Bounded Rationality and Local Interactions in ABMs

Models and Simulations in Philosophy
November 4th, 2013

Review

- First Class:
  - Two Platonic Puzzles: Justice and Meaning
  - ABMs vs. Equilibrium Explanations in Classical Economics and Mathematical Biology
- Second Class: Decision and game theory
- Third Class: Gauthier's attempt to characterize morality using game theory

Review

We did not get to discuss Gauthier's theory in full detail. Here's a summary.

Review

- In "Morality and Advantage", Gauthier concludes the question, "Why should I be moral?" has no satisfactory answer: there is a conflict between individual rationality and morality.
- In *Morals by Agreement*, Gauthier changes his mind. He argues that "moral" actions
  - are those that conform to rules that rational agents would agree to in a bargaining process (about how the pursuit of self-interest ought to be curtailed).
  - are rational to adhere to **after** such an agreement is made.

Review

- Gauthier's agreement is hypothetical.
  - **Question:** How might codes of conduct (i.e. "morality") arise?
- Moreover, his explanation of why individuals will adhere to the agreement *ex post* requires assuming individuals are rational.
  - **Question:** Why does morality persist among individuals who are boundedly rational?

Review

Today: We'll describe some common models to answer these questions.

- Introduction to ABMs
- Contrast ABMs with one population model, the replicator dynamics.

ABMs vs. Classical Economic Models

Classic Models

- Rational
- Homogeneous agents
- Global Interaction
- Equilibria

ABMs

- Boundedly Rational
- Heterogenous Agents
- Local interactions
- Dynamics

Getting More Precise

But we did **not**:

- Explain the meaning of bounded rationality
- Explain how one might represent local interactions among agents
- Investigate dynamic population-level models and contrast them with ABMs

Outline

Rationality and Expected Utility

- The Standard in Economics: An agent is rational if she acts **as if** she were maximizing expected utility.
- That is, the agent may not act **with the intent** of maximizing expected utility. She may happen to do maximize utility accidentally or uncounsciously (due to practice and training, or genetic predisposition).
- There are a number of arguments for the claim that expected utility maximization is the **unique** rational decision rule; we won't discuss them here.

Bounded Rationality

- "Bounded rationality" is a term of art. No one defines it.
- Here is **my** best attempt to explain what I think is meant.
- Call an agent deliberately rational if she is rational and acts **with the purpose** of maximizing expected utility.

Bounded Rationality

An agent is boundedly rational if she is

- **Neither** deliberately rational nor rational (simpliciter),
- but, in certain important contexts, she is rational or approximates rationality (simpliciter).

Deliberate Rationality

What does it take to be deliberately rational?

Deliberate EU Maximization

To act with the purpose of maximizing expected utility (i.e. to be deliberately rational), one must

- Consider all available actions,
- Consider all possible states of the world,
- Know the payoff of each action in each possible state of the world,
- Assign each state of the world some probability of occurring,
- Calculate the SEU of each action and compare the results.

Deliberate EU Maximization

Each of these tasks may be difficult for fallible agents with limited time, memory, and computational abilities ...

Difficulty of Deliberation

Here are some cases in which each of the tasks may be difficult:

- Consider all available actions,
  - Ways to get from upper Manhattan to Brooklyn
  - Chess strategies
  - Any decision where many actions are available.
- Consider all possible states of the world,
  - Possible traffic patterns in Manhattan.
  - Possible opponent strategies in chess.

Difficulty of Deliberation

Here are some cases in which each of the tasks may be difficult:

- Know each action's payoff in each possible state of the world,
  - How long will a taxi take if the Brooklyn bridge is congested, there is construction in midtown, etc.?
  - Economic and/or Social policy. What will be the effect of austerity measures in Europe?
- Assign each state of the world some probability of occurring,
  - What's the probability there is construction in midtown today?
  - Climate Policy - What is the probability that mean global surface temperature rises by at least two degrees centigrade?
- Calculate each action's SEU and compare the results.
  - Any of the cases above.

Bounded Rationality

By my definition, a boundedly rational agent fails to do one of the following:

- Consider all available actions,
- Consider all possible states of the world,
- Know the (numerical) payoff of each action in each possible state of the world,
- Assign each state of the world some probability of occurring,
- Calculate SEU of all actions and compare the results.

Bounded Rationality

Instead, a boundedly rational agent might decide as follows:

Bounded Rationality

Boundedly rational agents may

- Consider some small subset of available actions
  - E.g., Kasparov considers only three moves a second.
- Consider some small subset of possible states of the world,
  - E.g., Individuals generally ignore low probability states of the world (e.g., airplane crashes) when making particular decisions (e.g., about whether to fly or take a train)

Bounded Rationality

Boundedly rational agents may

- Make qualitative comparisons of outcomes of actions
  - E.g., In the state of the world in which it rains, I might consider taking an umbrella to better than going without one, but I don't know *how much* better.
- Make qualitative judgments of likelihood; or omit judgments of likelihood at all in other circumstances.
  - E.g., Qualitative Probability - I believe it is likely that it will rain this week, but I do not have an exact percentage (e.g., 95%) that quantifies my belief.
  - E.g. Omission - If you use minimax reasoning, for instance.

Bounded Rationality

Boundedly rational agents may

- Not perform utility calculations and compare all actions.
  - Omit calculations; use rules of thumbs or heuristics to compare actions.
  - We are not all like Darwin when it comes to marriage decisions.
- Not maximize SEU, but rather satisfice for example.

We'll examine some more examples shortly ...

Bounded Rationality

Disclaimer: There's a more common way of understanding bounded rationality, which is due to Newell and Simon.

Here it is, though I don't like the definition ...

Bounded Rationality

Boundedly rational agents redefine the decision problem and maximize SEU for the new problem.

> *For the first consequence of the principle of bounded rationality is that the intended rationality of an actor requires him to construct a simplified model of the real situation in order to deal with it. He behaves rationally with respect to this model, and such behavior is not even approximately optimal with respect to the real world.*

[Simon, 1957], pp. 198-199.

Bounded Rationality

Example: Instead of searching for a winning move, chess players might aim to have their pieces in the "right position."

Outline

ABMs vs. Population Models

Major Difference 1: Classical rationality vs. bounded

Major Difference 2: Global vs. Local Interactions

Game Theory in Biology

- One common "population level" model for explaining the emergence of norms is called the replicator dynamics.
- The model was originally introduced in biology.
- So before discussing the replicator dynamics, it will be helpful to discuss a common and fruitful way of thinking that shows similarities between
  - Models of natural selection
  - Rational Choice Theory (i.e. decision and game theory)

How are decision (and game theory) relevant for models of natural selection?

An Informal Argument:

1. Actions = Phenotypes (e.g., traits and behaviors)
2. Payoffs = Offspring
3. By definition, organisms that have the highest actual payoffs (offspring) will become more prevalent in the population.
4. So intuitively, actions (i.e. phenotypes) that have the highest expected payoffs (offspring) will become more prevalent.
   - The expected number of offspring of an organism with a given phenotype, given the current distribution of phenotypes in the population, is often called the fitness of the phenotype.

Conclusion: Nature can modeled as choosing organisms with particular phenotypes so as to maximize expected utility, where utility is number of offspring.

> *There exist deep and interesting connections, both thematic and formal, between evolutionary theory and the theory of rational choice . . . In rational choice theory, agents are assumed to make choices that maximize their utility, while in evolutionary theory, natural selection 'chooses' between alternative phenotypes, or genes, according to the criterion of fitness maximization. As a result, evolve organisms often exhibit behavioral choices that appear designed to maximize their fitness, which suggests the principles of rational choice might be applicable to them.*

Okasha and Binmore [2012].

Decision Theory in Biology

Moral: Rational choice theory can be useful in helping us understand evolution.

What about the reverse?

Cultural Evolution

- **Observation:** The "informal" argument discusses phenotypes, i.e realized behaviors or traits: organisms' genotypes matter only insofar as they produce traits or behavior that affect survival and reproduction.
- Human culture is a collection of behaviors and artifacts: it is not primarily a genetic phenomenon.
- So models of natural selection might be applicable to modeling cultural evolution as well.
- In biology, there is a mechanism by which traits are passed from parent to offspring: genes. What is the corresponding mechanism for culture?

> *Because of their common informational and evolutionary character, there are strong parallels between genetic and cultural modeling [Mesoudi et al., 2006]. Like biological transmission, culture is transmitted from parents to offspring, and like cultural transmission, so in microbes and many plant species, genes are regularly transferred across lineage boundaries [Abbott et al., 2003, Jablonka and Lamb, 1995, Rivera and Lake, 2004]. Moreover, anthropologists reconstruct the history of social groups by analyzing homologous and analogous traits, much as biologists reconstruct the evolution of species by the analysis of shared characters and homologous DNA [Mace et al., 1994]. Indeed, the same programs biological systematists are used by cultural anthropologists [Holden, 2002, Holden and Mace, 2003].*

Gintis [2012]. pp 216-217.

Outline

Replicator Dynamics

Let's see how the above argument can be made a bit more precise ...

Hawk Dove

Imagine two conspecifics are competing for a similar resource:

	Hawk	Dove
Hawk	0, 0	4, 1
Dove	1, 4	2, 2

Story: Individuals either fight ("Hawk") or not for the resource.

- If they don't fight, they share the value of the resource.
- If one fights and the other doesn't, then the one who fights gets the resource.
- However, the cost of the fighting is higher than the value of the resource.

Hawk Dove

Imagine two conspecifics are competing for a similar resource:

	Hawk	Dove
Hawk	0, 0	4, 1
Dove	1, 4	2, 2

What is/are the Nash equilibria of this game?

Replicator Dynamics

- Imagine the payoffs indicate offspring: conspecifics with more resources reproduce more often.
- Now imagine that conspecifics, when searching for resources, encounter other **random** members of the population.
- What are their expected payoffs?

Replicator Dynamics

- Let p denote the proportion of the population that exhibit Hawk behavior, and $1 - p$ that Dove behavior.
- Then, as the conspecifics encounters other random members of the population, the fitness (i.e. expected utility) of Hawk and Dove respectively are:

$$\begin{aligned} F(Hawk) &= p \cdot 0 + (1-p) \cdot 4 \\ F(Dove) &= p \cdot 2 + (1-p) \cdot 1 \end{aligned}$$

Replicator Dynamics

- Let $F(\textsc{ave})$ denote the average fitness of all phenotypes in the population. In this case,

$$F(\textsc{ave}) = p \cdot F(Hawk) + (1-p) \cdot F(Dove)$$

- In large populations, after one round of play the actual number of offspring for each phenotype will (with high probability) be close to the expected value, i.e. to the fitness of the phenotype.

Replicator Dynamics

In large populations, therefore, one can show that proportion of Hawk players change as follows:

$$p' - p = p \cdot \frac{F(Hawk)}{F(\textsc{ave})}$$

where p' is the proportion of Hawks after one round of play. This equation is called the replicator dynamics.

The Importance of Local Interactions

- Remember, Fisher argued that if the male/female ratio were not 1:1, then organisms that tended to have more male (resp. female) offspring would have an evolutionary advantage in a mostly female (resp. male) population.
- Recall, we discussed the fact that Fisher's argument seems to assume large populations in which each organism has a large number of potential mates ...
- It is less easy to see why an organism with few potential mates (e.g., a person born in Wyoming) has any evolutionary advantage, regardless of its genetic tendency to produce offspring of one sex.

The Importance of Local Interactions

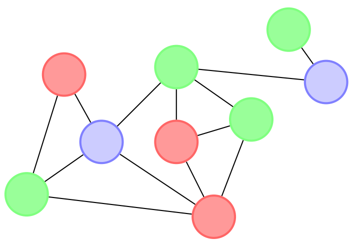
The replicator dynamics makes the same assumptions:

- Each individual plays the game with a random member of the **entire** population (and not those nearby).
- The population is large enough so that the expected offspring of organisms with a given phenotype is close to their actual number of offspring.

Representing Local Interactions

How can we represent local interactions, in which agents typically communicate (or not), cooperate (or not) etc., with a fraction of the population?

Networks



Nodes = Agents
Edges = Indicate which agents "interact"
Colors = "Type" of Agent

Common Social Networks

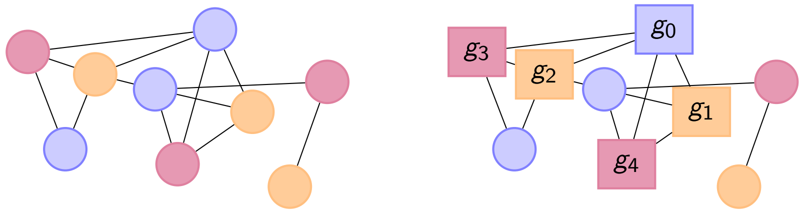
What are some common social networks that might be represented in this way?

- Facebook (Edges indicate the "friend" relation)
- The world-wide web (Edges indicate reciprocal links)
- Co-authorship networks (Edges indicate co-authors)
- Actor Network (Edges indicate the actors have appeared in a movie together)

Common Features of Social Networks

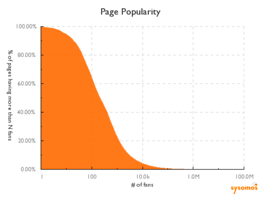
Many social networks share network structure.

Neighborhoods



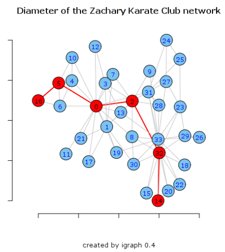
g_0's neighborhood

Common Features of Social Networks



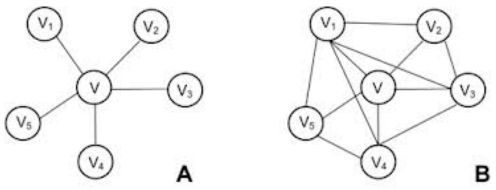
- Power law degree distribution
  - The degree of a node is the number of its neighbors.
  - A power law degree distribution indicates most agents have a few neighbors; few have a modest number; even fewer have many; etc.

Common Features of Social Networks



- Small diameter and average-path-length
  - The diameter is the longest path in the network
  - The average-path-length is what it sounds like.
  - E.g., [Milgram, 1967]'s small world experiment
  - E.g., The Kevin Bacon Game
  - E.g., Erdös Numbers

Common Features of Social Networks



- High clustering
  - Roughly, a graph is clustered if your neighbors' neighbors are your neighbors.
  - E.g., The philosophers with whom I have co-authored papers have also generally co-authored papers with one another.

Common Features of Social Networks

Average-path-length, diameter, degree distributions, etc. are called network structure.

Imitate the Best and Bounded Rationality

Networks are useful not only for representing local interactions, but also for modeling bounded rationality.

In what way is "imitate the best" a bounded rational strategy?

Bounded Rationality

- Does the agent compare all available actions?
  - No. She considers only those actions (i) employed by her neighbors and (ii) that were employed on the last stage of inquiry.
  - The agent may not even know which actions are available.

Bounded Rationality

- Does the agent consider all possible states of the world?
  - No. In fact, the decision rule doesn't consider states of the world at all.
  - The agent only considers what actions were performed and their payoffs. She may be completely ignorant that payoffs depend upon some unknown "state of the world."

Bounded Rationality

- Does the agent know the payoffs of each action in each state of the world?
  - No. As above, she need not even that states of the world exist.
- Does the agent assign probabilities to each state of the world?
- Does the agent perform calculations and then compare actions?
  - A bit. The agent finds the best action employed by her neighbors. That involves some comparisons, but it requires no calculations.

Games on Networks

The next four chapters of [Alexander, 2007] have the same structure:

1. Alexander introduces a two-person game (e.g., the prisoner's dilemma or stag hunt)
2. He argues that particular actions in the game correspond to particular norms of behavior:
   - Silence in the prisoner's dilemma = Cooperation
   - Hunting Stag = Trust

Games on Networks

The next four chapters of [Alexander, 2007] have the same structure:

3. He argues that the replicator dynamics cannot explain the spread of each norm.
4. He then imagines that agents in a network play the game repeatedly with their neighbors, and use some boundedly rational strategy for learning what action to play next.
5. He analyzes (i) boundedly rational strategies and (ii) network structures that cause the norm to spread throughout the network.

Outline

Topics

Topics we'll discuss today:

- Nested Loops and If-Else Statements
- Procedures and Reporters
- Writing Pseudo-Code

References I

Abbott, R. J., James, J. K., Milne, R. I., and Gillies, A. C. (2003). Plant introductions, hybridization and gene flow. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 358(1434):1123–1132.

Alexander, J. M. (2007). *The structural evolution of morality*. Cambridge University Press Cambridge.

Gintis, H. (2012). An evolutionary perspective on the univfication of the behavioral sciences. In *Evolution and Rationality: Decisions, Cooperation, and Strategic Behavior*. Cambridge University Press.

Holden, C. J. (2002). Bantu language trees reflect the spread of farming across sub-saharan africa: a maximum-parsimony analysis. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 269(1493):793–799.

Holden, C. J. and Mace, R. (2003). Spread of cattle led to the loss of matrilineal descent in africa: a coevolutionary analysis. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 270(1532):2425–2433.

References II

Jablonka, E. and Lamb, M. J. (1995). *Epigenetic inheritance and evolution: the Lamarckian dimension*. Oxford University Press.

Mace, R., Pagel, M., Bowen, J. R., Otterbein, K. F., Ridley, M., Schweizer, T., and Voland, E. (1994). The comparative method in anthropology [and comments and reply]. *Current Anthropology*, 35(5):549–564.

Mesoudi, A., Whiten, A., and Laland, K. N. (2006). Towards a unified science of cultural evolution. *Behavioral and Brain Sciences*, 29(4):329346.

Milgram, S. (1967). The small world problem. *Psychology today*, 2(1):60–67.

Okasha, S. and Binmore, K. (2012). *Evolution and Rationality: Decisions, Co-operation, and Strategic Behaviour*. Cambridge University Press.

Rivera, M. C. and Lake, J. A. (2004). The ring of life provides evidence for a genome fusion origin of eukaryotes. *Nature*, 431(7005):152–155.

Simon, H. A. (1957). Models of man; social and rational.