Complexity Science, Agent-Based Simulation & Energy Research

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Agenda

• Part I: Complexity Science & Agent-Based Simulation
  – Complexity Science
  – Agent-based simulation

• Part II: Energy Research with Agents
  – Brief Review of Previous Studies
  – Case Study: Modelling Office Energy Consumption with Agents
Part I: Complexity Science & Agent Based Simulation

• What is Complexity?
  – Refers to “Systems with many different parts which by a rather mysterious process of self-organization, become more ordered and more informed than systems which operates in approximate thermodynamic equilibrium with their surroundings” (Cowan, 1994)

• What is Complexity Science?
  – the scientific study of complex systems, systems with many parts that interact to produce global behaviour that cannot easily be explained in terms of interactions between the individual constituent elements.
Part I: Complexity Science & Agent Based Simulation

• Complexity Adaptive Systems (CAS)
  • A system that is composed of many autonomous/semi-autonomous entities
  • System level behaviour is the result of a number of entities behaviour and their interactions
  • The emergence and evolution of system level behaviour are dynamic processes which take time and often hard to predict
  • Self-organisation of interacting adaptive entities enables the system to be adaptive to its environment
Part I: Complexity Science & Agent Based Simulation

- Complexity Adaptive Systems (CAS)

Part I: Complexity Science & Agent Based Simulation

• General Theories in Complexity Science
  – Connectivity and Interdependence
  – Co-evolution
  – Dissipative Structure and Far-From-Equilibrium
  – Self-organisation and Emergence
Part I: Complexity Science & Agent Based Simulation

• Connectivity and Interdependence
  – Each entity in a CAS behaves on its own, but its behaviour may affect or be affected by the behaviour of its interacting entities
  – For example, consumers
Part I: Complexity Science & Agent Based Simulation

• Co-evolution
  – The evolution of one domain or entity is partially dependent on the evolution of other related domains or entities; or that one domain or entity changes in the context of the other(s) (Mitleton-Kelly, 2003)
  – For example, software industry and hardware industry
Part I: Complexity Science & Agent Based Simulation

• Dissipative Structure & Far-From-Equilibrium
  – No rigid structure, entities scatter in various directions
  – The ways in which open systems exchange energy, matter, or information with their environment and which when pushed “far-from-equilibrium” create new structures and order (Mitleton-Kelly, 2003)
  – Not in a stable state where linear laws, equations and formulas apply
Part I: Complexity Science & Agent Based Simulation

• Self-organisation and Emergence

  – The tendency of an open system to generate new structure and patterns based on its own internal dynamics (Olson & Eoyang, 2001); e.g. wound

  – The spontaneous coming together of a group to perform a task; the group decides what, when and how to do (Mitleton-Kelly, 2003); e.g. football match

  – System level properties derive from its components’ activities and their interactions, but cannot be reduced to them (Checkland, 1981)
Part I: Complexity Science & Agent Based Simulation

- **Research Methods in Complexity Science**
  - Traditional quantitative and qualitative methods (e.g. LSE complexity science group directed by Mitleton-Kelly, Cranfield complexity science group directed by Allen)
  - Computational Simulation Methods
    - Discrete Event Simulation
    - System Dynamics
    - Agent-based Simulation
Part I: Complexity Science & Agent Based Simulation

• What is an agent?
  – Simply speaking, the basic unit of a CAS
  – Every thing can be seen as an agent
  – More an approach than a physical thing
  – Originated in artificial intelligence in the 1970s
  – Rapidly developed in the 1990s
Part I: Complexity Science & Agent Based Simulation

• The concept of an agent
  – A hardware or software-based computer system that is of the following attributes (Wooldridge & Jennings, 1995):
    – Autonomy: operates without human direct interventions
    – Social ability: interacts with others
    – Reactivity: perceives the environment, and respond in a timely fashion
    – Pro-activeness: does not just simply act in response to environment, but is able to exhibit goal-direct behaviour on its own initiative
Part I: Complexity Science & Agent Based Simulation

- Levels of Agents

[Diagram showing three levels of agents with overlapping properties such as Autonomy, Social ability, Reactivity, Pro-activeness, Mobility, Learning, Basic logic, Emotions, Rationality, Intelligence.]
Part I: Complexity Science & Agent Based Simulation

• Agent Architecture
  – Simple reflex agents (Russell & Norvig, 1995)
    • *Pseudo Code*: If conditions *then* action

![Diagram of agent architecture](image-url)
Part I: Complexity Science & Agent Based Simulation

• Agent Architecture
  – Agents that keep track of the world (Russell & Norvig, 1995)
    • Pseudo Code: \textbf{If} conditions \textbf{then} check state, \textbf{then} action
Part I: Complexity Science & Agent Based Simulation

- Agent Architecture
  - Goal-based agents (Russell & Norvig, 1995)
Part I: Complexity Science & Agent Based Simulation

• Agent Architecture
  – Utility-based agents (Russell & Norvig, 1995)
Part I: Complexity Science & Agent Based Simulation

• Design an agent

  Formulating the attributes of the agent

  Studying the behaviour and interactions of realistic object the agent represents

  Compiling and formulating the behaviour and interactions into algorithms

  Translating these algorithms into computer languages

  Encapsulating the codes—a software agent
Part I: Complexity Science & Agent Based Simulation

• Design an agent-based model
Part I: Complexity Science & Agent Based Simulation

- Overview of agent-based simulation method
Part II Energy Research with Agents

• Brief Review of Previous Study
• Case Study: Modelling Office Energy Consumption via Agent Based Simulation
Brief Review of Previous Study

• The energy research:
  – Electricity and gas markets: vertically integrated networks, often considered as CASs.
  – Transport systems: networks with various interacting entities, often considered as CASs.
Brief Review of Previous Study

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  – Electricity and gas markets: vertically integrated networks, often considered as CASs.
  – Transport systems: networks with various interacting entities, often considered as CASs
Brief Review of Previous Study

• Major research areas:
  – **Electricity wholesale market**: assessing market power of big generation companies (e.g. Li & Tesfatsion, 2009; Bunn & Oliveira, 2005), assessing the effectiveness of economic regulations (e.g. Bunn and Oliveira, 2001; Amin, 2002; Koritarov, 2004)
  – **Innovation Diffusion in the electricity market**: assessing the effectiveness of innovation policies (Zhang & Nuttall, 2008; Houwing, et al, 2008)
  – **Transport systems**: optimize energy consumption with transport systems (e.g. Ghauche, 2010; Sullivan, Salmeen and Simon, 2009)
Case Study

• Modelling Office Energy Consumption: An Agent Based Approach
Office Energy Consumption

• A sub-project under the City Energy Future Project
• Target the organisational behaviour of using energy
  – Reasons: UK government’s 2020 target of cutting emission (by 34% of 1990 levels)
  – 14% of overall energy consumption is in the service sector (e.g. heating, lighting, computing)
Office Energy Consumption

• An integration of four elements

Energy Management Policies Made by the Energy Management Division

Energy Management Technologies

Office Electric Equipments and Appliances

Staff’s behaviour of using energy
Office Energy Consumption

- Previous literature primarily focuses on building energy consumption prediction, energy management technology development and building energy consumption benchmarks, and ignores human factors.
- We aim to develop a simulation model integrating the four elements and provide decision support for energy management divisions.
Office Energy Consumption

• Specifically focus on electricity consumption
• Electricity are consumed by electric appliances and equipment
• Two kinds of office building electric appliances: base appliances and flexible appliance
Office Energy Consumption

\[ C_{\text{total}} = C_{\text{base}} + C_{\text{flexible}} \]

\[ C_{\text{flexible}} = \beta_1 C_{f1} + \beta_2 C_{f2} + \beta_3 C_{f3} + \cdots + \beta_n C_{fn} \]

\[ C_{\text{total}} = C_{\text{base}} + (\beta_1 C_{f1} + \beta_2 C_{f2} + \beta_3 C_{f3} + \cdots + \beta_n C_{fn}) \]
Case Study

- Case: First Floor, School of Computer Science, Jubilee Campus, University of Nottingham
# Case Study

## Table 1: Details of Rooms and Electric Equipment and Appliances

<table>
<thead>
<tr>
<th>Item</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rooms</td>
<td>47</td>
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<tr>
<td>Lights</td>
<td>239</td>
</tr>
<tr>
<td>Computers</td>
<td>180</td>
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<tr>
<td>Printers</td>
<td>24</td>
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<td>Information Displays</td>
<td>4</td>
</tr>
<tr>
<td>Energy Users</td>
<td>213</td>
</tr>
</tbody>
</table>
Case Study

• Agents
  – Staff and Students (proactive agents)
  – Computers (passive agents)
  – Lights (passive agents)
Case Study

• Behaviour of Energy User Agents
Case Study

• Behaviour of Computer Agents
Case Study

- Behaviour of Light Agents
Case Study

• Model Implementation

System Level Electricity Consumption of the School

Base electric appliances

Base Electricity Consumption

Flexible Electricity Consumption

Computer agent 1

Computer agent 2

Computer agent n

Energy user agent 1

Energy user agent 2

Energy user agent n

Light agent 1

Light agent 2

Light agent n
Simulation Experiments

• Experiment 1: Replicate current policy

Note: In this figure the simulation result is the average of results of 20 replications with different random seeds.
Simulation Experiments

- Experiment 2: Automated Strategy vs. Staff-Controlled Strategy

![Graph showing electricity consumption comparison between Automated Scenario and Staff-Controlled Scenario over seven days.]

- Automated Scenario
- Staff-Controlled Scenario
Simulation Experiments

Experiment 3: Understand the proportions of electricity consumed by lights and computers
Conclusions

• Agent-based simulation, as an powerful research method in complexity science, can be widely applied to study energy issues arising in complex energy systems such as markets, communities and buildings
Questions and Comments?