agent-based modelling is getting more fashionable in OR
  - Many software developers started to integrate agent like intelligent objects into their simulation products
- There is still a need to formalise ABM in OR
  - Development process
  - Validation process
- There is a lack of re-usable components or agent templates
- There are still no OR ABM books or courses available
- From academia to business: What is needed?
  - Clients should be involved in the whole process

References

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