Agents to the Rescue: Creating Artificial Labs for Evaluating Human-Natural Systems

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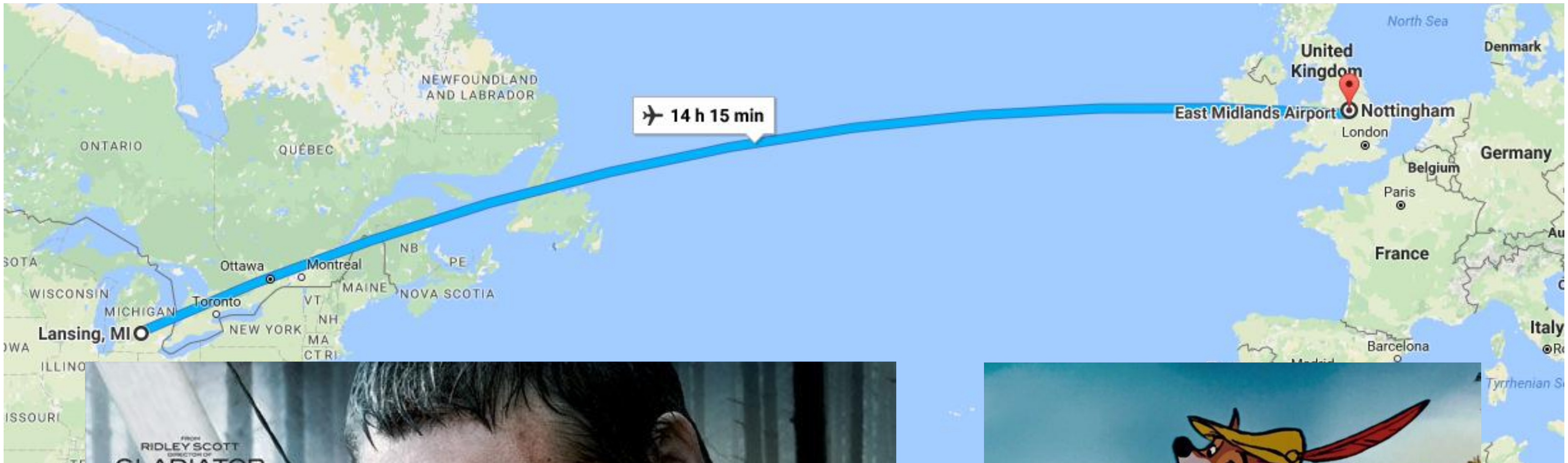
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My Research Interest

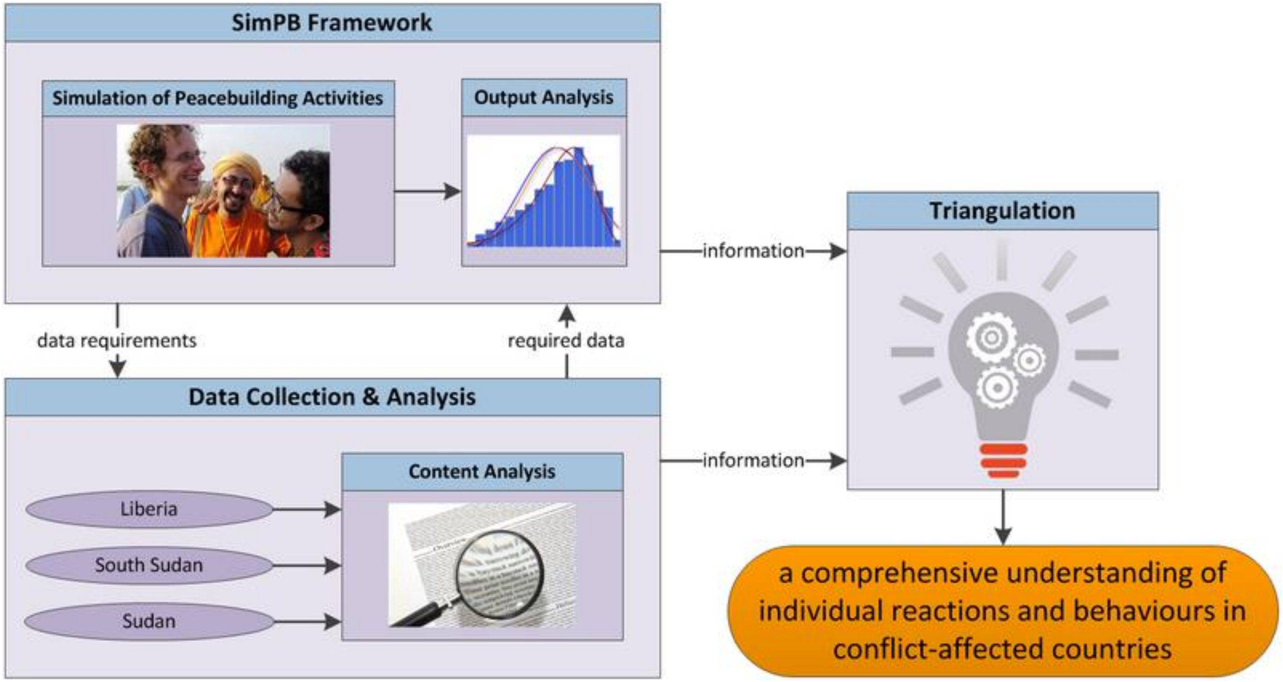
- Technical Aspects of Agent Based Modelling (ABM)
  - Engineering agent-based models for Social Simulation
    - From stereotypes to multi-agent systems
    - Using software engineering tools to define agents and their interactions
  - Treating concepts as agents (e.g. knowledge; traffic hotspots)
  - Coupling different types of agents (e.g. software + behavioural)

Research Interest

- Interdisciplinary Applications of ABM
  - Business studies (Risk Assessment; Supply Chains)
  - Economics (Game Theory; Agent Based Computational Economics)
  - Social Sciences (Political Science; Social Simulation)
  - Engineering (Manufacturing; Urban Modelling; Energy; Transportation)
  - Computer Science (Robotics; Game Development)
  - Systems Biology (Immunology)
  - Ecology (Animal Conservation)
  - Epidemiology (Population Health)

Project Example: Political Science

- SimPB: Simulating Peace Building Activities



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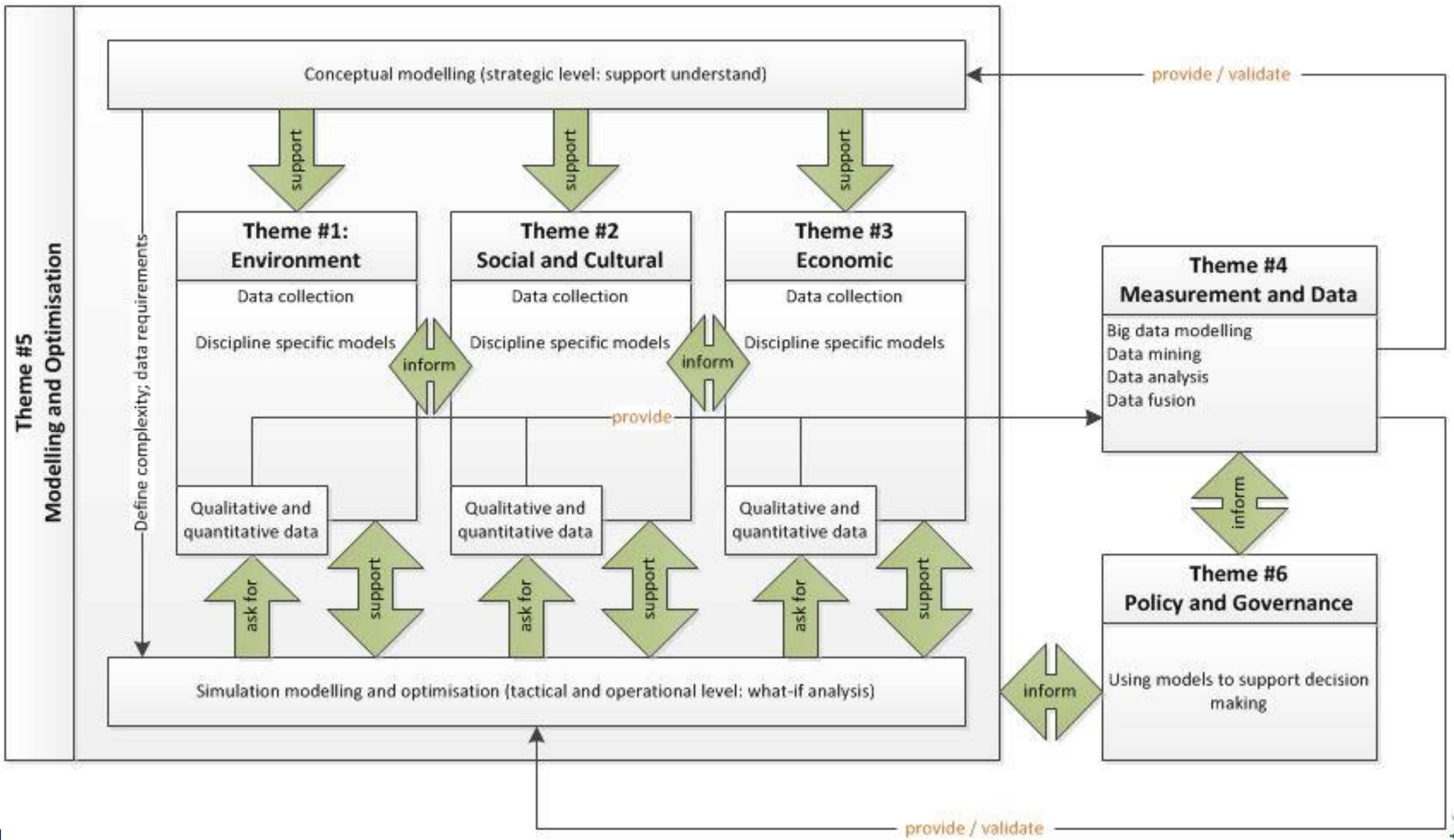
Project Examples: Urban Modelling

- Sustaining Urban Habitats: An Interdisciplinary Approach



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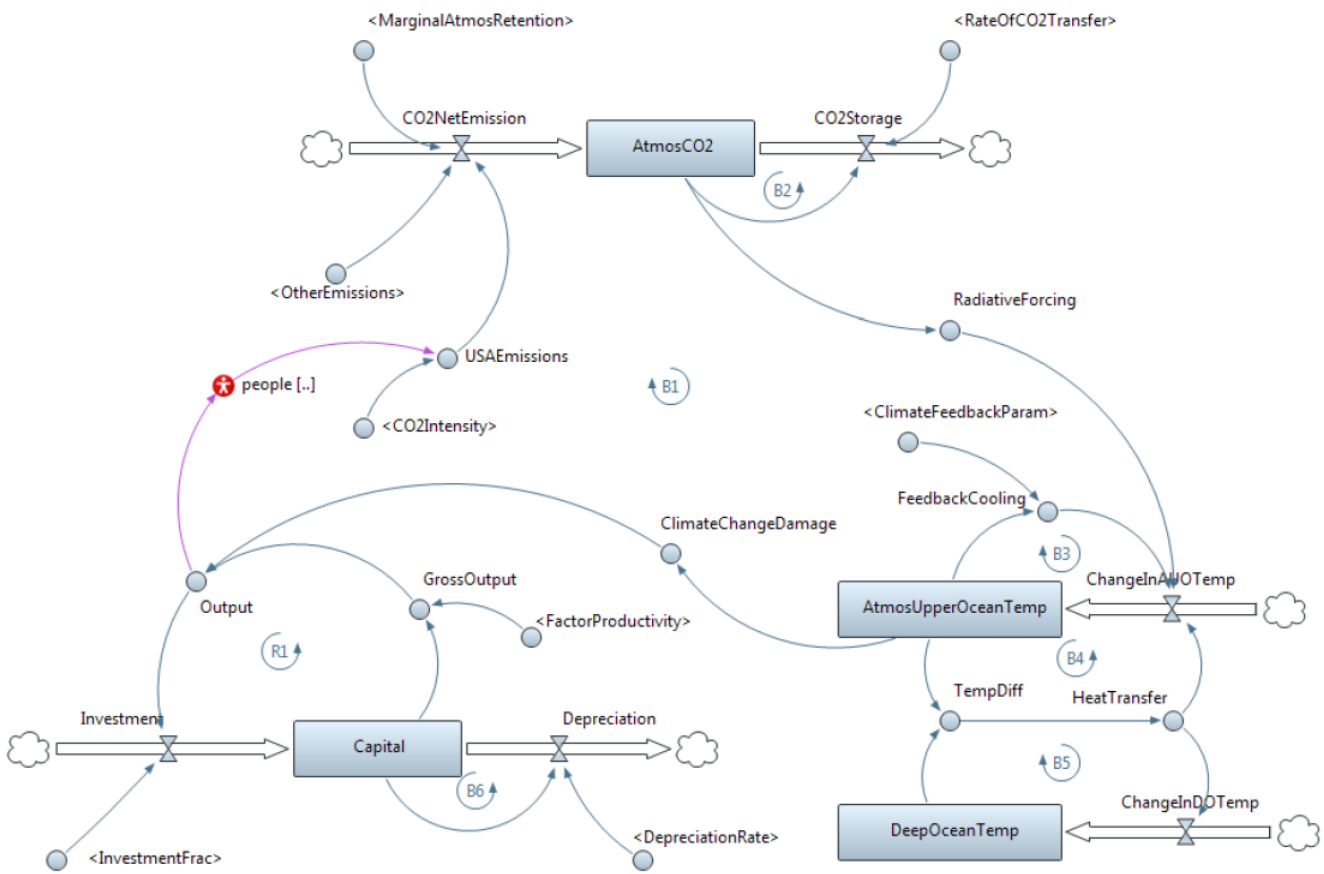
Project Example: Climate Change

- HCAM: Hybrid Climate Assessment Modelling



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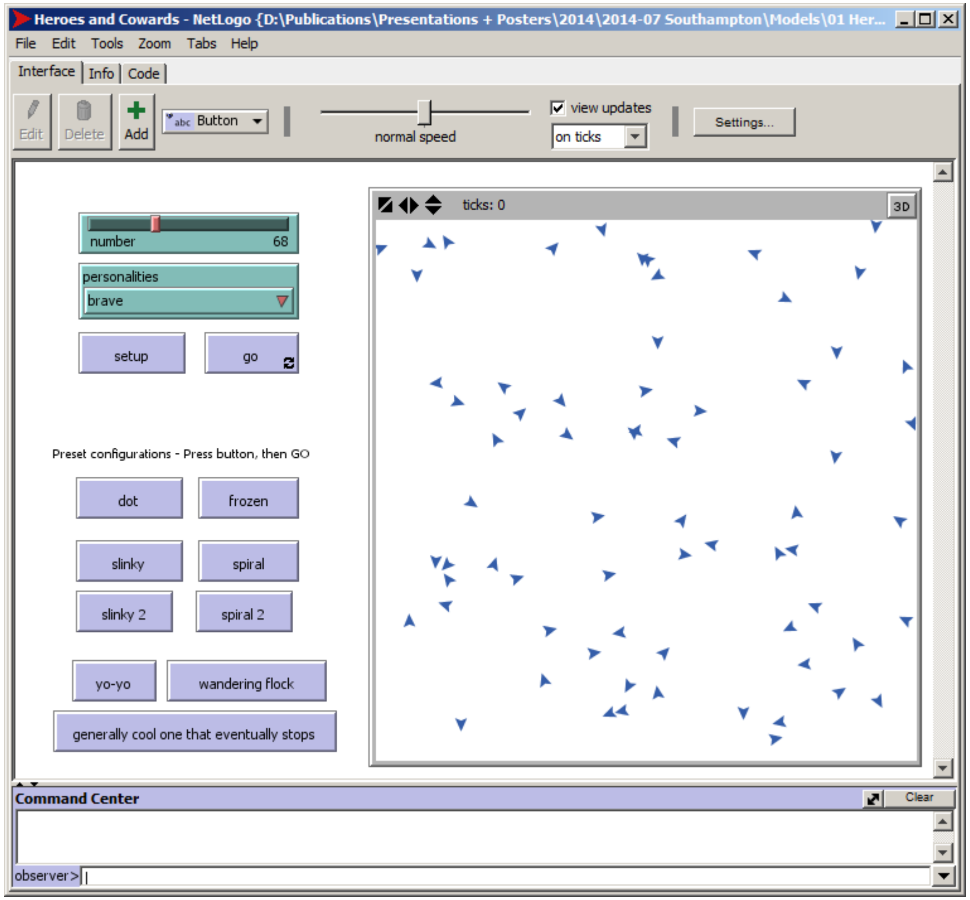
Agent-Based Modelling and Simulation

Agent-Based Modelling

- Heroes and Cowards Game (Wilensky and Rand 2015)
  - Hero rule

Agent-Based Modelling

- Heroes and Cowards Game : All heroes



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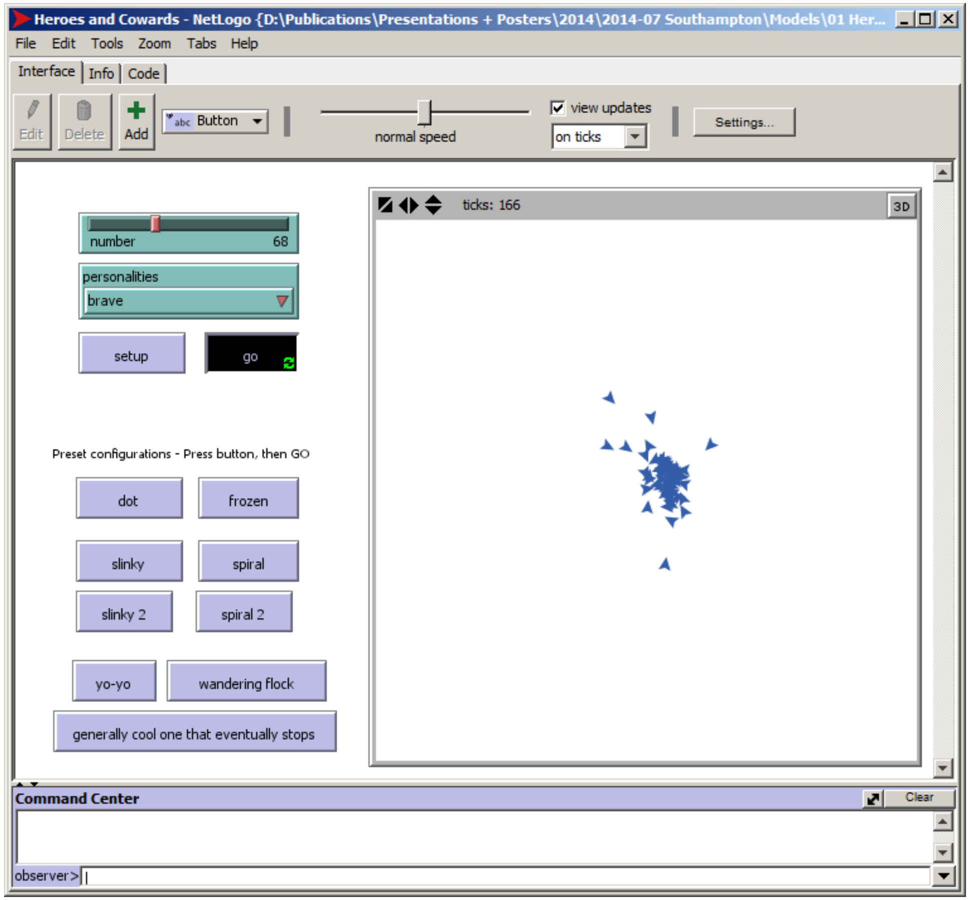
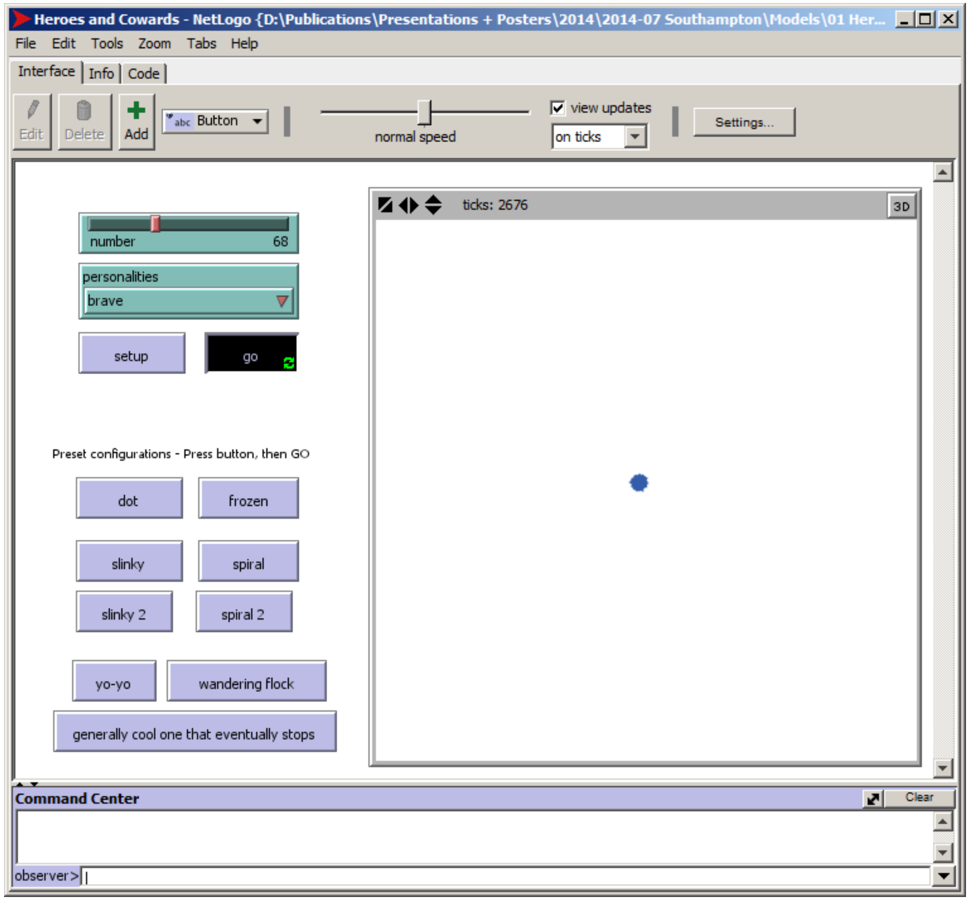
Agent-Based Modelling

- Heroes and Cowards Game : All heroes



Agent-Based Modelling

- Heroes and Cowards Game : All heroes



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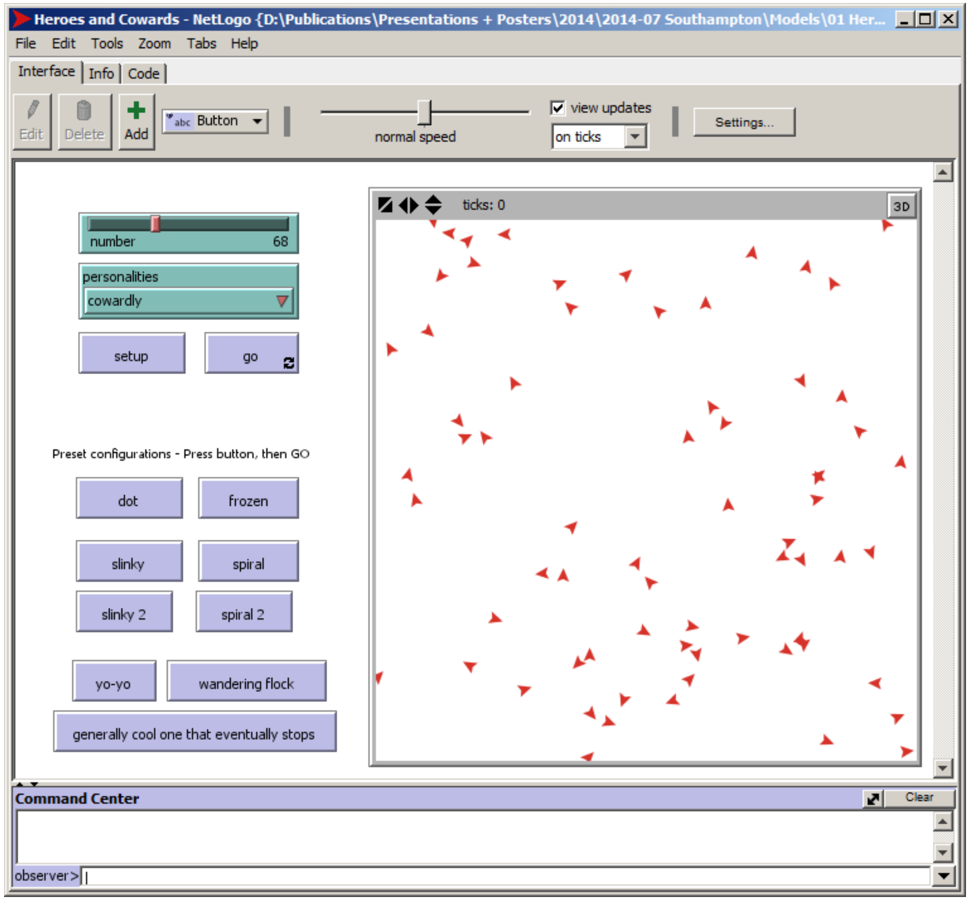
Agent-Based Modelling

- Heroes and Cowards Game
  - Coward rule

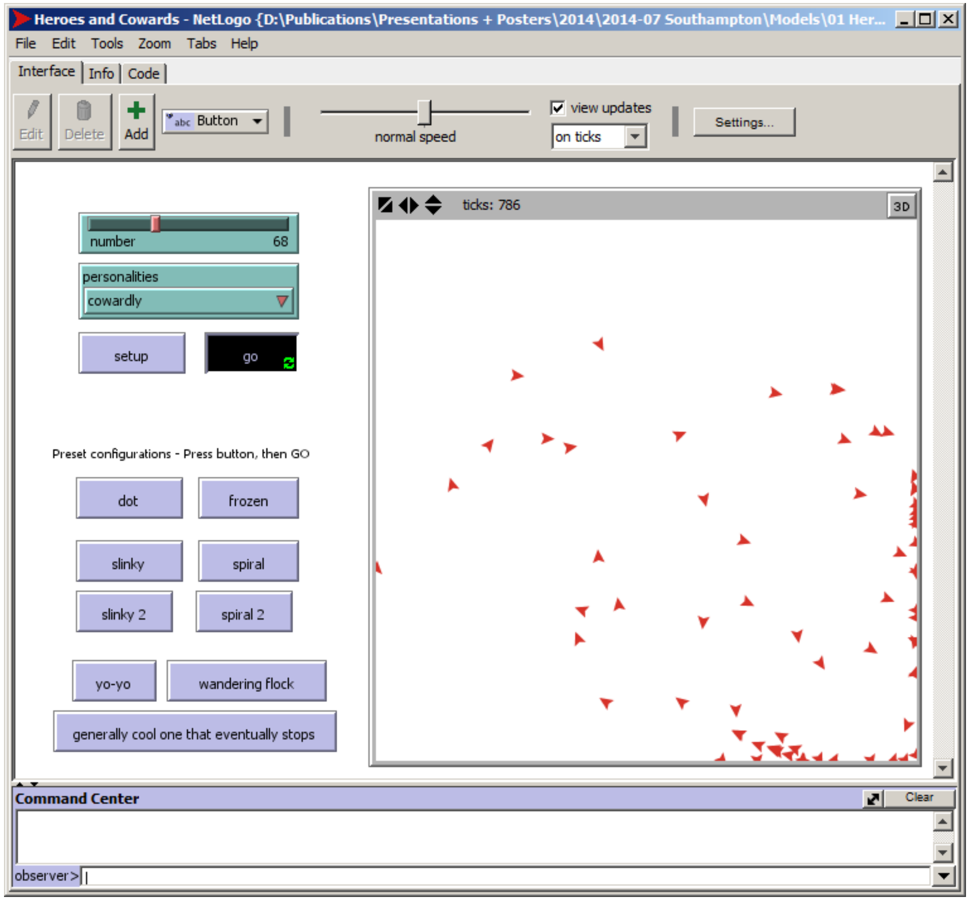
Agent-Based Modelling

- Heroes and Cowards Game: All cowards



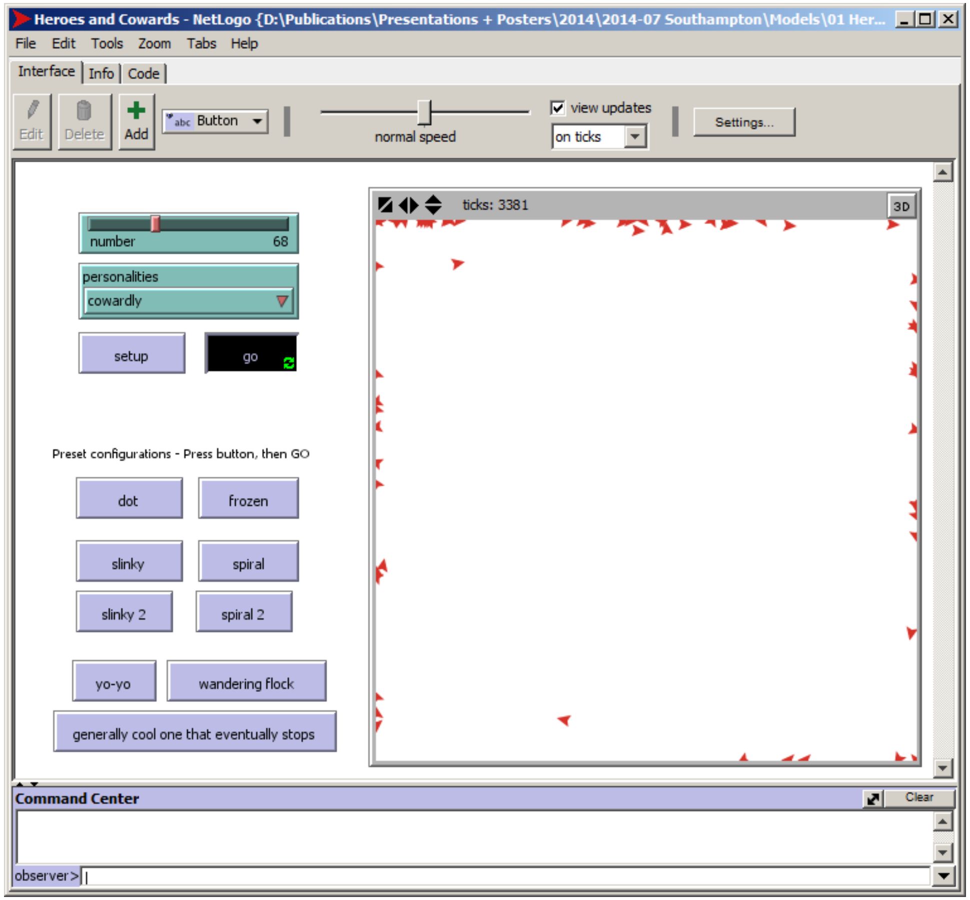
Agent-Based Modelling

- Heroes and Cowards Game: All cowards



Agent-Based Modelling

- Heroes and Cowards Game: All cowards



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Agent-Based Modelling

- What do we mean by "agent"?
  - Agents are **"objects with attitude"** (Bradshaw 1997)
  - Similar to non-player characters in computer games
- Properties:
  - Discrete entities
    - Have a memory
    - Have their own goals and behaviours
    - Have their own thread of control
  - Autonomous decisions
    - Capable to adapt and to modify their behaviour
  - Proactive behaviour
    - Actions depending on motivations generated from their internal state

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 **well suited to modelling** systems with heterogeneous, autonomous and proactive actors, such as **human-centred systems**.

Agent-Based Modelling

- Agents can represent
  - Individuals
  - Households
  - Organisations
  - ...
- Emergence
  - Individual agents interact with each other and their environment to produce complex collective behaviour patterns
    - Example: Flocking of birds; traffic jam dynamics
  - An emergent phenomenon can have properties that are decoupled from the properties of the part

Agent-Based Modelling

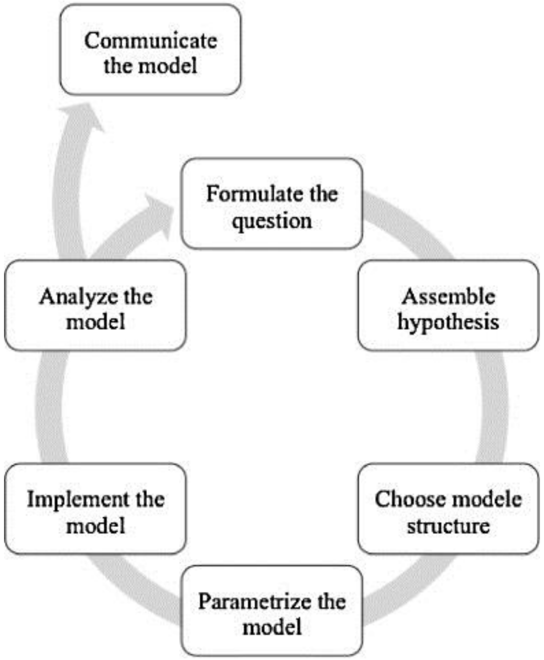
- When to use ABM? (Siebers et al. 2010)
  - When the problem has a **natural representation as agents** - when the goal is modelling the behaviours of individuals in a diverse population
  - When agents have relationships with other agents, especially **dynamic relationships** - agent relationships 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 Modelling

- Modelling approaches
  - Data driven
    - Identify active entities (agents)
    - Define their states and behaviour
    - Put them in an environment
    - Establish connections
    - Test the model

AnyLogic Help (2013)

  - Theory driven



Grimm and Railsback (2005)

Engineering Agent-Based Social Simulations

Siebers and Klügl (in press)

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Introduction

- Problem
  - Agent-Based Social Simulation (ABSS) partially suffers from the fact that despite of its increasing popularity there is no standard way of addressing model development
  - This becomes even more of a problem for:
    - Larger projects
    - Collaborative projects
    - Multi disciplinary projects

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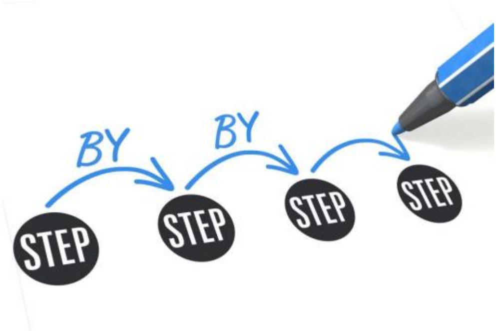
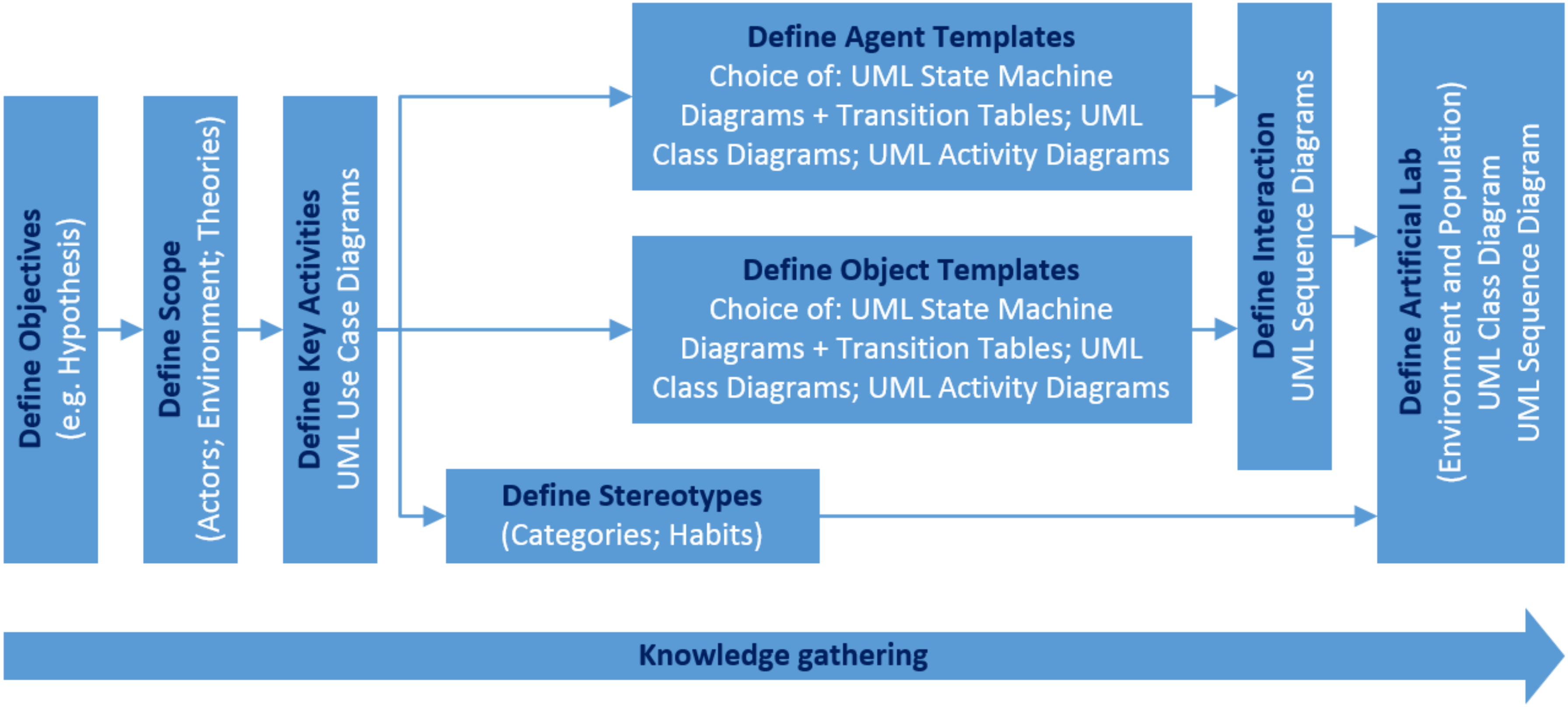
Introduction



- Solution
  - Software Engineering has developed a set of tools that enables following a "formal" approach to system analysis and model design
  - Such elements of a systematic proceeding make different steps explicit as well as provide clear and precise languages to:
    - Capture the concepts and content and assumptions of the model
    - Documenting not just the final result but also intermediate steps
  - The result is a well structures and well documented conceptual model that is easy to maintain and easy to extend

Introduction

- Solution: The EABSS Development Framework



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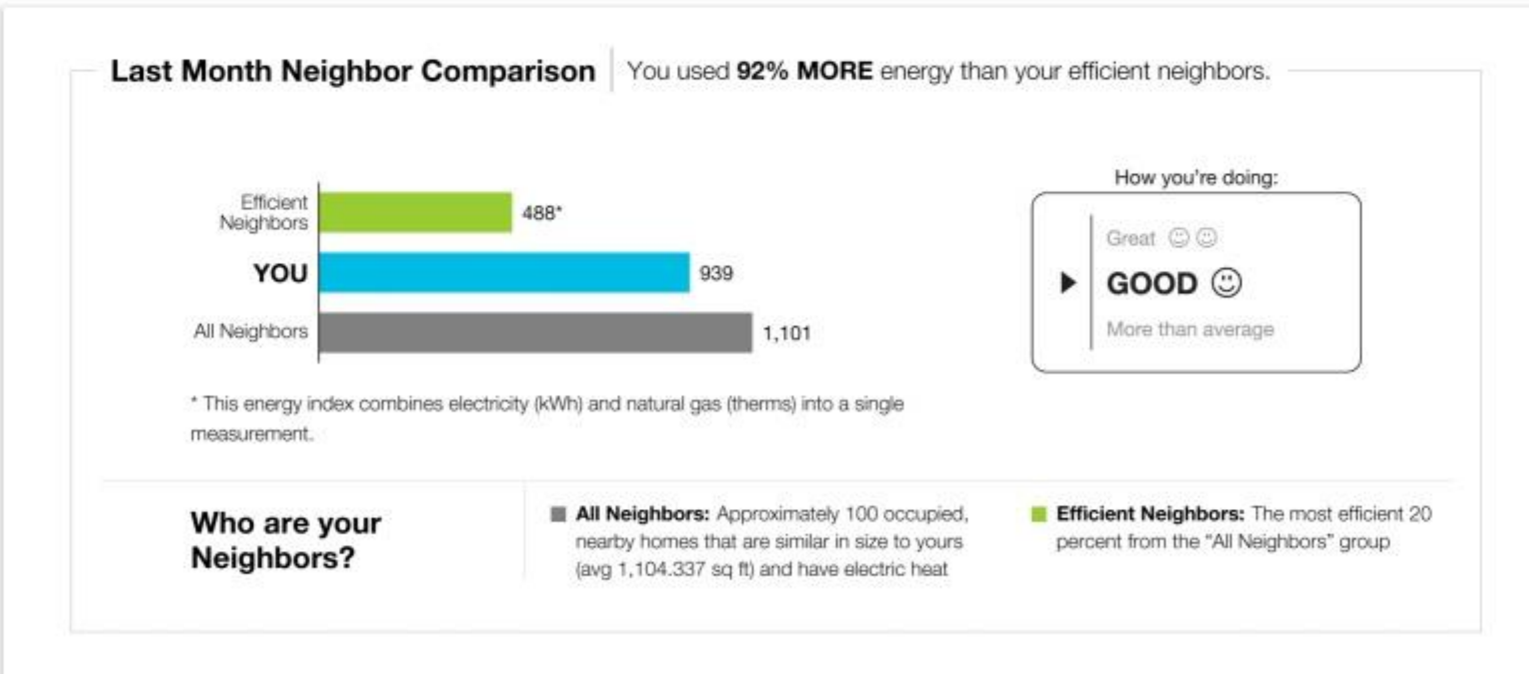
Introduction

- Solution: The EABSS Development Framework
  - Can be used for exploratory and explanatory studies
  - Agile approach
    - Requires frequent interactions with stakeholders
    - Requires frequent iterations (to improve definitions from previous tasks)
    - Not investing a lot of time into specifications that are obsolete after the next discussion
  - A forum for debates amongst stake holders

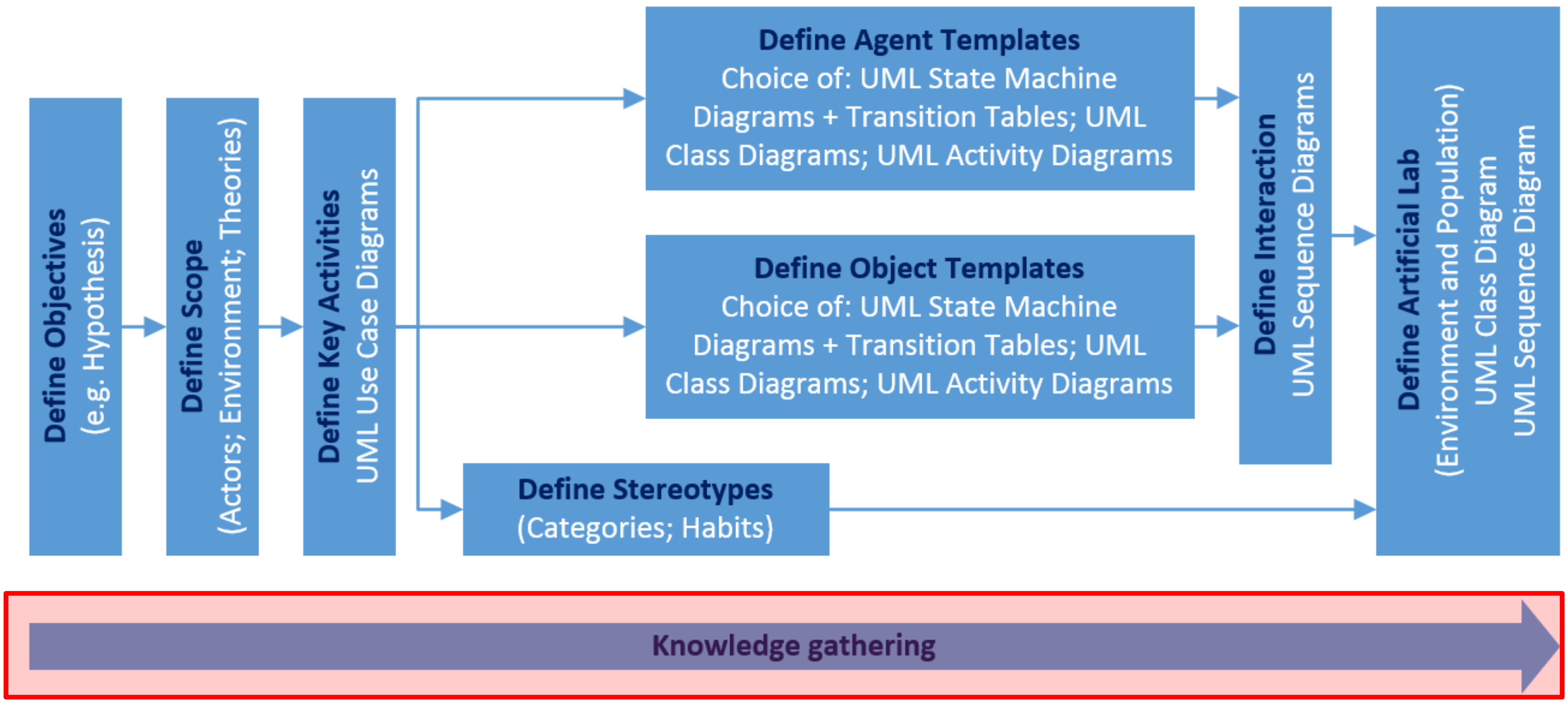
Illustrative Example

- Normative Comparison in an Office Environment
  – Studying the impact of normative comparison amongst colleagues with regards to energy consumption in an office environment



after Susanty (2015)

Overview of our ABSS Development Framework



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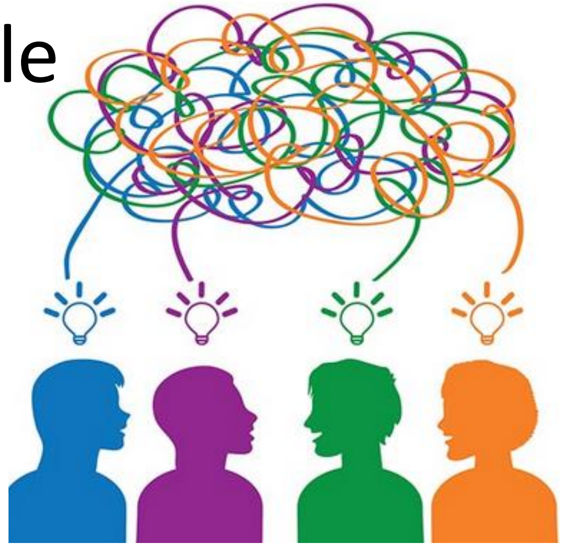
Knowledge Gathering

- Knowledge gathering happens throughout the structured modelling approach through
  - Literature review
  - Focus group discussions
  - Observations
  - Surveys

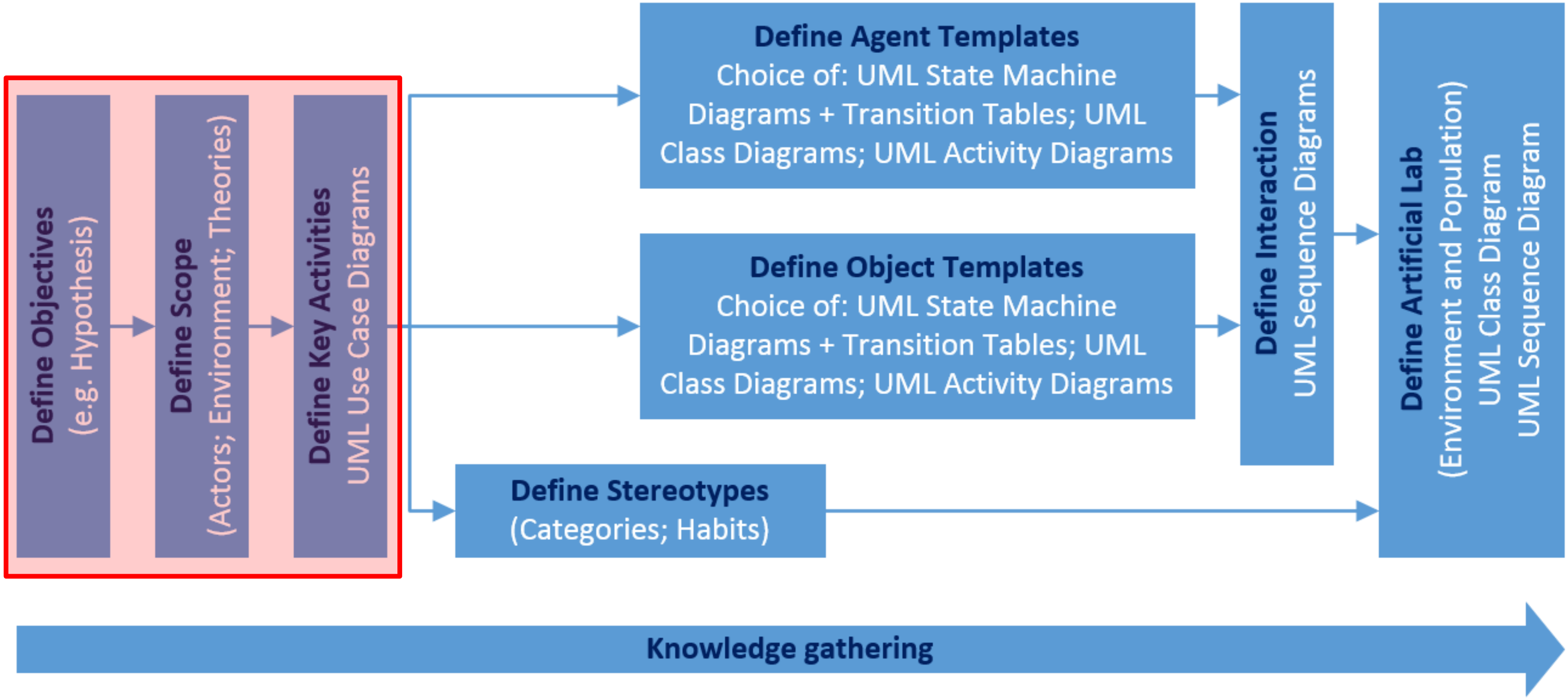
- Either a prerequisite for tasks (e.g. a literature review) or is embedded within the tasks (e.g. focus group discussions)

Illustrative Example



- Focus groups:
  - Facilitator from
    - Computer Science
  - Participants consisted of a mixture of academics and researchers from
    - Computer Science
    - Business Management
    - Psychology

Overview of our ABSS Development Framework



Defining the Objectives

- Define objectives in relation to the aim of the study
  - Combination of a literature review and focus group discussions

- How can test these objectives?
  - Consider relevant experimental factors and responses
    - Experimental factors are simulation inputs that need to be set initially to test different scenarios related to the objectives
    - Responses are simulation outputs that provide insight and show to what level the objectives have been achieved
  - Hypotheses are very helpful for defining an initial set of experimental factors and responses

Illustrative Example

- Aim
  - Study normative comparison in an office environment

- Objectives
  - Answer the following questions:
    - What are the effects of having the community influencing the individual?
    - What is the extent of impact (significant or not)?
    - Can we optimise it using certain interventions?

  - Hypotheses
    - Peer pressure leads to greener behaviour
    - Peer pressure has a positive effect on energy saving

Illustrative Example

- Experimental factors
  - Initial population composition
    - Categorised by greenness of behaviour
  - Level of peer pressure
    - "individual apportionment" vs. "group apportionment"

- Responses
  - Actual population composition
    - Capturing changes in greenness of behaviour
  - Energy consumption
    - Of individuals and at average

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Defining the Scope

- We are interested in specifying the model scope
  - Requires some initial knowledge gathering
    - Literature review and observation of the existing system
  - With the help of the knowledge gathered one can then define the scope of the model by defining a scope table
    - Focus group discussions

Defining the Scope

- We are interested in specifying the model scope
  - In order to make decisions about including/excluding elements one needs to answer the following questions:
    - What is the appropriate level of abstraction for the objective(s) stated before? This would define the level of abstraction acceptable
    - Do the elements have a relevant impact on overall dynamics of the system? Then they should be included
    - Do the elements show similar behaviour to other elements? Then they should be grouped

Illustrative Example

- Scope
  - We decided that "transparency" would be the key driver for our decision making; we want to abstract/simplify as much as possible while still keeping a "realistic model"
  - In order to have easy access to data we decided to use our own offices as the data source

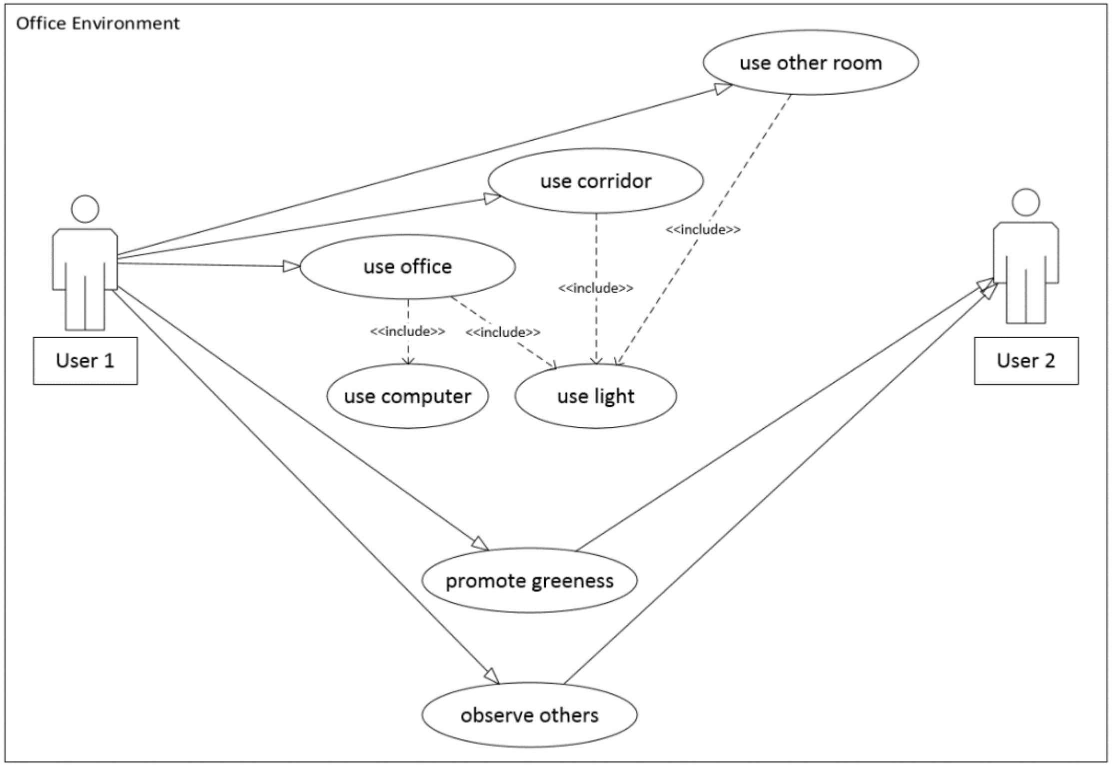
Category		Element	Decision	Justification
Actor		Staff	Include as group (User)	Regularly occupy the office building
		Research fellows		
		PhD students		
		UG+MSc students	Exclude	Do not have control over their work environment
		Visitors	Exclude	Insignificant energy use
Physical Environment	Appliance	HVAC (Heating + Ventilation + Aircon) system	Exclude	We only need one major energy consumer to test the theory; we decided to go for electricity
		Lighting	Include	Interacts with users on a daily basis; controlled by user
		Computer	Include	Interacts with users on a daily basis; controlled by user
		Monitor	Exclude	Modelled as part of the computer
		Continuously running appliances	Exclude	Constant consumption of electricity; not controllable by individuals
		Personal appliances	Exclude	No way to measure consumption
	Weather	Temperature	Exclude	Not necessary for proof-of-principle
		Natural light level	Exclude	Not necessary for proof-of-principle
	Room	Office	Include	Location where electronic appliances are installed
		Lab	Exclude	Mainly used by UG+MSc
		Kitchen	Include as group (Other Room)	Common areas frequently used by "users"
		Toilet		
		Corridor	Include	Commonly used when "users" move around
Social / Psychological Aspect		Comparative feedback	Include	Effective strategy to reduce energy consumption in residential building
		Informative feedback	Include	Effective strategy to remove barriers in performing specific behaviour
		Apportionment level	Include	Potential strategy to reduce energy consumption in office building
		Freeriding	Include	Behaviour that differentiate two apportionment strategy
		Sanction	Include	Factor to encounter freeriding behaviour
		Anonymity	Include	Factor to encounter freeriding behaviour

Defining Key Activities

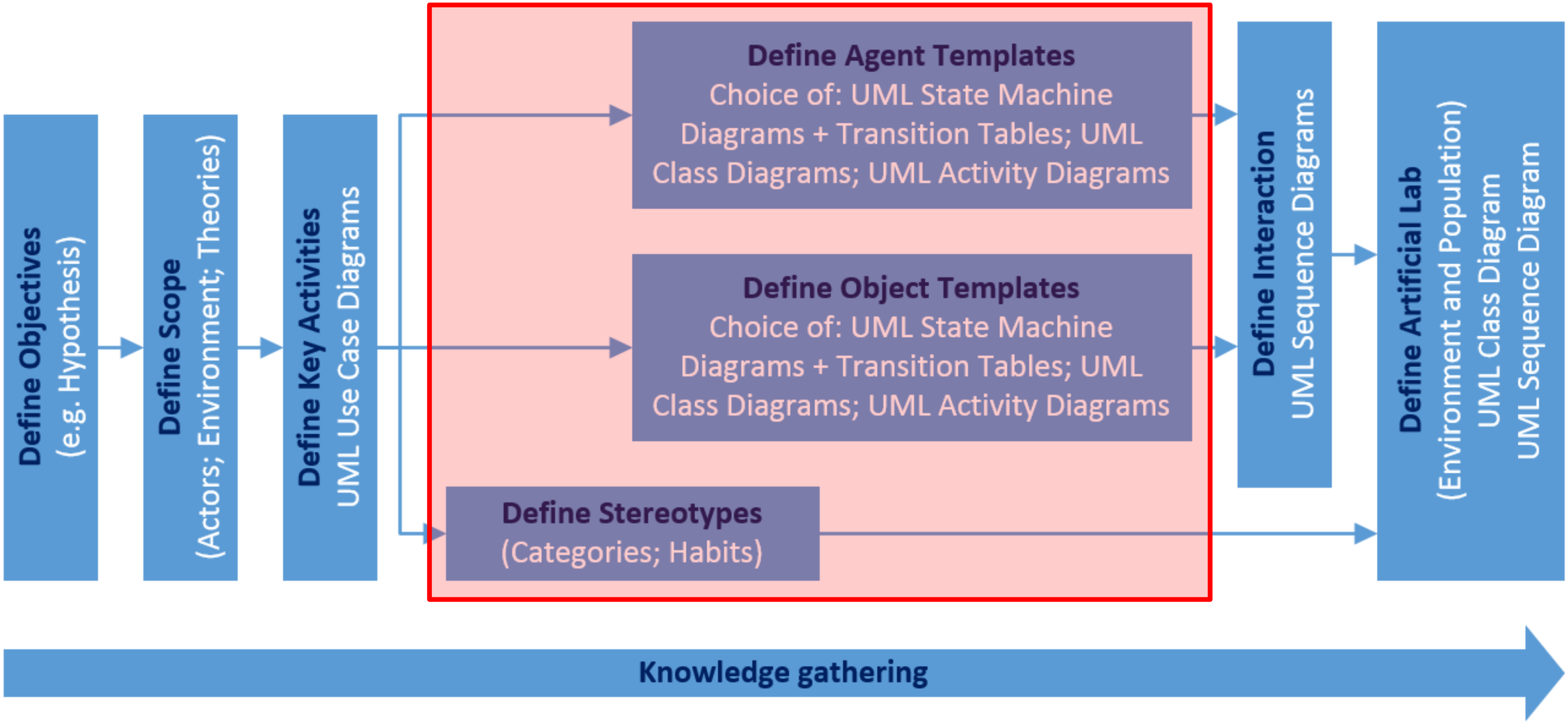
- Interaction can take place between actors and between an actor and the physical environment it is in
- Capturing these at a high level can be done with the help of UML use case diagrams
  - When using use case diagrams in an ABSS context the actors are inside the system; they represent the humans that interact with each other and the environment; the system boundaries are the boundaries of the relevant locations
- Derived through focus group discussions

Illustrative Example

- System boundaries
  - Building boundaries of the office environment



Overview of our ABSS Development Framework



Defining Stereotypes

- In order to be able to represent a specific population in our simulation models we define stereotypes that allow us to classify the members of this population
  - Option 1: Stereotype templates (derived from focus group discussions)
  - Option 2: Utility function (derived from the literature)
- Data for classifying the population can later be collected through surveys

Illustrative Example

- We identified two categories of stereotypes
  - Habits for work time
    - Arrival time at office
    - Leaving time from office
  - Habits for Energy Saving Awareness
    - Energy saving awareness
    - Likelihood of switching off unused electric appliances
    - Likelihood of promoting greenness

Illustrative Example

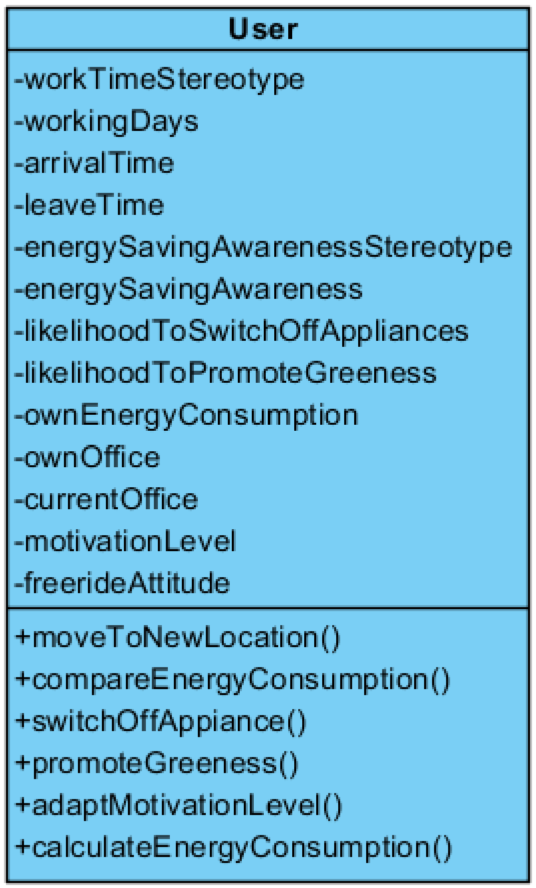
Stereotype	Working days	Arrival time	Leave time
Early bird	Mon-Fri	5am-9am	4pm-7pm
Time table complier	Mon-Fri	9am-10am	5pm-6pm
Flexible worker	Mon-Fri	10am-1pm	5pm-11pm
Hardcore worker	Mon-Fri + Sat	8am-10am	5pm-11pm

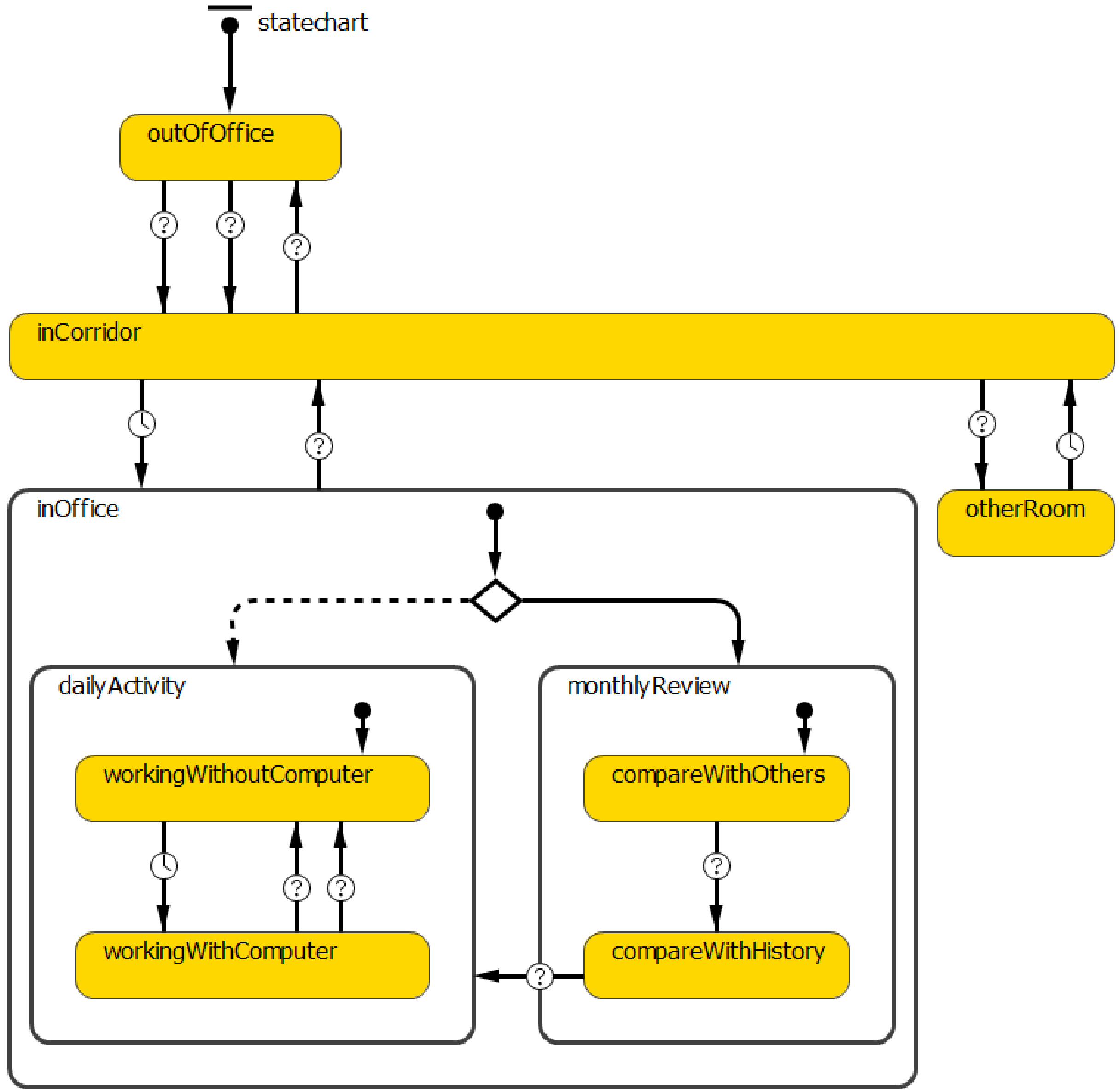
Stereotype	Energy saving awareness [0-100]	Probability of switching off unnecessary appliances	Probability of sending emails about energy issues to others
Environmental champion	95-100	0.95	0.9
Energy saver	70-94	0.7	0.6
Regular user	30-69	0.4	0.2
Big user	0-29	0.2	0.05

Defining Agent and Object Templates

- Actor types identified in scope table
  - We have to develop an agent template
- Physical environment identified in the scope table
  - We have to develop object templates where appropriate
  - For other things we need to consider other modelling methods
- Relevant UML diagram types:
  - UML class diagram (to define structure)
  - UML state machine diagram (to define behaviour)
  - UML activity diagram (to define logic)

- Derived through focus group discussions





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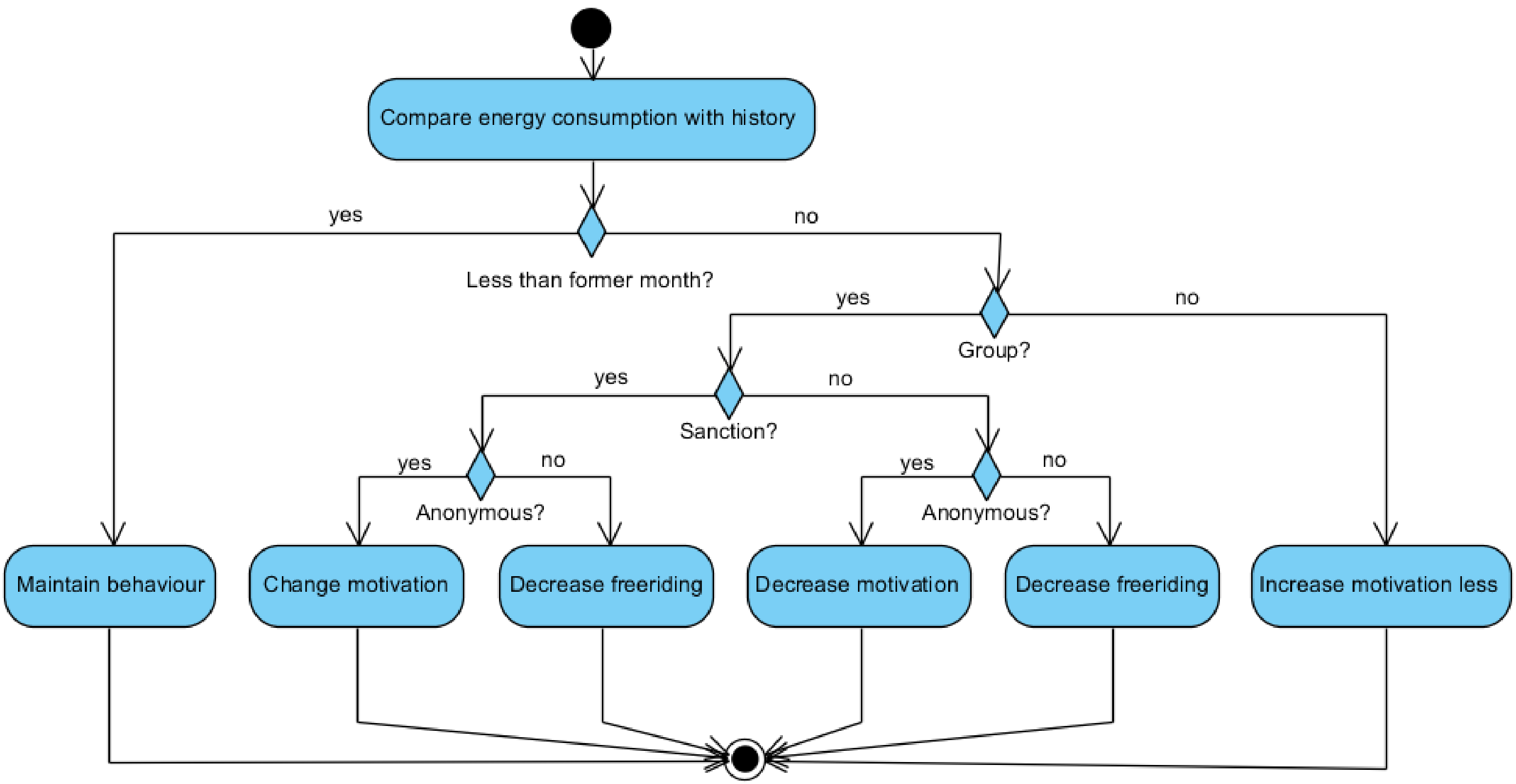
Illustrative Example

From state	To state	Triggered by	When?
outOfOffice	inCorridor	Condition	At typical arrival time during the working week for all
outOfOffice	inCorridor	Condition	At typical arrival time on Saturdays for hard-core workers only
inCorridor	outOfOffice	Condition	At typical leave time
inCorridor	inOffice	Timeout	At average after 5 minutes
inOffice	inCorridor	Condition	At random while at work or when leaving
inCorridor	otherRoom	Condition	At random while at work
otherRoom	inCorridor	Timeout	At average after 10 minutes
…	…	…	…

Illustrative Example



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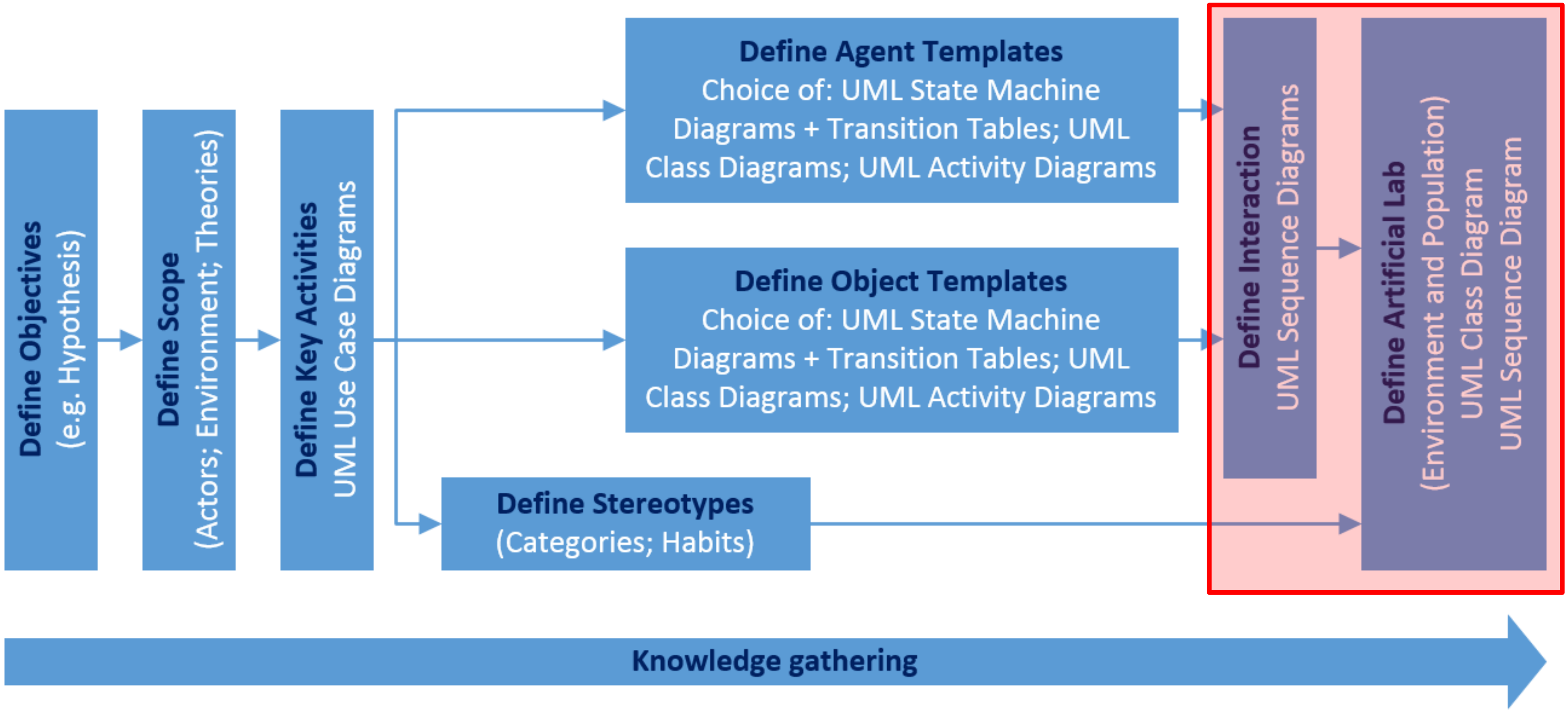

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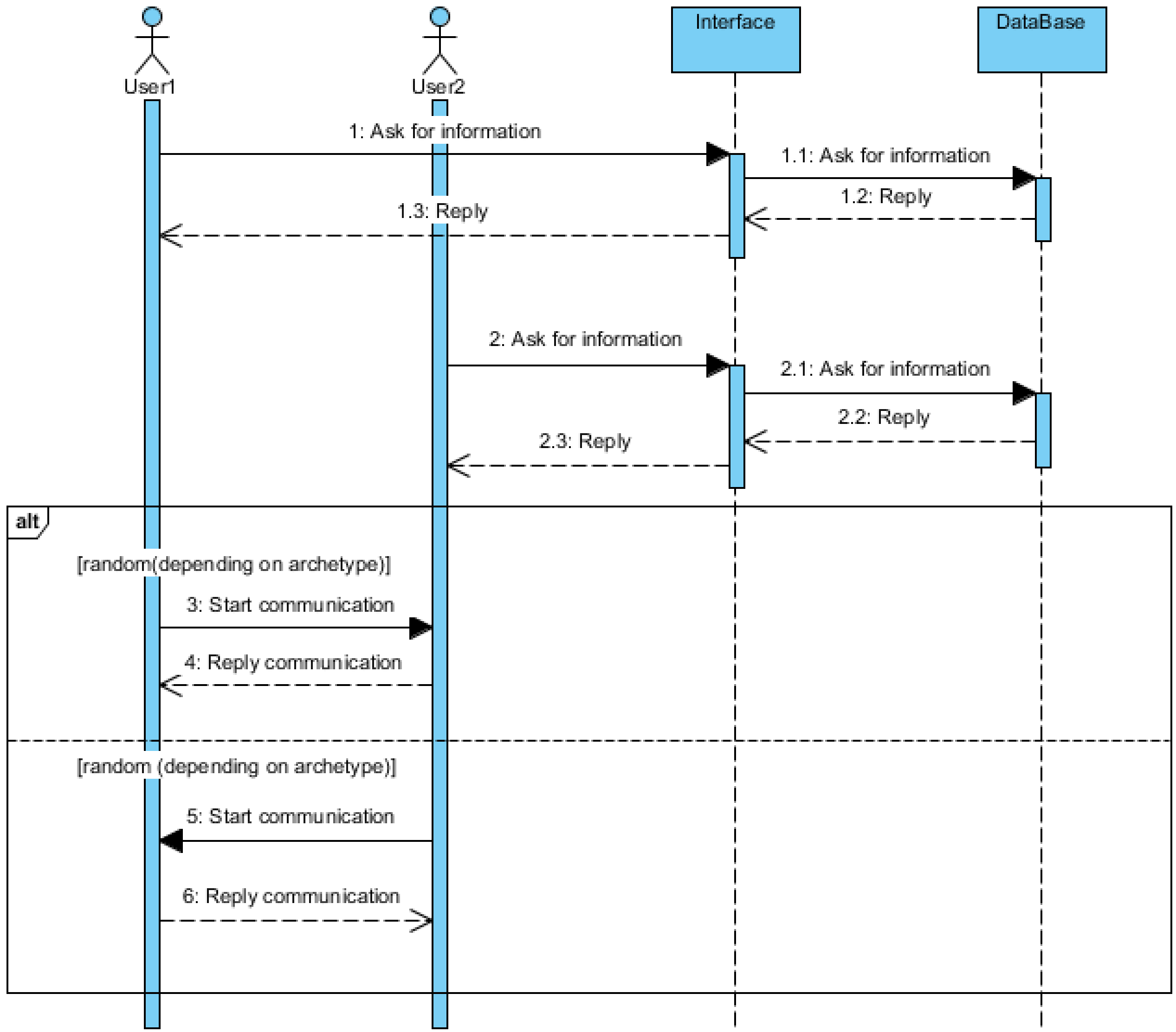
Defining Interactions

- Capturing interactions in more detail can be done by using UML sequence diagrams; this can be used to further specify use cases that involve direct interactions (usually in form of message passing) between entities (agents and objects)

- Derived through focus group discussions

Compare energy consumption with others



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Defining the Artificial Lab

- Finally we need to define an environment in which we can embed all our entities and define some global functionality
  - We need to consider things like:
    - Global variables (e.g. to collect statistics)
    - Compound variables (e.g. to store a collection of agents and objects)
    - Global functions (e.g. to read/write to a file)
  - We also need to make sure that we have all variables in place to set the experimental factors and to collect the responses we require for testing our hypotheses

- Derived through focus group discussions and by looking at the list of objectives and the scope table

Illustrative Example

Artificial Lab
-schoolEnergyConsumption -numEnvironmentalChampions -numEnergySavers -numGeneralUsers -numBigUsers -isDataApportinmentAvailable -isApportionmentLevelGroup -isInformativeFeedbackAvailable -isAnonymityGiven -isSanctionImplemented -users[] -offices[] -lights[] -computers[]
+calculateSchoolConsumption() +writeDataToFile() +findOffice()

Defining the Artificial Lab

- Sometimes it can be helpful to create a sequence diagram to visually show the order of execution describing the actions taken on various elements at each step of the simulation from a high level approach
- The way and order in which all entities are initialised, as well as the way and order how they are updated and how their interactions are handled, is often not trivial and a major source of artefacts

Implementation

- We now have a well structures and well documented conceptual model that is easy to maintain and easy to extend

- The information gathered is sufficient for the implementation
  - Can be done by a modeller who is part of the team
  - Can be passed on to a software engineer

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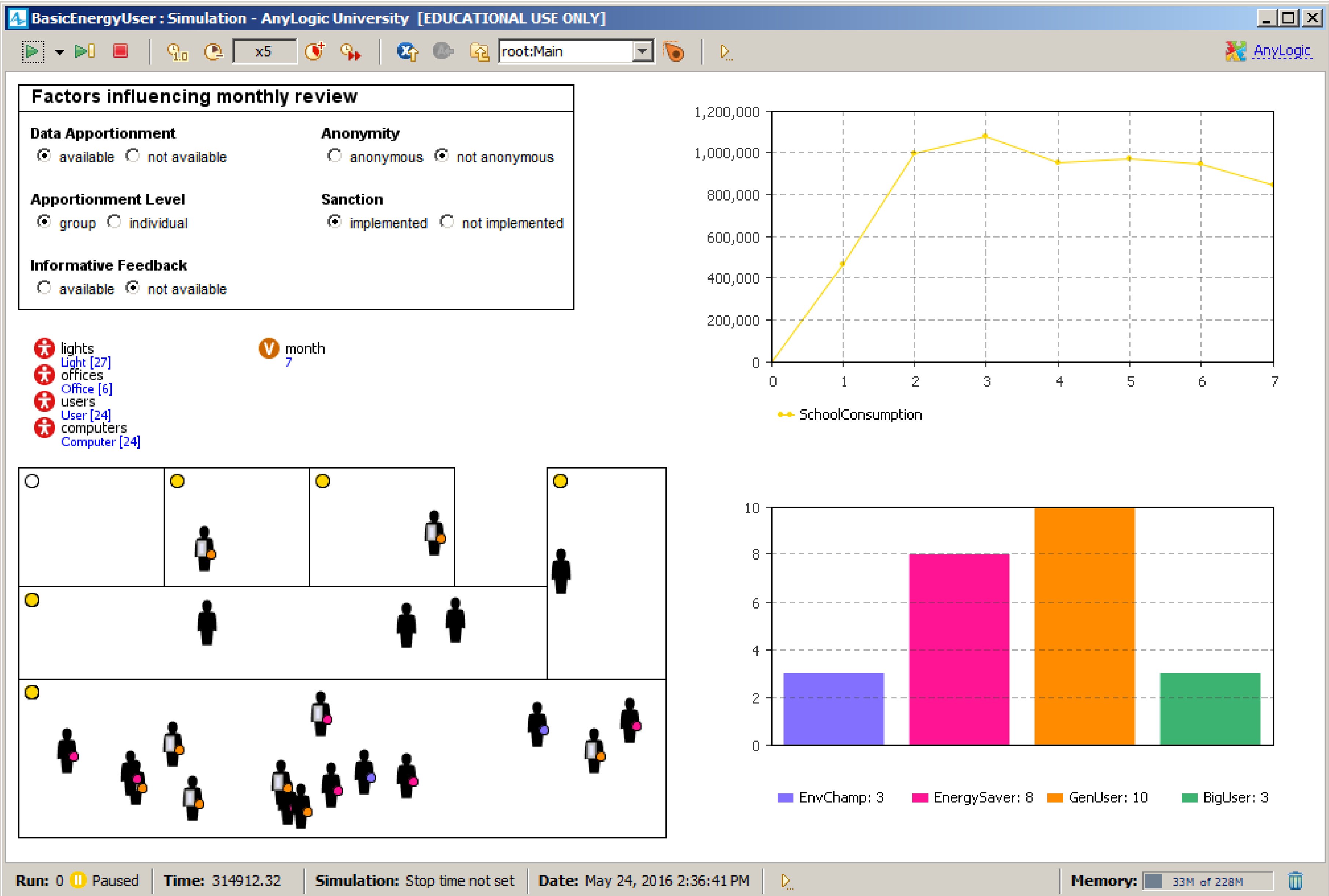

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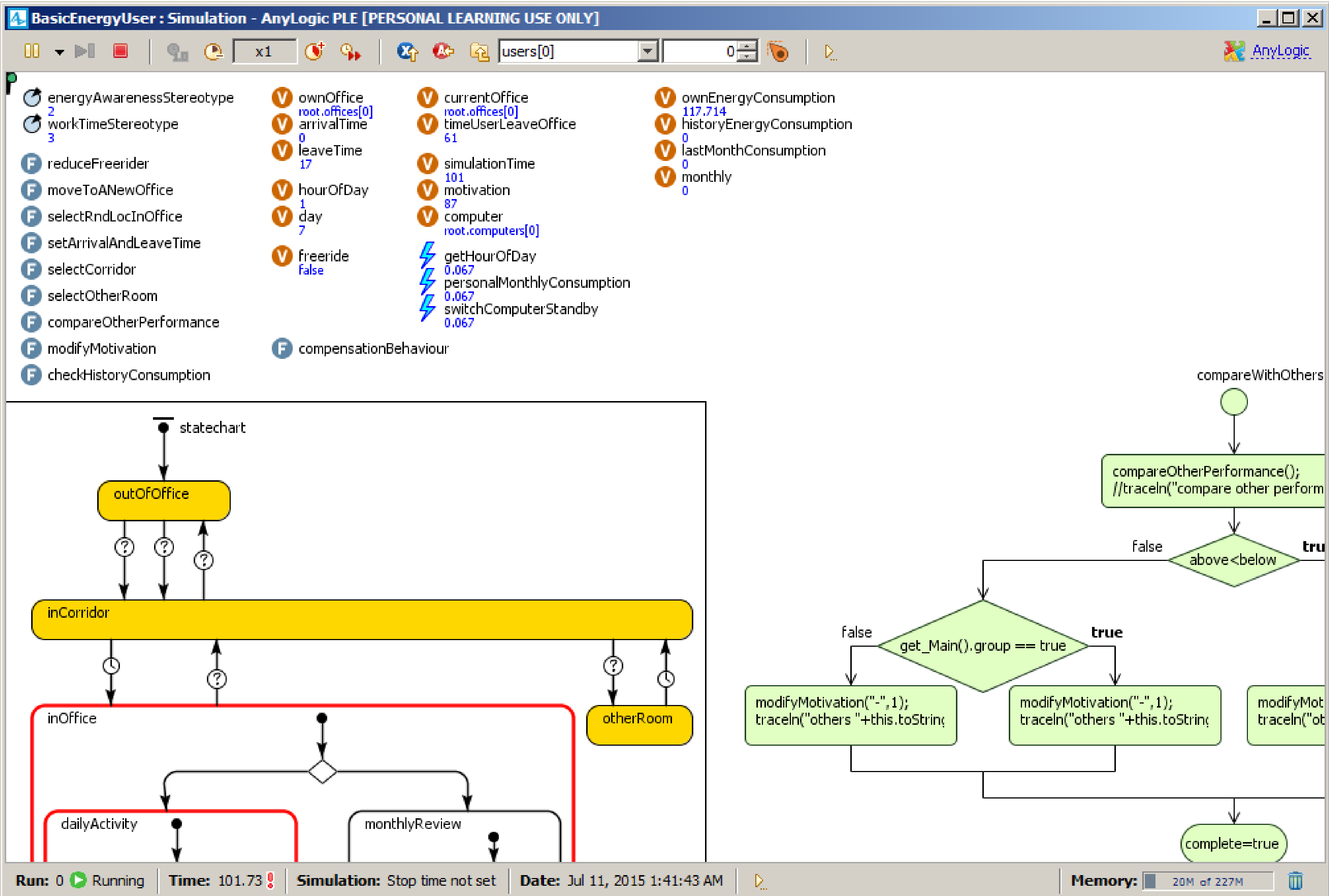
BasicEnergyUser : Simulation - AnyLogic PLE [PERSONAL LEARNING USE ONLY]
x1
users[0]
0
AnyLogic
energyAwarenessStereotype
2
workTimeStereotype
3
reduceFreerider
moveToANewOffice
selectRndLocInOffice
setArrivalAndLeaveTime
selectCorridor
selectOtherRoom
compareOtherPerformance
modifyMotivation
checkHistoryConsumption
ownOffice
root.offices[0]
arrivalTime
0
leaveTime
17
hourOfDay
1
day
7
freeride
false
compensationBehaviour
currentOffice
root.offices[0]
timeUserLeaveOffice
61
simulationTime
101
motivation
87
computer
root.computers[0]
getHourOfDay
0.067
personalMonthlyConsumption
0.067
switchComputerStandby
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lastMonthConsumption
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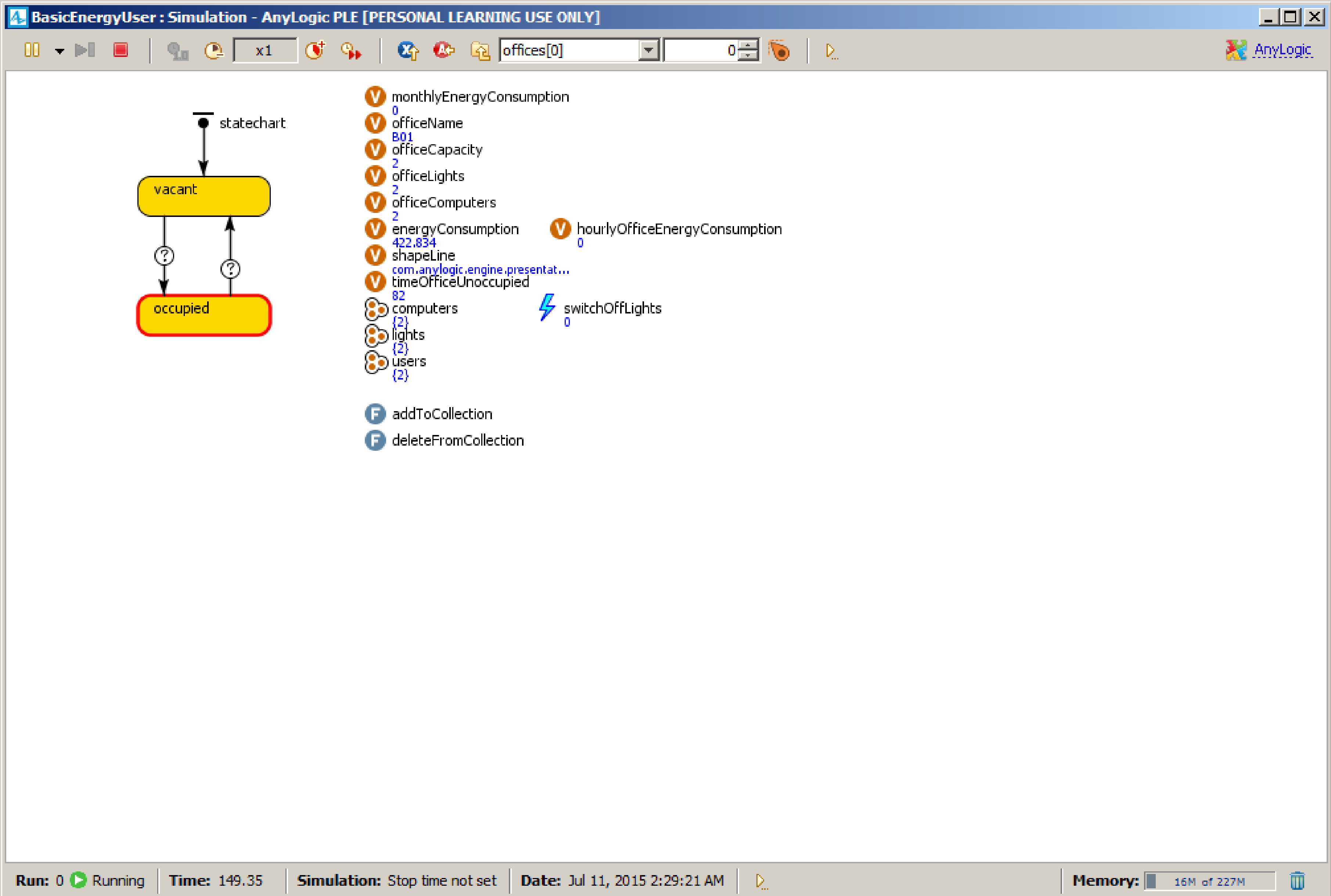

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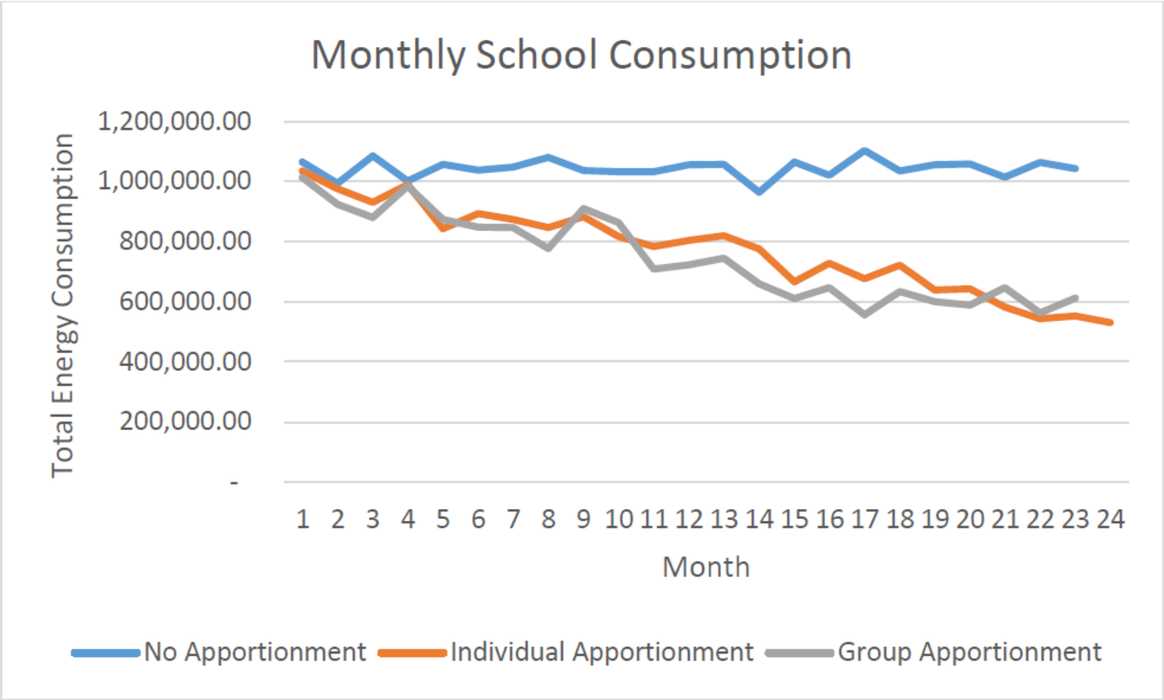
Experimentation

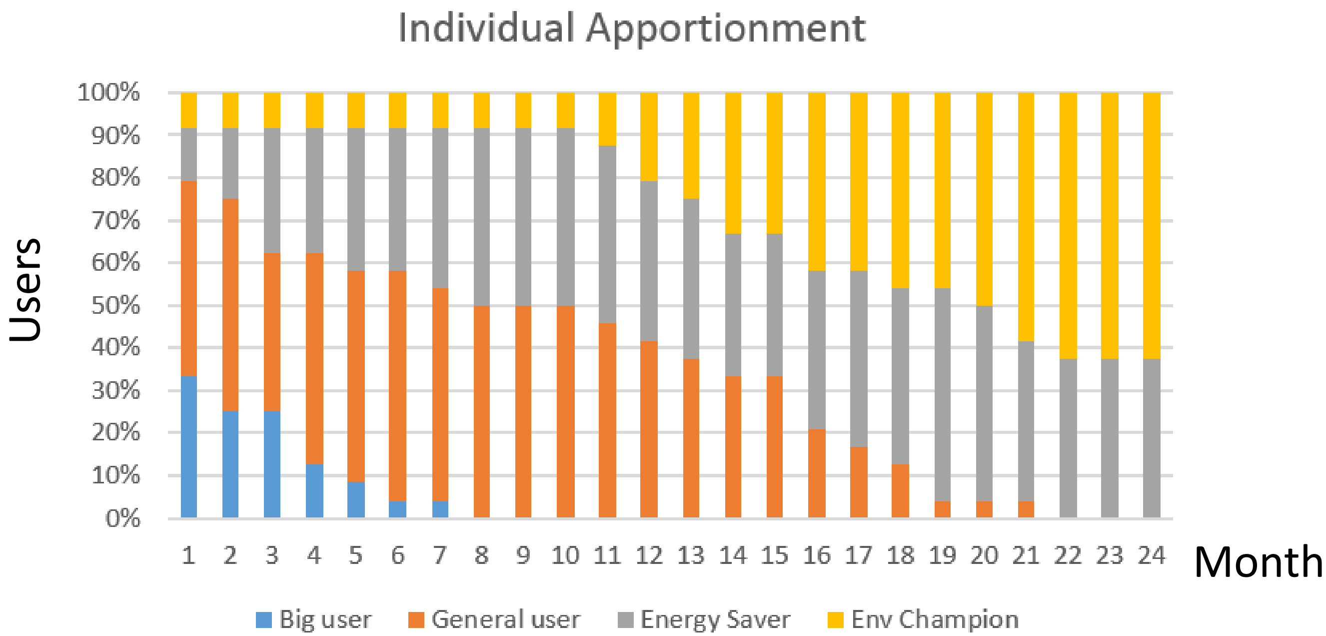
- Do some validation before running any experiments
  - Sensitivity analysis (there are many different ways of doing it)
  - Creating a base scenario and comparing simulation results to real world historic data (if available) or discuss results with domain experts
  - Show your model / results to domain experts

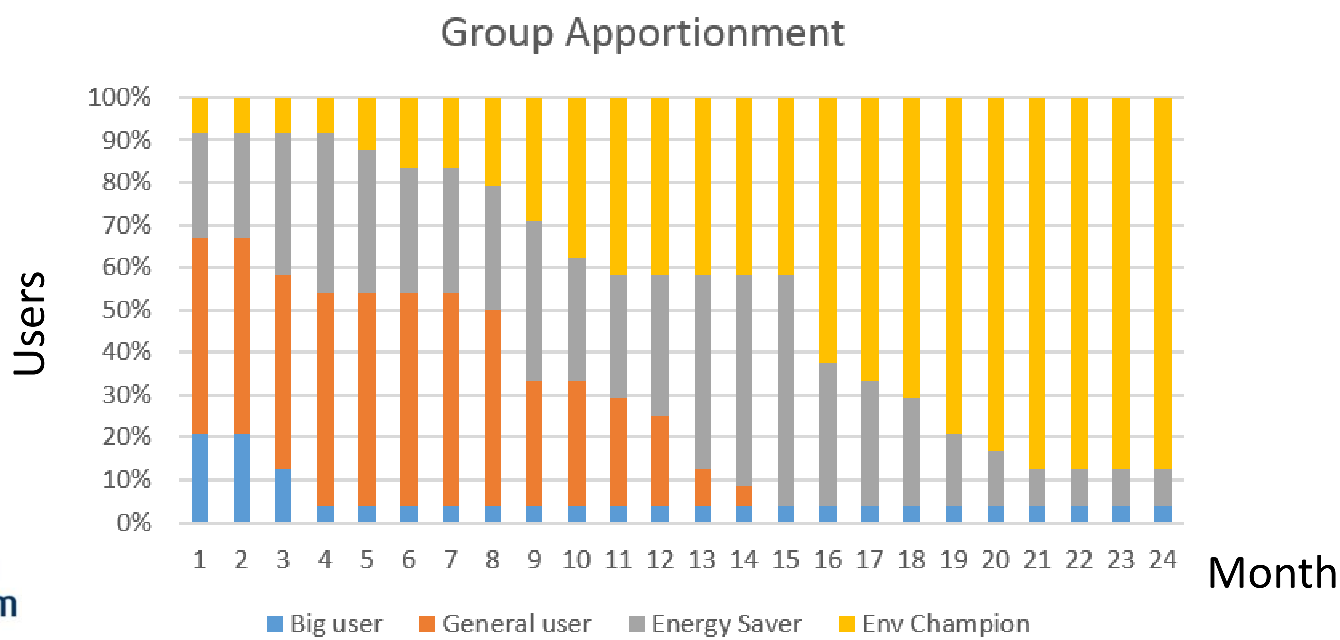
- Run experiments required to test the objectives define in your conceptual model
  - All required experimental factors and responses for running the planned experiments should be available

Illustrative Example

- Scenarios
  - Data apportionment varies; apportionment level varies; anonymous; informative feedback available; sanction implemented




Individual Apportionment
Users
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Month
Big user
General user
Energy Saver
Env Champion


Group Apportionment
Users
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Month
Big user
General user
Energy Saver
Env Champion

Case Study

- Technology Adoption in the Transition to a Smart Grid: The Case of Photovoltaic (PV) System Adoption in the UK

after Snape (2015)

Thanks to Grazziela Figueredo and Richard Snape for helping me with the case study

Case Study
Knowledge Gathering

- Focus groups:
  - Facilitator from
    - School of Computer Science
  - Participants consisted of a mixture of academics and researchers from
    - School of Engineering and Sustainable Development
    - Advanced Data Analysis Centre
    - School of Psychology

- Background knowledge from related project
  - Reverse engineering to create a concise documentation

Case Study
Defining the Objectives

- Aim
  - Study the adoption patterns of PV cells on people's roof-tops
- Objectives
  - Study the effect of the introduction of Feed-in-Tariff (FiT)
  - Study the effect of change to FiT
  - Study the effect of neighbourhood observation
- Hypotheses
  - Introduction of FiT would incentivise a high rate of adoption
  - If a system is too difficult to install > this will act like a block
  - Observation of neighbours would encourage individuals to adopt

Case Study

Defining the Objectives

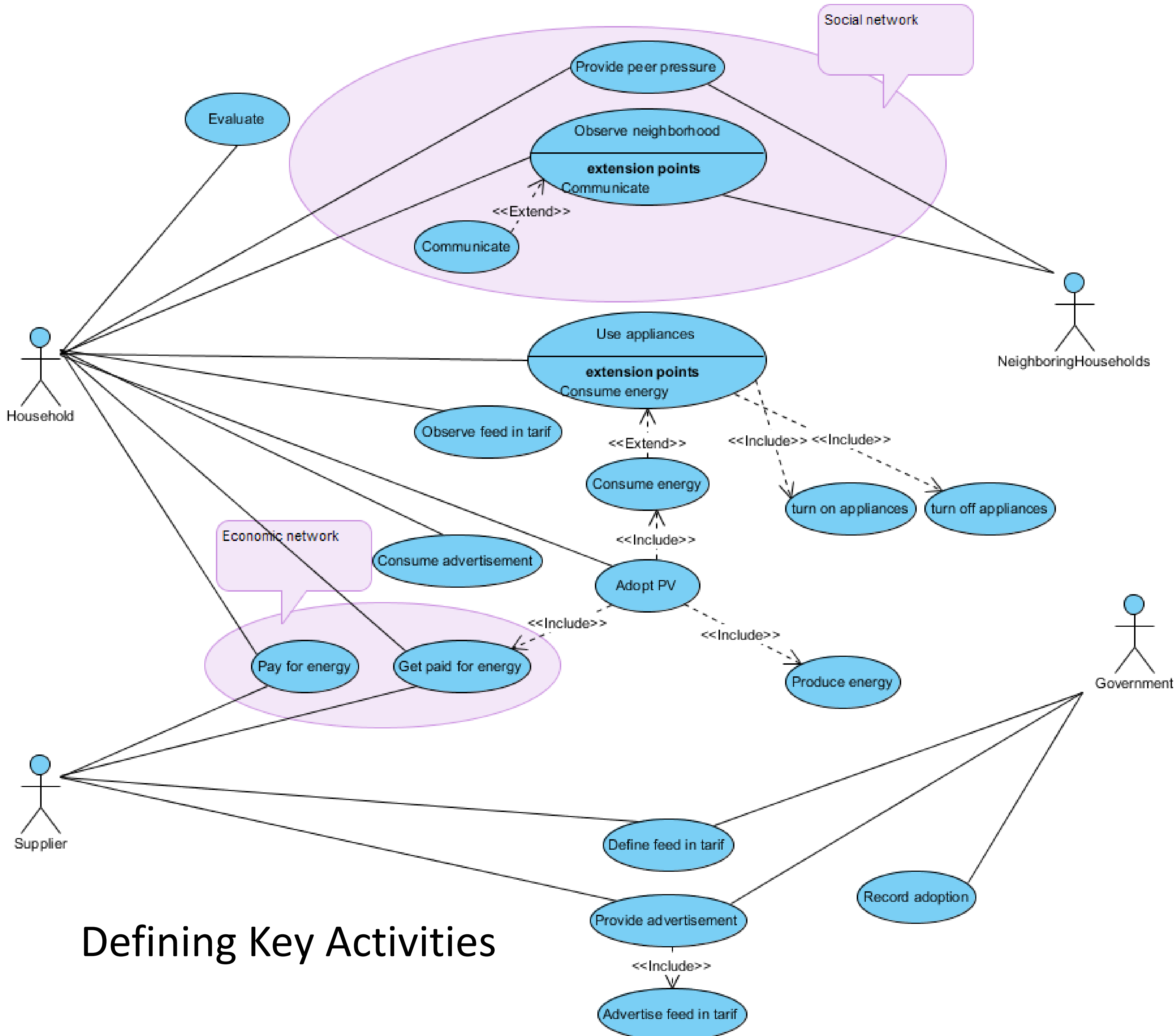
- Experimental factors
  - Initial population composition
    - Categorised by greenness of behaviour
  - Observation radius

- Responses
  - Actual population composition
    - Capturing changes in greenness of behaviour
  - % adoption

Case Study
Defining the Scope

- Scope
  - Explanatory model
    - Answer real world policy questions
  - Low level (individual households)
    - But ...
      - Computational limitations (limited use of HPC)
      - Manpower and time constraints for conducting the study
      - Data availability limited

Category		Element	Decision	Group	Group name	Justification
Actor	1	Household	include			
	2	Houshold member (occupant)	exclude			Considered by household (abstraction)
	3	Installer	exclude			
	4	Government	include	4+5+12+13	?	Part of the environment
	5	Electricity supplier	include	4+5+12+13	?	
	6	Manufacturer	exclude			
	7	Neighbouring household	include			
	8	Neighbouring household member	exclude			Considered by neighbouring household (abstraction)
	9	Neighbourhood	exclude			
	10	Consumer group	exclude			Considered by individual owned PVC systems
	11	Community	exclude			Considered by individual owned PVC systems
	12	Firm	include as group	4+5+12+13	?	
	13	Regulator	include as group	4+5+12+13	?	
Technology / Appliances	14	PVC	include as group	14+15+16	?	
	15	Inverter	include as group	14+15+16	?	
	16	Meter (smart)	include as group	14+15+16	?	
	17	Computer	include as group	17+18+19+20+21	Household appliances	Represents "Demand"
	18	Light	include as group	17+18+19+20+21	Household appliances	Represents "Demand"
	19	Cooker	include as group	17+18+19+20+21	Household appliances	Represents "Demand"
	20	Fridge	include as group	17+18+19+20+21	Household appliances	Represents "Demand"
	21	Heating	include as group	17+18+19+20+21	Household appliances	Represents "Demand"
Weather	22	Sunshine / natural light	include			Part of the environment
	23	Temperature	include			Part of the environment
	24	Clouds	include			Part of the environment
Buildings / Rooms	25	House orientation (spatial model)	include			
	26	Shading	exclude			Not enough computing power
	27	Visibility of PVCs	include			Using approximation
	28	Density of housing	include			Using approximation
	29	House interior	exclude			
Psychological factors	30	Comparative feedback (motivation)	include			
	31	Reaction to incentives (economic rationality/sensitivity)	include			
	32	Level of greeness	include			
	33	Family structure (who makes decisions)	exclude			
	34	Perception of risk	exclude			Consider for future research
	35	Affectiveness	include			
	36	Perception of urgency (rushed decision)	include			
	37	Advertising effectiveness	include			
	38	Word of mouth (networking)	include			
	39	Obervation (feeds perceived norm)	include			
Networks	40	Physical network	exclude			Network not overloaded in UK
	41	Comms network	exclude			No smart network
	42	Economic network (supply chain)	include			
	43	Social network	include			
Misc	44	Energy	exclude			Not explicitely modelled > output; not relevant for UK



Defining Key Activities

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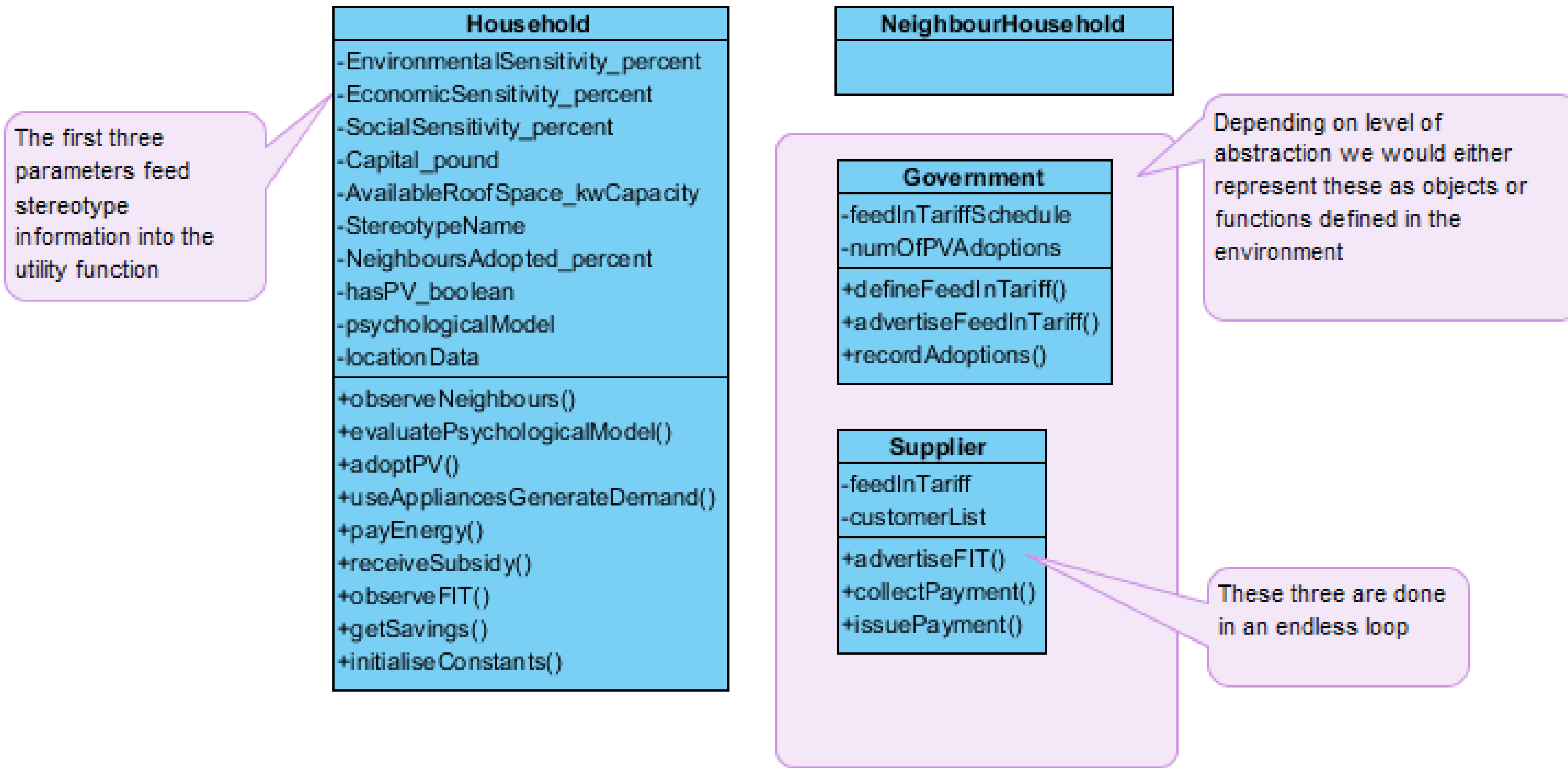
Case Study

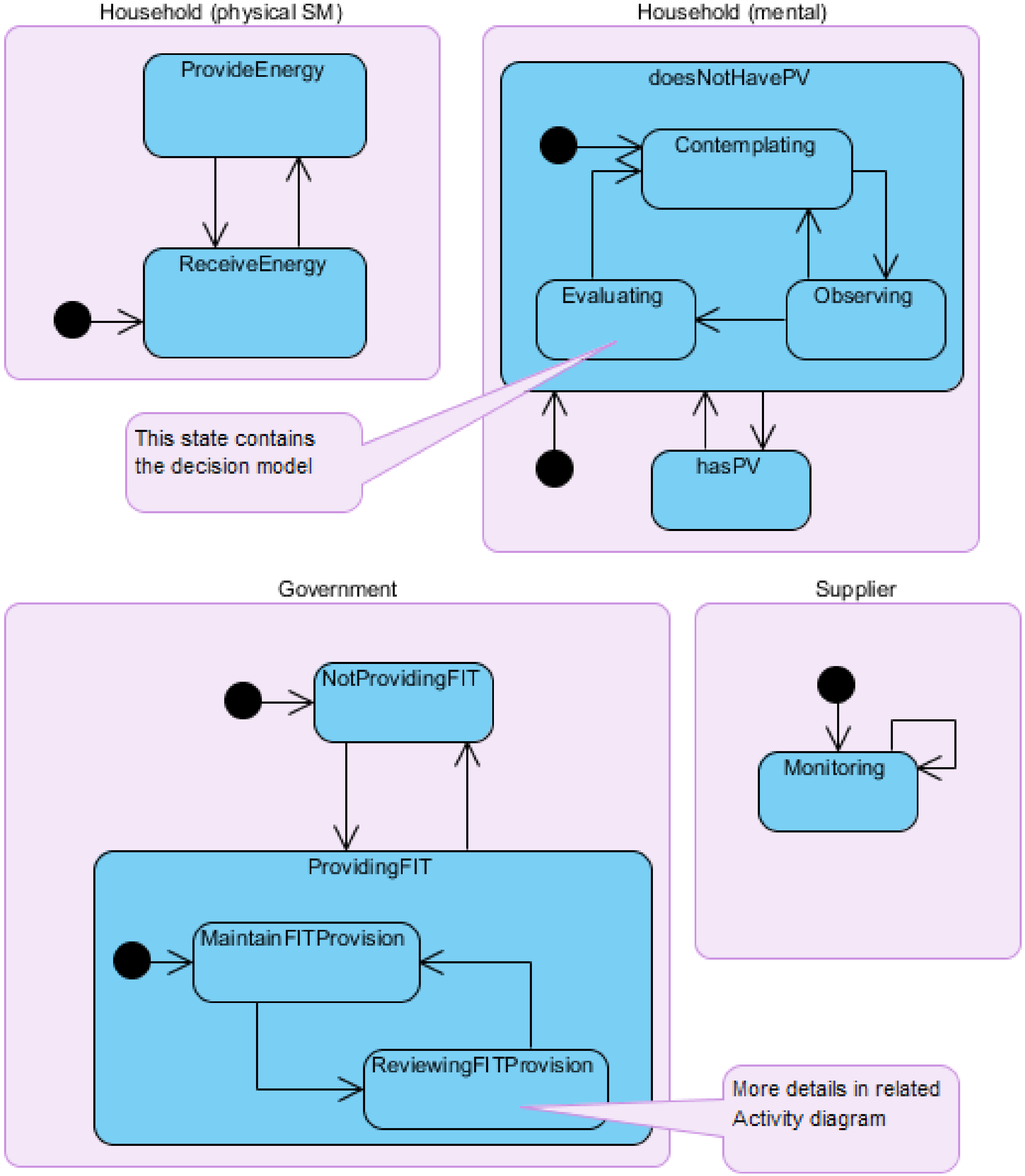
Defining Stereotypes

- We identified several categories of stereotypes
  - Structural factors:
    - Demographics
      - Type of occupancy (owner occupier; private rented; social housing)
      - Capital
  - Psychological factors:
    - DEFRA's occupant behaviour model (7 stereotypes)
      - Likelihood of being social
      - Likelihood of being environmental friendly
      - Likelihood of being economically driven
      - Adoption likelihood = $k_x*w_{social}+k_y*w_{econ}+k_z*w_{envir}$ (k=observation; w=weight)

Case Study

Defining Agent and Object Templates





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Case Study
Defining Agent and Object Templates

- Details of the "Evaluating" state within the Household (mental) state machine diagram
  - Decision model based on Social Cognitive Theory (Bandura 1986)

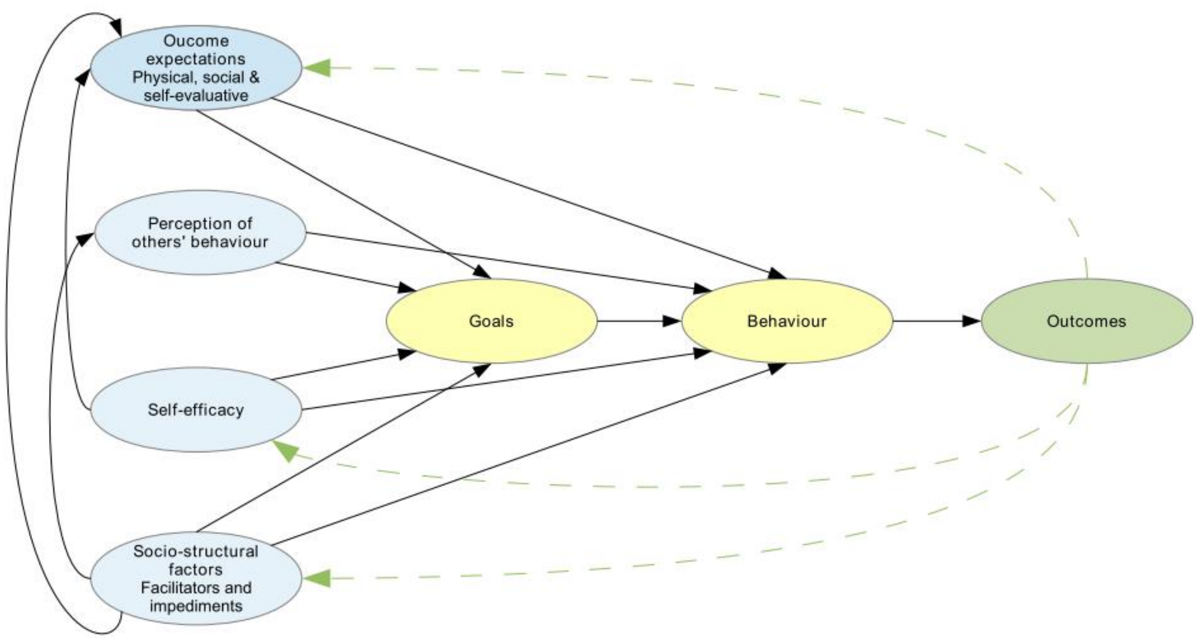
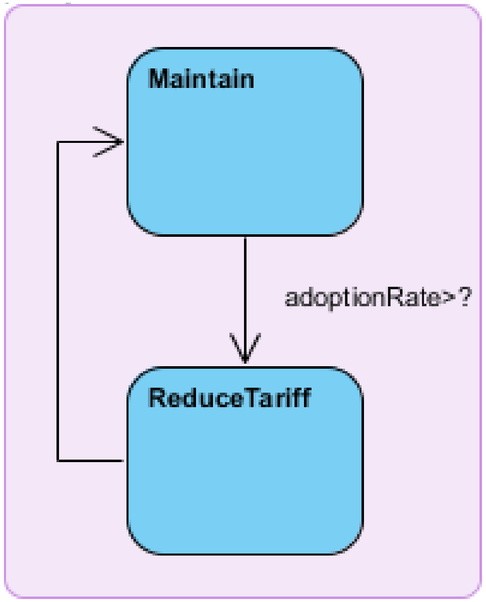


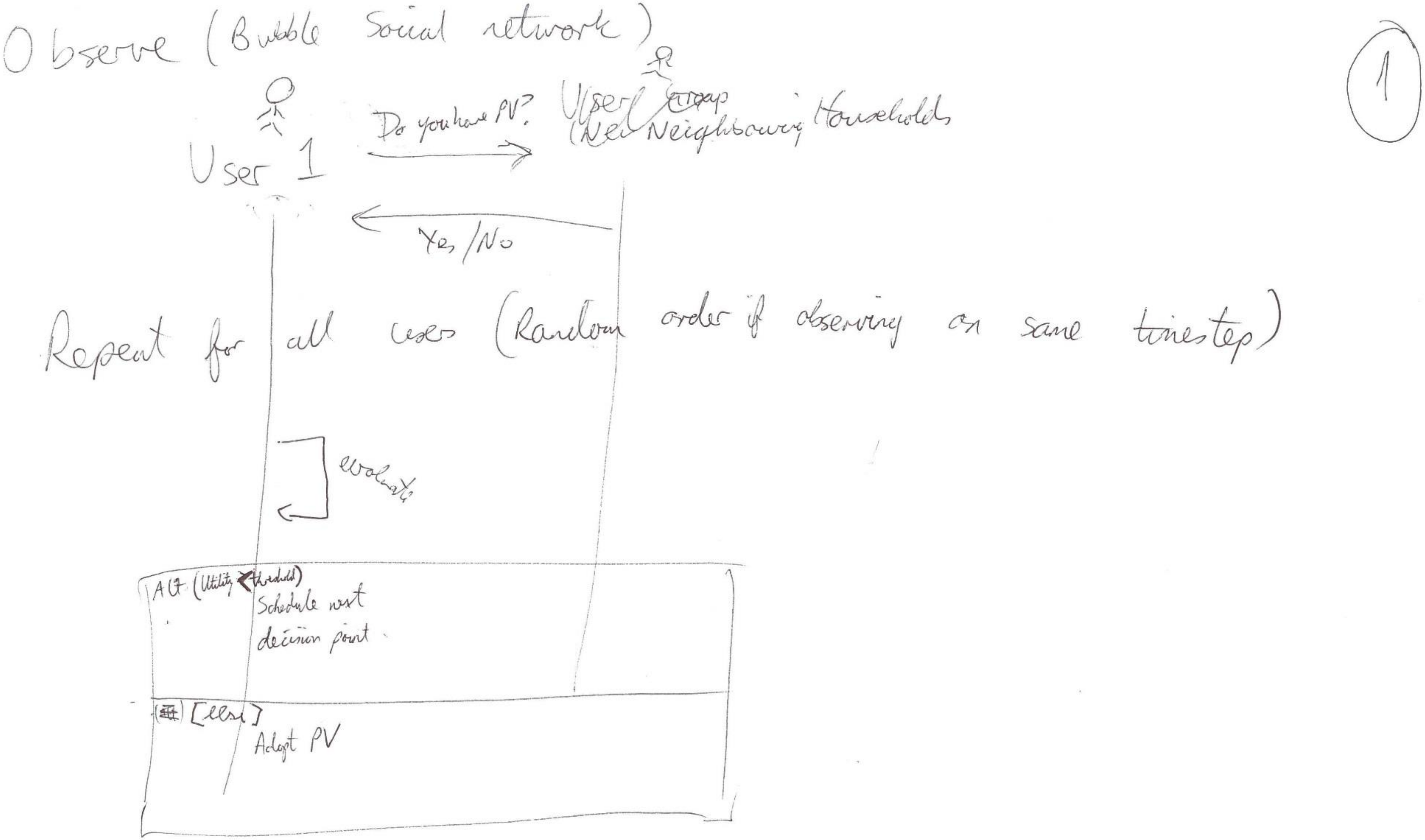
Figure 6.6: The SCT model. Constructs combine to influence a person's goal setting and behaviour. In turn a behaviour results in an outcome, which itself influences the original constructs (shown here in green).

Case Study

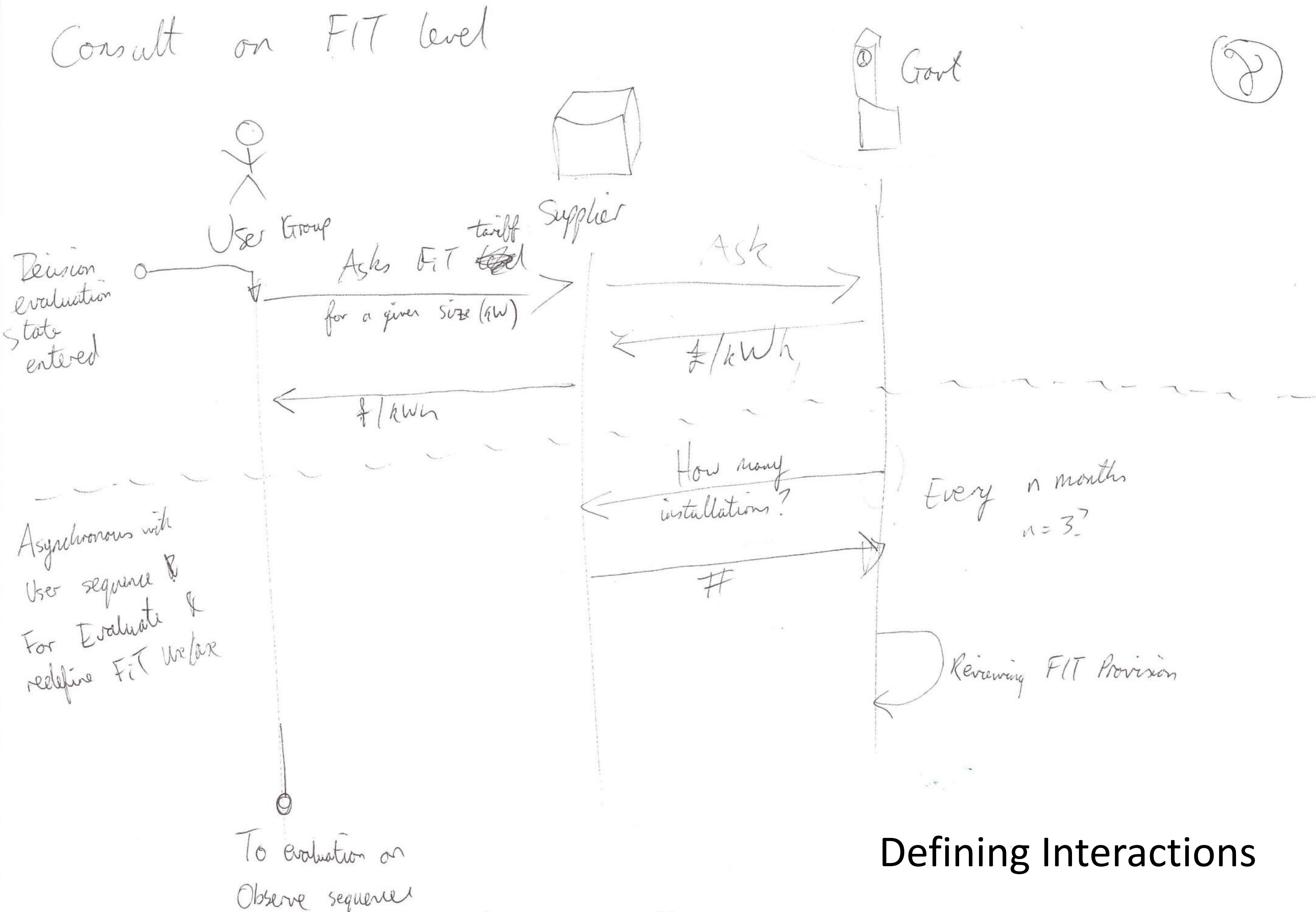
Defining Agent and Object Templates

- Details of the "ReviewingFITProvision" state within the Government state machine diagram
  - Activity diagram





Defining Interactions



Defining Interactions

Case Study

Defining the Artificial Lab

Artificial Lab
-numHouseholds -Geography -numPerStereotype[] -numSuppliers -networkType -weater -choiceModel -isOfferingFiT -initialTariffLevels -FiTAdvertAndUpdateFrequency -capitalPerHousehold -demandPerHousehold
+countAdopters() +countInstalledCapacity() +initialiseHouseholds() +initialiseNetworks() +calculateEnergyProduction() +calculateEnergyConsumption()

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Case Study

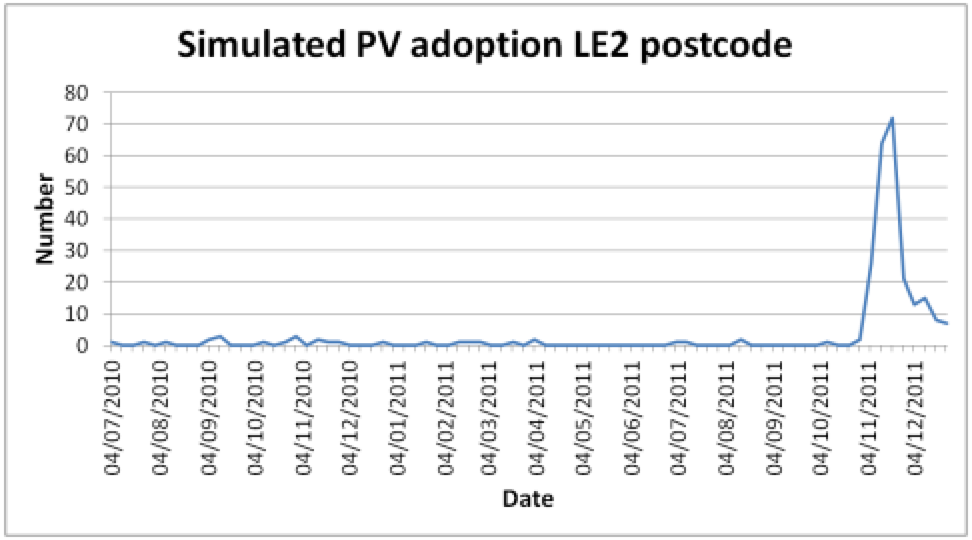
Defining the Artificial Lab

Initialisation Sequence

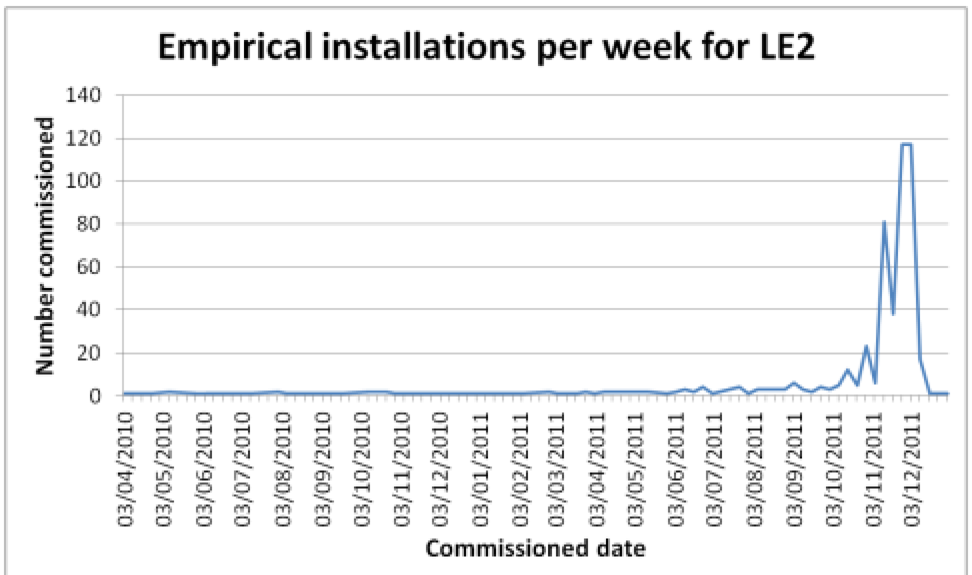
initialise Geography
↓
initialise Govt
↓
initialise Suppliers
↓
initialise Households ~~add~~

~~initialise Networks~~ → add To Geography → initialise Networks → main loop

(see sequence diagrams)



(a) Modelling spike in adoption using urgency as a component of outcome expectation (LE2 area)



(b) Observed spike in adoption due to policy announcement in late 2011 (LE2 are)

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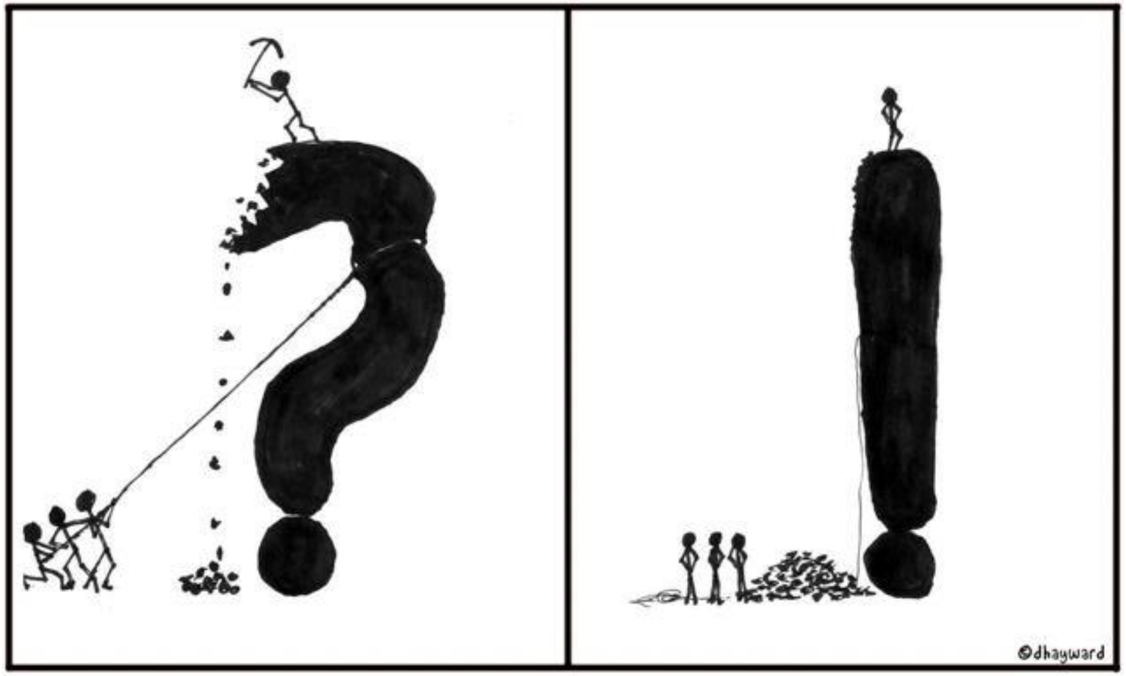
Questions / Comments



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