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

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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

http://www.cs.nott.ac.uk/~pszps/research.html
Project Examples: Urban Modelling

- Sustaining Urban Habitats: An Interdisciplinary Approach

http://www.cs.nott.ac.uk/~pszps/research.html
Project Example: Climate Change

- HCAM: Hybrid Climate Assessment Modelling

http://www.cs.nott.ac.uk/~pszps/research.html
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
Agent-Based Modelling

- Heroes and Cowards Game: All heroes
Agent-Based Modelling

- Heroes and Cowards Game: All heroes
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
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

  – Theory driven

  Communicate the model
  Formulate the question
  Analyze the model
  Assemble hypothesis
  Implement the model
  Choose model structure
  Parametrize the model

Grimm and Railsback (2005)

AnyLogic Help (2013)
Engineering Agent-Based Social Simulations

Siebers and Klügl (in press)
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
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
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 stakeholders
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

Define Objectives
(e.g. Hypothesis)

Define Scope
(Actors; Environment; Theories)

Define Key Activities
UML Use Case Diagrams

Define Agent Templates
Choice of: UML State Machine Diagrams + Transition Tables; UML Class Diagrams; UML Activity Diagrams

Define Object Templates
Choice of: UML State Machine Diagrams + Transition Tables; UML Class Diagrams; UML Activity Diagrams

Define Interaction
UML Sequence Diagrams

Define Artificial Lab
(Environmen and Population)
UML Class Diagram
UML Sequence Diagram

Define Stereotypes
(Categories; Habits)

Knowledge gathering
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

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(e.g., Hypothesis)

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Define Interaction
UML Sequence Diagrams

Define Artificial Lab
(Environment and Population)

UML Class Diagram
UML Sequence Diagram

Define Stereotypes
(Categories; Habits)

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

- Define Objectives (e.g., Hypothesis)
- Define Scope (Actors, Environment, Theories)
- Define Key Activities UML Use Case Diagrams

- Define Agent Templates
  Choice of: UML State Machine Diagrams + Transition Tables; UML Class Diagrams; UML Activity Diagrams

- Define Object Templates
  Choice of: UML State Machine Diagrams + Transition Tables; UML Class Diagrams; UML Activity Diagrams

- Define Stereotypes (Categories; Habits)

- Define Interaction
  UML Sequence Diagrams

- Define Artificial Lab (Environment and Population)
  UML Class Diagram
  UML Sequence Diagram

Knowledge gathering
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

<table>
<thead>
<tr>
<th>Stereotype</th>
<th>Working days</th>
<th>Arrival time</th>
<th>Leave time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early bird</td>
<td>Mon-Fri</td>
<td>5am-9am</td>
<td>4pm-7pm</td>
</tr>
<tr>
<td>Time table complier</td>
<td>Mon-Fri</td>
<td>9am-10am</td>
<td>5pm-6pm</td>
</tr>
<tr>
<td>Flexible worker</td>
<td>Mon-Fri</td>
<td>10am-1pm</td>
<td>5pm-11pm</td>
</tr>
<tr>
<td>Hardcore worker</td>
<td>Mon-Fri + Sat</td>
<td>8am-10am</td>
<td>5pm-11pm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stereotype</th>
<th>Energy saving awareness [0-100]</th>
<th>Probability of switching off unnecessary appliances</th>
<th>Probability of sending emails about energy issues to others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental champion</td>
<td>95-100</td>
<td>0.95</td>
<td>0.9</td>
</tr>
<tr>
<td>Energy saver</td>
<td>70-94</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Regular user</td>
<td>30-69</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Big user</td>
<td>0-29</td>
<td>0.2</td>
<td>0.05</td>
</tr>
</tbody>
</table>
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
# Illustrative Example

<table>
<thead>
<tr>
<th>From state</th>
<th>To state</th>
<th>Triggered by</th>
<th>When?</th>
</tr>
</thead>
<tbody>
<tr>
<td>outOfOffice</td>
<td>inCorridor</td>
<td>Condition</td>
<td>At typical arrival time during the working week for all</td>
</tr>
<tr>
<td>outOfOffice</td>
<td>inCorridor</td>
<td>Condition</td>
<td>At typical arrival time on Saturdays for hard-core workers only</td>
</tr>
<tr>
<td>inCorridor</td>
<td>outOfOffice</td>
<td>Condition</td>
<td>At typical leave time</td>
</tr>
<tr>
<td>inCorridor</td>
<td>inOffice</td>
<td>Timeout</td>
<td>At average after 5 minutes</td>
</tr>
<tr>
<td>inOffice</td>
<td>inCorridor</td>
<td>Condition</td>
<td>At random while at work or when leaving</td>
</tr>
<tr>
<td>inCorridor</td>
<td>otherRoom</td>
<td>Condition</td>
<td>At random while at work</td>
</tr>
<tr>
<td>otherRoom</td>
<td>inCorridor</td>
<td>Timeout</td>
<td>At average after 10 minutes</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
Illustrative Example

Compare energy consumption with history

- **Yes**
  - Less than former month?
    - **Yes**
      - Group?
        - **Yes**
          - Sanction?
            - **Yes**
              - Anonymous?
                - **Yes**
                  - Maintain behaviour
                - **No**
                  - Decrease freeriding
            - **No**
              - Anonymous?
                - **Yes**
                  - Decrease motivation
                - **No**
                  - Decrease freeriding
    - **No**
      - Sanction?
        - **Yes**
          - Anonymous?
            - **Yes**
              - Decrease motivation
            - **No**
              - Decrease freeriding
        - **No**
          - Anonymous?
            - **Yes**
              - Decrease motivation
            - **No**
              - Decrease freeriding

- **No**
  - Less than former month?
    - **Yes**
      - Group?
        - **Yes**
          - Sanction?
            - **Yes**
              - Anonymous?
                - **Yes**
                  - Decrease motivation
                - **No**
                  - Decrease freeriding
            - **No**
              - Anonymous?
                - **Yes**
                  - Decrease motivation
                - **No**
                  - Decrease freeriding
    - **No**
      - Sanction?
        - **Yes**
          - Anonymous?
            - **Yes**
              - Decrease motivation
            - **No**
              - Decrease freeriding
        - **No**
          - Anonymous?
            - **Yes**
              - Decrease motivation
            - **No**
              - Decrease freeriding

Increase motivation less
Overview of our ABSS Development Framework

Define Objectives (e.g., Hypothesis) → Define Scope (Actors; Environment; Theories) → Define Key Activities (UML Use Case Diagrams) → Define Agent Templates (Choice of: UML State Machine Diagrams + Transition Tables; UML Class Diagrams; UML Activity Diagrams)

Define Object Templates (Choice of: UML State Machine Diagrams + Transition Tables; UML Class Diagrams; UML Activity Diagrams) → Define Stereotypes (Categories; Habits) → Define Interaction (UML Sequence Diagrams) → Define Artificial Lab (Environment and Population) (UML Class Diagram; UML Sequence Diagram)

Knowledge gathering
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
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
- isDataApportionmentAvailable
- 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
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
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
<table>
<thead>
<tr>
<th>Category</th>
<th>Element</th>
<th>Decision</th>
<th>Group</th>
<th>Group name</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actor</td>
<td>Household</td>
<td>include</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Household member (occupant)</td>
<td>exclude</td>
<td>4+5+12+13</td>
<td>?</td>
<td>Part of the environment</td>
</tr>
<tr>
<td></td>
<td>Installer</td>
<td>exclude</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Government</td>
<td>include</td>
<td>4+5+12+13</td>
<td>?</td>
<td>Considering by household (abstraction)</td>
</tr>
<tr>
<td></td>
<td>Electricity supplier</td>
<td>include</td>
<td>4+5+12+13</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Manufacturer</td>
<td>exclude</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neighbouring household</td>
<td>include</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neighbouring household member</td>
<td>exclude</td>
<td></td>
<td></td>
<td>Considered by individual owned PVC systems</td>
</tr>
<tr>
<td></td>
<td>Neighbourhood</td>
<td>exclude</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Consumer group</td>
<td>exclude</td>
<td></td>
<td></td>
<td>Considered by individual owned PVC systems</td>
</tr>
<tr>
<td></td>
<td>Community</td>
<td>exclude</td>
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<td></td>
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<td></td>
<td>Firm</td>
<td>include as group</td>
<td>4+5+12+13</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Regulator</td>
<td>include as group</td>
<td>4+5+12+13</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>Technology/Appliances</td>
<td>PVC</td>
<td>include as group</td>
<td>14+15+16</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inverter</td>
<td>include as group</td>
<td>14+15+16</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Meter (smart)</td>
<td>include as group</td>
<td>14+16</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Computer</td>
<td>include as group</td>
<td>17+18+19+20+21</td>
<td>Household appliances</td>
<td>Represents &quot;Demand&quot;</td>
</tr>
<tr>
<td></td>
<td>Light</td>
<td>include as group</td>
<td>17+18+19+20+21</td>
<td>Household appliances</td>
<td>Represents &quot;Demand&quot;</td>
</tr>
<tr>
<td></td>
<td>Cooker</td>
<td>include as group</td>
<td>17+18+19+20+21</td>
<td>Household appliances</td>
<td>Represents &quot;Demand&quot;</td>
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<tr>
<td></td>
<td>Fridge</td>
<td>include as group</td>
<td>17+18+19+20+21</td>
<td>Household appliances</td>
<td>Represents &quot;Demand&quot;</td>
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<td></td>
<td>Heating</td>
<td>include as group</td>
<td>17+18+19+20+21</td>
<td>Household appliances</td>
<td>Represents &quot;Demand&quot;</td>
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<td>Weather</td>
<td>Sunshine/natural light</td>
<td>include</td>
<td></td>
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<td>Part of the environment</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>include</td>
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<td></td>
<td>Part of the environment</td>
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<tr>
<td></td>
<td>Clouds</td>
<td>include</td>
<td></td>
<td></td>
<td>Part of the environment</td>
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<tr>
<td>Buildings/Roofs</td>
<td>House orientation (spatial model)</td>
<td>include</td>
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</tr>
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<td></td>
<td>Shading</td>
<td>exclude</td>
<td></td>
<td></td>
<td>Not enough computing power</td>
</tr>
<tr>
<td></td>
<td>Visibility of PVCs</td>
<td>include</td>
<td></td>
<td></td>
<td>Using approximation</td>
</tr>
<tr>
<td></td>
<td>Density of housing</td>
<td>include</td>
<td></td>
<td></td>
<td>Using approximation</td>
</tr>
<tr>
<td></td>
<td>House interior</td>
<td>exclude</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Psychological factors</td>
<td>Comparative feedback (motivation)</td>
<td>include</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reaction to incentives (economic rationality/sensitivity)</td>
<td>include</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Level of greenness</td>
<td>include</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Family structure (who makes decisions)</td>
<td>exclude</td>
<td></td>
<td></td>
<td>Consider for future research</td>
</tr>
<tr>
<td></td>
<td>Perception of risk</td>
<td>exclude</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Affectiveness</td>
<td>include</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Perception of urgency (rushed decision)</td>
<td>include</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Advertising effectiveness</td>
<td>include</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Word of mouth (networking)</td>
<td>include</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Observation (feeds perceived norm)</td>
<td>include</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Networks</td>
<td>Physical network</td>
<td>exclude</td>
<td></td>
<td></td>
<td>Network not overloaded in UK</td>
</tr>
<tr>
<td></td>
<td>Comms network</td>
<td>exclude</td>
<td></td>
<td></td>
<td>No smart network</td>
</tr>
<tr>
<td></td>
<td>Economic network (supply chain)</td>
<td>include</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Social network</td>
<td>include</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Misc</td>
<td>Energy</td>
<td>exclude</td>
<td></td>
<td></td>
<td>Not explicitly modelled &gt; output; not relevant for UK</td>
</tr>
</tbody>
</table>
Defining Key Activities
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 environmentally friendly
      – Likelihood of being economically driven

  – Adoption likelihood = $k_x \cdot w_{social} + k_y \cdot w_{econ} + k_z \cdot w_{envir}$ (k=observation; w=weight)
Case Study
Defining Agent and Object Templates

**Household**
- EnvironmentalSensitivity_percent
- EconomicSensitivity_percent
- SocialSensitivity_percent
- Capital_pound
- AvailableRoofSpace_kwCapacity
- StereotypeName
- NeighboursAdopted_percent
- hasPV_boolean
- psychologicalModel
- locationData

+ observeNeighbours()
+ evaluatePsychologicalModel()
+ adoptPV()
+ useAppliancesGenerateDemand()
+ payEnergy()
+ receiveSubsidy()
+ observeFIT()
+ getSavings()
+ initialiseConstants()

**NeighbourHousehold**

**Government**
- feedInTariffSchedule
- numOfPVAdoptions
  + defineFeedInTariff()
  + advertiseFeedInTariff()
  + recordAdoptions()

**Supplier**
- feedInTariff
- customerList
  + advertiseFIT()
  + collectPayment()
  + issuePayment()

The first three parameters feed stereotype information into the utility function.

Depending on level of abstraction we would either represent these as objects or functions defined in the environment.

These three are done in an endless loop.
Case Study

Household (physical SM)
- ProvideEnergy
- ReceiveEnergy

Household (mental)
- doesNotHavePV
  - Contemplating
  - Evaluating
  - Observing
  - hasPV

Government
- NotProvidingFIT
  - ProvidingFIT
    - MaintainFIT Provision
    - ReviewingFIT Provision

Supplier
- Monitoring

This state contains the decision model
More details in related Activity diagram
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
Observe (Bubbles Social network)

User 1

Do you have PV? User map (Neighbouring Households)

Yes/No

Repeat for all users (Random order of observing on same timestep)

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()
Case Study
Defining the Artificial Lab

Initialization Sequence
initialize geography
initialize government
initialize suppliers
initialize households
initialize receptors
add to geography
initialize networks

(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 area)
References

Questions / Comments

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