

Artificial Intelligence II

CSC 720—Spring 2011

Jon Doyle

Department of Computer Science
North Carolina State University

January 25, 2011

Economic rationality

Some history

AI: reaction against and revitalization of economics

- Failures of utilitarian models shunt attention to alternatives
 - Logical reasoning
 - Heuristic reasoning
- 40 years of avoidance before practical means for exploiting economic models
 - Bayesian probabilistic networks
 - Multiattribute utility and qualitative preference models
- Recasting AI theories using economic concepts
 - Providing realistic ideas of limited rationality
 - Now a major element of AI education and research (Russell and Norvig 1995)

The economic theory of rationality

- Focuses on the rationality of decisions
- Has as large a role to play in AI as mathematical logic
- Helps understand psychological rationality

Economic rationality

A theory of *choice among alternatives*

- Preference
- Utility
- Expected utility
- Rational choice

Preference

Comparisons between alternatives

- $A \succ B$
The agent *strictly prefers* B to A
- $A \sim B$
The agent is *indifferent* between A and B
- $A \succsim B$
The agent *weakly prefers* B to A

Rationality requirements

Consistency and completeness conditions on preferences

- ① Either $A \succsim B$ or $B \succsim A$ (completeness)
- ② If $A \succsim B$, then $B \not\succ A$ (consistency)
- ③ If $A \succsim B$ and $B \succsim C$, then $A \succsim C$ (transitivity)

Are preferences fundamental?

- Only in economic theory!
- Economics *per se* mainly avoids question of origins of preference
 - Greed, philanthropy, selfishness, altruism, love, hate, habit, compulsion, are all irrelevant
 - Preference just reflects the upshot no matter what the motivations
- Economics as a “value free” theory

Utility

Numerical representation u of preference rankings:

- $u(A) < u(B)$ whenever $A \succ B$
- $u(A) = u(B)$ whenever $A \sim B$

Important points:

- The representation is not unique
- This utility is ordinal
- Utility \neq cost
- Utility \neq goal
- Utility \neq pleasure – pain

Probability

Measure p over a sigma algebra F over set Ω

- $p : F \rightarrow \mathbb{R}^+$; that is, $p(E) \geq 0$ for each $E \in F$
- $p(\Omega) = 1$
- $p(\bigcup_i E_i) = \sum_i p(E_i)$ for countable sets of pairwise disjoint events

Why rationality?

Dutch Book argument

- If your belief probabilities do not satisfy the axioms of probability, I can make money off of you

Cox's Theorem

- Any intuitive plausibility measure must be equivalent to a probability measure (but see the fine print)
 - Plausibility of A determines plausibility of $\neg A$
 - Plausibility of $A \wedge B$ is determined by plausibility of A and plausibility of A given B
 - Plausibility of a proposition is the same independent of the order in which one considers evidence supporting it

Expected utility

Subjective Bayesian decision theory

- Probability measures p_A (from \succsim)
- Cardinal utility function U (from \succsim)
- Expected utility function $\hat{U}(A)$

$$\hat{U}(A) \stackrel{\text{def}}{=} \sum_S p_A(S) U(S)$$

- $A \succsim B$ if and only if $\hat{U}(A) \leq \hat{U}(B)$
- Rationality as maximizing expected utility

Rational choice

Choose *maximally preferred* alternatives

- Alternative set $\mathcal{A} = \{A_1, A_2, \dots\}$
- Choose A_i only if $A_j \succsim A_i$ for every $A_j \in \mathcal{A}$
- Several, one, or none maximal
- Explicit vs. implicit rationality

Summary

Qualitative theory of rational choice
Likelihood and preference comparisons
Consistency and completeness assumptions



Quantitative theory of rational choice
Probability and utility functions
Maximizing expected utility

Issues

Universality of rationality

- Can any behavior be made rational?
- With stability in value judgments?

Universality of utility

- Fragmentation of values

Logic *and* economics

Logic and economics are complementary, not competing

- Logic concerns meaning and possibility
Deduction is a method for perceiving these
- Economics concerns utility and probability
Actions embody choices based on perceptions

Normative economic rationality

- Formalizes heuristic “usefulness”
- Subsumes logic
- Decouples rationality from intelligence
- *The proper knowledge-level norm for reasoning*

Heuristic reasoning

Heuristic guidance of reasoning ignores choice

- Make hopefully useful inferences
- Ignore consistency and completeness

"Principle of rationality. If an agent has knowledge that one of its actions will lead to one of its goals, then the agent will select that action." (Newell 1982)

- *If it seems useful, do it!*
- Useful but haphazard results
- Formally disreputable

Specific roles for rational choice

Do heuristic techniques really increase expected utility?

- Heuristics as implicitly rational procedures
- Analyze existing techniques
- Identify circumstances in which they are rational
- Make them more rational

Rational approximation

Incremental improvement of imprecise answers

- Monotone approximation of complete answers
 - Theory of data-structures
 - Constraints
- Monotone approximation of maximal utility
 - Flexible computation
 - Anytime algorithms
- Monotone approximation of maximal probability
 - Probabilistic algorithms (Monte-Carlo, Las Vegas)
 - PAC algorithms

Rational representation

Choice of representations

- Data-structures
- Conceptual organization
- Mental constitutions
- Pragmatic roles

Rational guidance of search and inference

Choosing reasoning steps and methods

- Estimate probabilities of outcomes of computations
- Estimate utilities of outcomes of computations
- Choose steps and methods of maximal estimated expected utility
- Halt deliberation when further computation is estimated to be worthless
- Guiding search
- Expected value of information (EVI)
- Choosing methods
- Estimating costs of inference

Rational learning

Learning involves selection, not just memorization

- What should be learned?
- What should be forgotten?
- What should be summarized?
- Comparison of alternative theories and explanations
Operationality criteria vs. utility measures
- Comparison of alternative categorizations and taxonomic organizations
- Are PAC definitions of maximal expected utility?

Rational planning

Plans should be efficient, not merely effective

- Goals routinely involve efficiency
- Comparison of alternative plans
- Planning for contingencies
 - Plan-time/execution-time costs of reasoning
 - Time/memory tradeoffs
- Decision-theoretic planning
- Structured utility representation
- POMDP policy construction

Rational interaction

What makes something “general-purpose”?

- GP \neq domain independent
- GP \neq fixed typical purpose
- GP means *adaptable to any purpose*
- Empathetic adoption of expectations and preferences

Summary

AI needs the theory of economic rationality

- Thinking is costly, and intelligent thinking requires mental efficiency (indeed, *rational self-government*)
- There is no alternative theory for understanding the capabilities and behaviors of heuristic systems
- It helps AI draw on and contribute to other fields (see *Strategic Directions in Artificial Intelligence*)