

## ***AGENT-BASED MODELS***

**In ABM/ACE models, a population of software objects is:**

- instantiated, and each agent is given**
- certain internal states (e.g., preferences, endowments) and**
- rules of behaviour (e.g., seek utility improvements).**

**The agents are then permitted to interact directly with one another and a macrostructure emerges from these interactions.**

## Patterns Emerge

**Patterns in this macrostructure may then be (Axtell, 2005).**

- compared with empirical data,**
- agent internal states and rules revised, and**
- the process repeated until an empirically plausible model obtains.**

**e.g. ACE stock markets have been used to model heterogeneous agents: will the stylised features of such markets emerge? Yes.**

## **What is an Agent?**

**An agent: a self-centred program that controls its own actions based on its perceptions of its operating environment.**

**Derived from the Distributed AI notion of a network of calculating nodes.**

**Example: the automata in Conway's Game of Life or Schelling's segregation game.**

**Another example of an agent that won \$2,000,000 in a challenge by the U.S. Department of Defense earlier this month ...**

**Stanley here.**

## Agents and agency

**Wooldridge & Jennings (1995) would give computer agents these properties:**

- **autonomy: no others control their actions and internal state,**
- **social ability: can interact and communicate with other agents**
- **reactive: they perceive their environment and respond**
- **proactive: they initiate goal-directed actions**
- **(intentionality: metaphors of beliefs, decisions, motives, and even emotions)**

## **Eight Desired Attributes of Modelled Agents (G&T)**

### **1. Knowledge & beliefs.**

**Agents act based on their knowledge of the environment (including other agents), which may be faulty — their beliefs, not true knowledge.**

### **2. Inference.**

**Given a set of beliefs, an agent might infer more information.**

### **3. Social models.**

**Agents, knowing about interrelationships between other models, can develop a “social model”, or a topology of their environment: who’s who. etc.**

## **Eight Desired Attributes ...**

### **4. Knowledge representation.**

**Agents need a representation of beliefs: e.g. predicate logic, semantic (hierarchical) networks, Bayesian (probabilistic) networks.**

**[Sebastian] Thrun [leader of the winning team in the 2005 DARPA Grand Challenge] had a Zen-like revelation: “A key prerequisite of true intelligence is knowledge of one’s own ignorance,” he thought. Given the inherent unpredictability of the world, robots, like humans, will always make mistakes. So Thrun pioneered what’s known as probabilistic robotics. He programs his machines to adjust their responses to incoming data based on the probability that the data are correct. — Pacella (2005).**

## **Eight Desired Attributes ...**

### **5. Goals.**

**Agents driven by some internal goal, e.g. survival, and its subsidiary goals (food, shelter). Usually definition and management of goals imposed on the agent.**

### **6. Planning.**

**Agent must (somehow) determine what actions will attain its goal(s). Some agents modelled without teleology (simple trial-and-error), others with inference (forward-looking), or planning.**

### **7. Language.**

**For communication (of information, negotiation, threats). Modelling language is difficult. (Want to avoid inadvertent communication, e.g. through the genome of a population in the GA.)**

### **8. Emotions.**

**Emergent features? Significant in modelling agents? Or epiphenomenal?**

## How to Model Agent Architecture?

**Early approach to modelling cognitive abilities (symbolic paradigm) was fragile, complex, and lacked commonsense.**

**Since then, five approaches:**

- 1. Production Systems**
- 2. Object Orientation**
- 3. Language Parsing & Generation**
- 4. Machine-Learning Techniques, and (most recently)**
- 5. Probabilistic Robotics (Thrun et al. 2005).**

**Ignore 3., 4. next lecture, 5. too new.**

## **Production Systems**

### **Contain:**

- 1. a set of rules (a condition + an action),**
- 2. a working memory, and**
- 3. a rule interpreter (is the condition satisfied? if so, act)**

**No prespecified order of rules: contingent.**

**The agent's designer specifies how to break ties among rules.**

## Object Orientation

In “object-oriented” programming languages:

- “objects” are program structures containing data + procedures for operating on those data;
- the data are stored in “slots” inside the object;
- the procedures are called “methods”;
- objects created from templates called “classes”;
- classes are ranked in a hierarchy, with subordinate classes more specialised.

e.g. Pedestrian flow in a shopping mall — Class: pedestrian; Slots: location, direction, gait; Subclass 1: lone walkers; Subclass 2: group walkers (with a List of Who, and Interactions with others in the group).

If the rules are specified at the class level, then all agents share the rules, but with different attributes.

OO computer languages: C++, Lisp, Java. etc.

## **Probabilistic Robotics**

**In the 2004 DARPA Grand Challenge, robots used Production System architecture.**

**Results: The most successful entrant in last year's race completed just 7.4 miles of the 150-mile off-road (desert) course, and only six of the fifteen cars competing travelled even 1.3 miles.**

**In the 2005 Grand Challenge, many robots used probabilistic (or Bayesian or fuzzy-logic) architecture.**

**Results: "Stanley," Stanford's robotic Volkswagen Touareg beat the field, completing the 132-mile race with a winning time of 6 hours 53 minutes and 58 seconds (an average speed of 19.1 mph). Four other vehicles successfully completed the race. All but one of the 23 finalists in the 2005 race surpassed the 7.36 mile distance completed by the best vehicle in the 2004 race.**

## Grand Challenge Rules

- **The vehicle must travel autonomously on the ground in under ten hours.**
- **The vehicle must stay within the course boundaries as defined by a data file provided by DARPA.**
- **The vehicle may use GPS and other public signals.**
- **No control commands may be sent to the vehicle while en route.**
- **The vehicle must not intentionally touch any other competing vehicle.**
- **An autonomous service station is permitted at a checkpoint area approximately halfway between start and finish.**

**The Stanford team won the first prize of US \$2,000,000.**

## **Modelling the Environment**

**Definition of the environment depends on what is being modelled.**

**For individuals:**

- **move in a space, or on a network;**
- **use sensors to perceive the environment, including others;**
- **perhaps be able to affect the environment directly;**
- **perhaps receive and send signals in the environment.**

**For computer agents, the order of agents running can be crucial (“concurrency”). Sometimes, buffering their signals is sufficient.**

## **G & T Use NetLogo to build a multi-agent simulation.**

## ***Economic Journal* June 2005 Feature —**

- **focussed on Complex Adaptive Systems CAS in economics**
- **appeared just after Leombruni & Richiardi asked, “Why are economists sceptical about agent-based simulations?” (*Physica A* 355: 103–109, 2005.)**
- **included 4 papers: introduced by Markose, with papers by Axtell, Robson, and Durlauf**
- **addressing, respectively,**
  - **markets as complex adaptive systems,**
  - **formal complexity issues,**
  - **the co-evolutionary Red Queen effect and novelty, and**
  - **the empirical and testable manifestations of CAS in economic phenomena.**

## **Leombruni & Richiardi's answer:**

**(From 1970, only 8 ACE articles of 26,698 in top 20 econ journals.)**

### **Possible reasons:**

- i. interpretation of the simulation dynamics and generalization of the results,**
- ii. estimation of the simulation model**
- iii. I would add: in general, *no necessary conditions* from simulation, just sufficient conditions**
- iv. and validation of the model.  
(but also applies to closed-form models)**

## **Markose and the *EJ* Feature on CAS:**

- many “anomalies” not understood or modelled using conventional optimisation economics:
  - innovation,
  - competitive co-evolution,
  - persistent heterogeneity,
  - increasing returns,
  - “the error-driven processes behind market equilibrium,”
  - herding,
  - crashes and extreme events such as October 1987.
- need the “adaptive or emergent methods” of ACE simulation

## Moreover ...

**Axtell (2005) argues that:**

- **the decentralised market as a whole can be seen as a collective computing device**
- **the parallel distributed agent-based models of  $k$ -lateral exchange → the specific level of complexity (polynomial) in calculations of equilibrium prices and allocations.**

## **Simon's Bounded Rationality**

**Agent-based models, following Simon (1982), also assume Bounded Rationality. Indeed, in the absence of Turing machine (universal calculator), it is difficult not to.**

**But Epstein (2006) reflects:**

**“One wonders how the core concerns and history of economics would have developed if, instead of being inspired by continuum physics ... blissfully unconcerned as it is with effective computability — it had been founded on Turing. Finitistic issues of computability, learnability, attainment of equilibrium (rather than mere existence), problem complexity, and undecidability, would then have been central from the start. Their foundational importance is only now being recognized.**

## **Epstein on the virtues of boundedly rational agents ...**

**“As Duncan Foley summarizes:**

**`The theory of computability and computational complexity suggest that there are two inherent limitations to the rational choice paradigm.**

**One limitation stems from the possibility that the agent’s problem is in fact undecidable, so that no computational procedure exists which for all inputs will give her the needed answer in finite time.**

**A second limitation is posed by computational complexity in that even if her problem is decidable, the computational cost of solving it may in many situations be so large as to overwhelm any possible gains from the optimal choice of action.’ (See Albin 1998, 46).”**

## References:

- Albin, P.S., ed. 1998. *Barriers and Bounds to Rationality: Essays on Economic Complexity and Dynamics in Interactive Systems*. PUP, Princeton. Introduction by D.K. Foley.
- Axtell R., The complexity of exchange, *The Economic Journal*, 115 (June), F193–F210, 2005.
- Durlauf S., Complexity and empirical economics, *The Economic Journal*, 115 (June), F225–F243, 2005.
- J.M. Epstein, Remarks on the Foundations of Agent-Based Generative Social Science, *Handbook of Computational Economics, Volume 2: Agent-Based Modeling*, edited by Leigh Tesfatsion and Kenneth L. Judd, Amsterdam: Elsevier Science, forthcoming, 2006.
- A. Hailu & S. Schilizzi, Are Auctions More Efficient Than Fixed Price Schemes When Bidders Learn? *Australian Journal of Management*, 29(2): 147–168, December 2004.
- R. Leombruni & M. Richiardi, Why are economists sceptical about agent-based simulations? *Physica A* 355: 103–109, 2005.
- S.M. Markose, Computability and evolutionary complexity: markets as complex adaptive systems (CAS), *The Economic Journal*, 115 (June), F159–F192, 2005.
- R.M. Pacella (2005), DARPA Grand Challenge, *Popular Science*, October.
- A.J. Robson, Complex evolutionary systems and the Red Queen, *The Economic Journal*, 115 (June), F211–F224, 2005.
- Simon, H.A. 1982. *Models of Bounded Rationality*. Cambridge, MA: MIT Press.
- Simon, H.A. 1987. Rationality in Psychology and Economics. *Rational Choice: The Contrast Between Economics and Psychology*, Hogarth, R.M. and Reder, M.W. eds. Chicago: University of Chicago Press.
- S. Thrun, W. Burgard, D. Fox, *Probabilistic Robotics*, MIT Press, September 2005.