CS 188: Artificial Intelligence
Spring 2006

Lecture 20: Utilities

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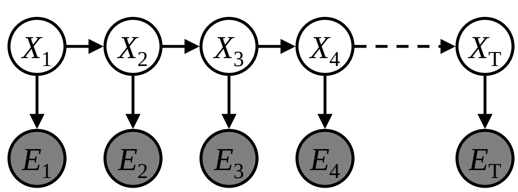
Recap: HMMs

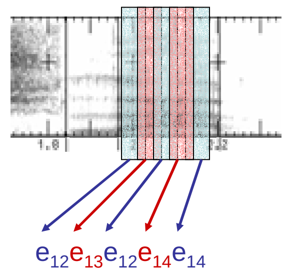
- Hidden Markov models (HMMs)
  - Underlying Markov chain over states X
  - You only observe outputs (effects) E at each time step
  - Want to reason about the hidden states X given observations E



$$P(x_{1:T}, e_{1:T}) = P(x_1)P(e_1|x_1)\prod_{i=2}^{T} P(x_i|x_{i-1})P(e_i|x_i)$$

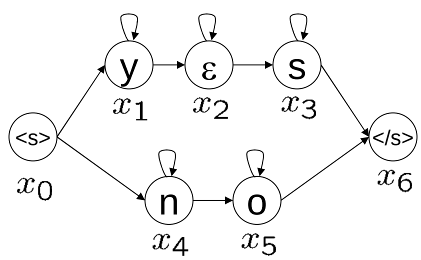
Recap: Speech Recognition

- Observations are acoustic measurements
  - Real systems:
    - 39 MFCC coefficients
    - Real numbers, modeled with mixtures of multidimensional Gaussians
  - Your projects:
    - 2 real numbers (formant frequencies)
    - Discretized values, discrete conditional probs



Speech Recognition

- States indicate which part of which word we're speaking
  - Each word broken into phonemes
  - Real systems: context-dependent sub-phonemes
  - Your projects: just one state per phoneme
- Example: Yes/No recognizer



$$P(x|x')$$

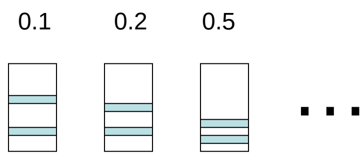
$$P(x|x_0) = \begin{cases} 0.5 & \text{if } x = x_1, \\ 0.5 & \text{if } x = x_4. \\ 0 & \text{otherwise} \end{cases}$$

$$P(x|x_1) = \begin{cases} 0.8 & \text{if } x = x_1, \\ 0.2 & \text{if } x = x_2. \\ 0 & \text{otherwise} \end{cases}$$

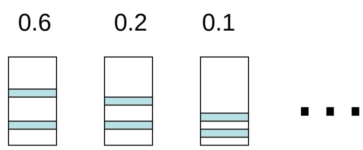
Speech Recognition

- Emission probs: distribution over acoustic observations for each phoneme
  - How to learn these? See project 3!

$P(e|\text{“o”})$



$P(e|\text{“}\epsilon\text{”})$

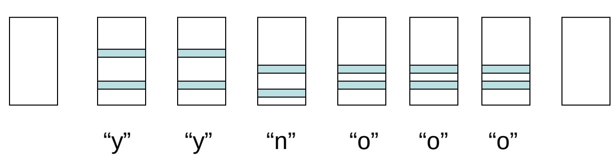


Example of Hidden Sequences

- For the yes/no recognizer, imagine we hear “yynooo”
- What are the scores of possible labelings?

	<s>	n	n	n	o	o	o	</s>	Low, but best?
	<s>	y	y	ε	ε	s	s	</s>	VV Low
X	<s>	y	y	ε	ε	ε	s	</s>	V Low
	<s>	y	y	n	o	o	o	</s>	ZERO

E



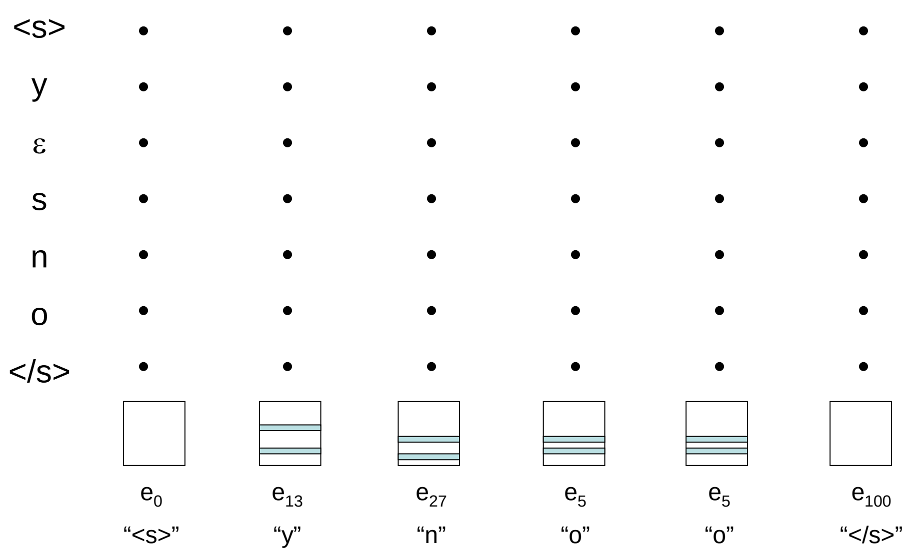
The Viterbi Algorithm

- The Viterbi algorithm computes the best labeling for an observation sequence
  - Incrementally computes best scores for subsequences
  - Recurrence:

$$\begin{aligned} m_t[x_t] &= \max_{x_{1:t-1}} P(x_{1:t-1}, x_t, e_{1:t}) \\ &= \max_{x_{1:t-1}} P(x_{1:t-1}, e_{1:t-1}) P(x_t|x_{t-1}) P(e_t|x_t) \\ &= P(e_t|x_t) \max_{x_{t-1}} P(x_t|x_{t-1}) \max_{x_{1:t-2}} P(x_{1:t-1}, e_{1:t-1}) \\ &= P(e_t|x_t) \max_{x_{t-1}} P(x_t|x_{t-1}) m_{t-1}[x_{t-1}] \end{aligned}$$

  - Also store backtraces which record the argmaxes

Example



Utilities

- So far: talked about beliefs

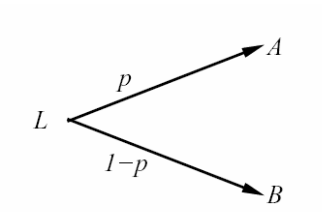
- Important difference between:
  - Belief about some variables
  - Rational action involving those variables
  - Remember the midterm question?

- Next: utilities

Preferences

- An agent chooses among:
  - Prizes: A, B, etc.
  - Lotteries: situations with uncertain prizes

$$L = [p, A;\ (1-p), B]$$



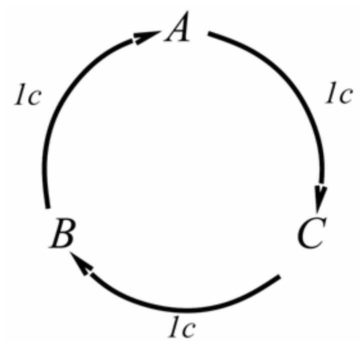
- Notation:

$A \succ B$	A preferred over B
$A \sim B$	indifference between A and B
$A \succeq B$	B not preferred over A

Rational Preferences

- We want some constraints on preferences before we call them rational

- For example: an agent with intransitive preferences can be induced to give away all its money
  - If B > C, then an agent with C would pay (say) 1 cent to get B
  - If A > B, then an agent with B would pay (say) 1 cent to get A
  - If C > A, then an agent with A would pay (say) 1 cent to get C



Rational Preferences

- Preferences of a rational agent must obey constraints.
  - These constraints (plus one more) are the axioms of rationality

Orderability

$$(A \succ B) \vee (B \succ A) \vee (A \sim B)$$

Transitivity

$$(A \succ B) \wedge (B \succ C) \Rightarrow (A \succ C)$$

Continuity

$$A \succ B \succ C \Rightarrow \exists p\ [p, A;\ 1-p, C] \sim B$$

Substitutability

$$A \sim B \Rightarrow [p, A;\ 1-p, C] \sim [p, B; 1-p, C]$$

Monotonicity

$$A \succ B \Rightarrow$$
$$(p \geq q \Leftrightarrow [p, A;\ 1-p, B] \succeq [q, A;\ 1-q, B])$$

- Theorem: Rational preferences imply behavior describable as maximization of expected utility

MEU Principle

- Theorem:
  - [Ramsey, 1931; von Neumann & Morgenstern, 1944]
  - Given any preferences satisfying these constraints, there exists a real-valued function U such that:

$$U(A) \geq U(B) \;\Leftrightarrow\; A \succeq B$$

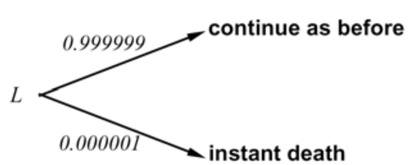
$$U([p_1, S_1;\ \ldots\ ;\ p_n, S_n]) = \sum_i p_i U(S_i)$$

- Maximum expected likelihood (MEU) principle:
  - Choose the action that maximizes expected utility
  - Note: an agent can be entirely rational (consistent with MEU) without ever representing or manipulating utilities and probabilities
  - E.g., a lookup table for perfect tictactoe

Human Utilities

- Utilities map states to real numbers. Which numbers?
- Standard approach to assessment of human utilities:
  - Compare a state A to a standard lottery L_p between
    - ``best possible prize'' u_+ with probability p
    - ``worst possible catastrophe'' u_- with probability 1-p
  - Adjust lottery probability p until A ~ L_p
  - Resulting p is a utility in [0,1]

pay $30 ~



Utility Scales

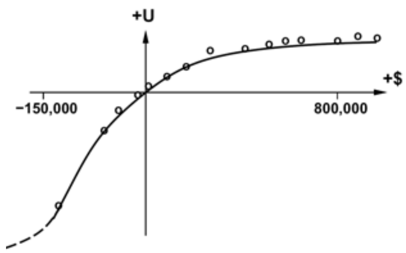
- Normalized utilities: $u_+ = 1.0$, $u_- = 0.0$
- Micromorts: one-millionth chance of death, useful for paying to reduce product risks, etc.
- QALYs: quality-adjusted life years, useful for medical decisions involving substantial risk
- Note: behavior is invariant under positive linear transformation

$$U'(x) = k_1 U(x) + k_2 \quad \text{where } k_1 > 0$$

- With deterministic prizes only (no lottery choices), only ordinal utility can be determined, i.e., total order on prizes

Money

- Money does not behave as a utility function
- Given a lottery L:
  - Define expected monetary value EMV(L)
  - Usually U(L) < U(EMV(L))
  - I.e., people are risk-averse
- Utility curve: for what probability p am I indifferent between:
  - A prize x
  - A lottery [p,$M; (1-p),$0] for large M?
- Typical empirical data, extrapolated with risk-prone behavior:



Example: Insurance

- Consider the lottery [0.5,$1000; 0.5,$0]?
  - What is its expected monetary value? ($500)
  - What is its certainty equivalent?
    - Monetary value acceptable in lieu of lottery
    - $400 for most people
  - Difference of $100 is the insurance premium
    - There's an insurance industry because people will pay to reduce their risk
    - If everyone were risk-prone, no insurance needed!

Example: Human Rationality?

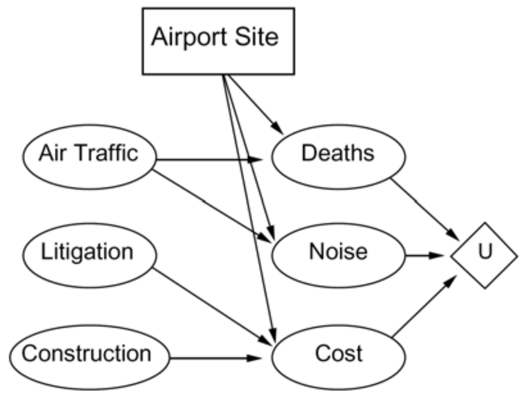
- Famous example of Allais (1953)
  - A: [0.8,$4k; 0.2,$0]
  - B: [1.0,$3k; 0.0,$0]

  - C: [0.2,$4k; 0.8,$0]
  - D: [0.25,$3; 0.75,$0]

- Most people prefer B > A, C > D
- But if U($0) = 0, then
  - B > A $\Rightarrow$ U($3k) > 0.8 U($4k)
  - C > D $\Rightarrow$ 0.8 U($4k) > U($3k)

Decision Networks

- Extended BNs
  - Chance nodes (circles, like in BNs)
  - Decision nodes (rectangles)
  - Utility nodes (diamonds)
- Can query to find action with max expected utility
- Online applets if you want to play with these



Value of Information

- Idea: compute value of acquiring each possible piece of evidence
  - Can be done directly from decision network
- Example: buying oil drilling rights
  - Two blocks A and B, exactly one has oil, worth k
  - Prior probabilities 0.5 each, mutually exclusive
  - Current price of each block is k/2
  - ``Consultant'' offers accurate survey of A. Fair price?
- Solution: compute expected value of information

  = expected value of best action given the information minus expected value of best action without information
- Survey may say ``oil in A'' or ``no oil in A'', prob 0.5 each (given!)

  = [0.5 * value of ``buy A'' given ``oil in A''] +
  [0.5 * value of ``buy B'' given ``no oil in A'']
  – 0
  = [0.5 * k/2] + [0.5 * k/2] - 0 = k/2

General Formula

- Current evidence E, current best action α
- Possible action outcomes S_i, potential new evidence E_j

$$EU(\alpha|E) = \max_a \sum_i U(S_i)\ P(S_i|E,a)$$

- Suppose we knew $E_j = e_{jk}$, then we would choose $\alpha(e_{jk})$ s.t.

$$EU(\alpha_{e_{jk}}|E, E_j = e_{jk}) = \max_a \sum_i U(S_i)\ P(S_i|E,a,E_j = e_{jk})$$

- BUT E_j is a random variable whose value is currently unknown, so:
  - Must compute expected gain over all possible values

$$VPI_E(E_j) = \left(\sum_k P(E_j = e_{jk}|E) EU(\alpha_{e_{jk}}|E, E_j = e_{jk})\right) - EU(\alpha|E)$$

- (VPI = value of perfect information)

VPI Properties

- Nonnegative in expectation

$$\forall j, E : VPI_E(E_j) \geq 0$$

- Nonadditive ---consider, e.g., obtaining E_j twice

$$VPI_E(E_j, E_k) \neq VPI_E(E_j) + VPI_E(E_k)$$

- O

$$\begin{aligned} VPI_E(E_j, E_k) &= VPI_E(E_j) + VPI_{E,E_j}(E_k) \\ &= VPI_E(E_k) + VPI_{E,E_k}(E_j) \end{aligned}$$

Next Class

- Start on reinforcement learning!
  - Central idea of modern AI
  - How to learn complex behaviors from simple feedback
  - Basic technique for robotic control
  - Last large technical unit of the course