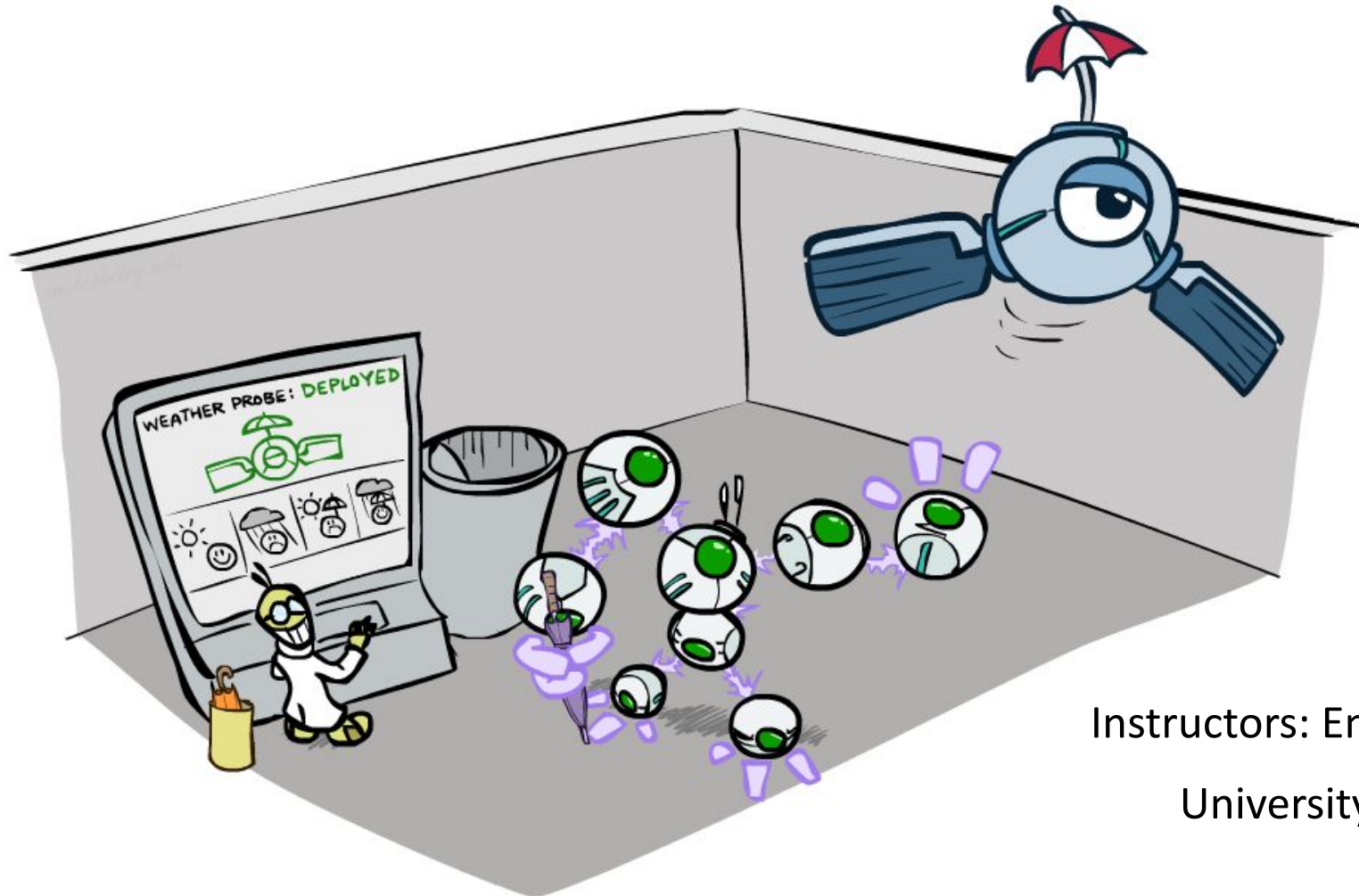


CS 188: Artificial Intelligence

Decision Networks and Value of Information



Instructors: Emma Pierson and Peyrin Kao
University of California, Berkeley

RESEARCH ARTICLE

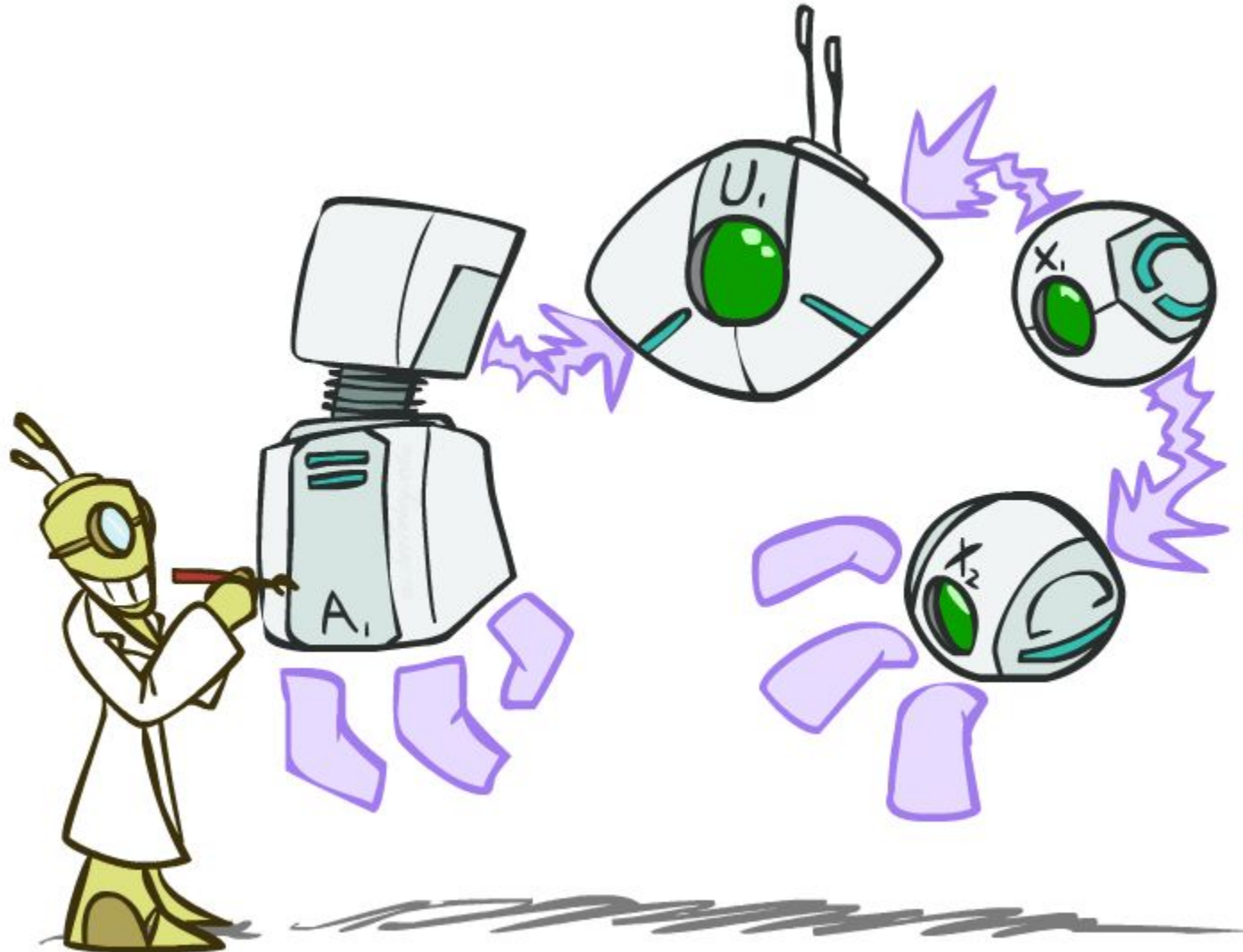
Uncertainty and Denial: A Resource-Rational Model of the Value of Information

Emma Pierson¹, Noah Goodman^{2*}

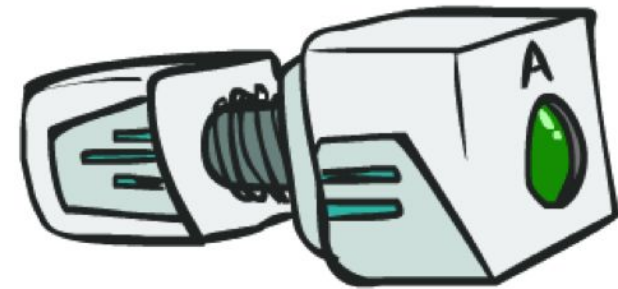
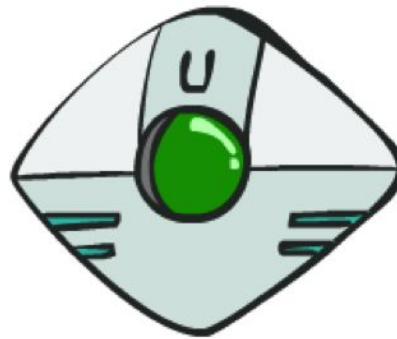
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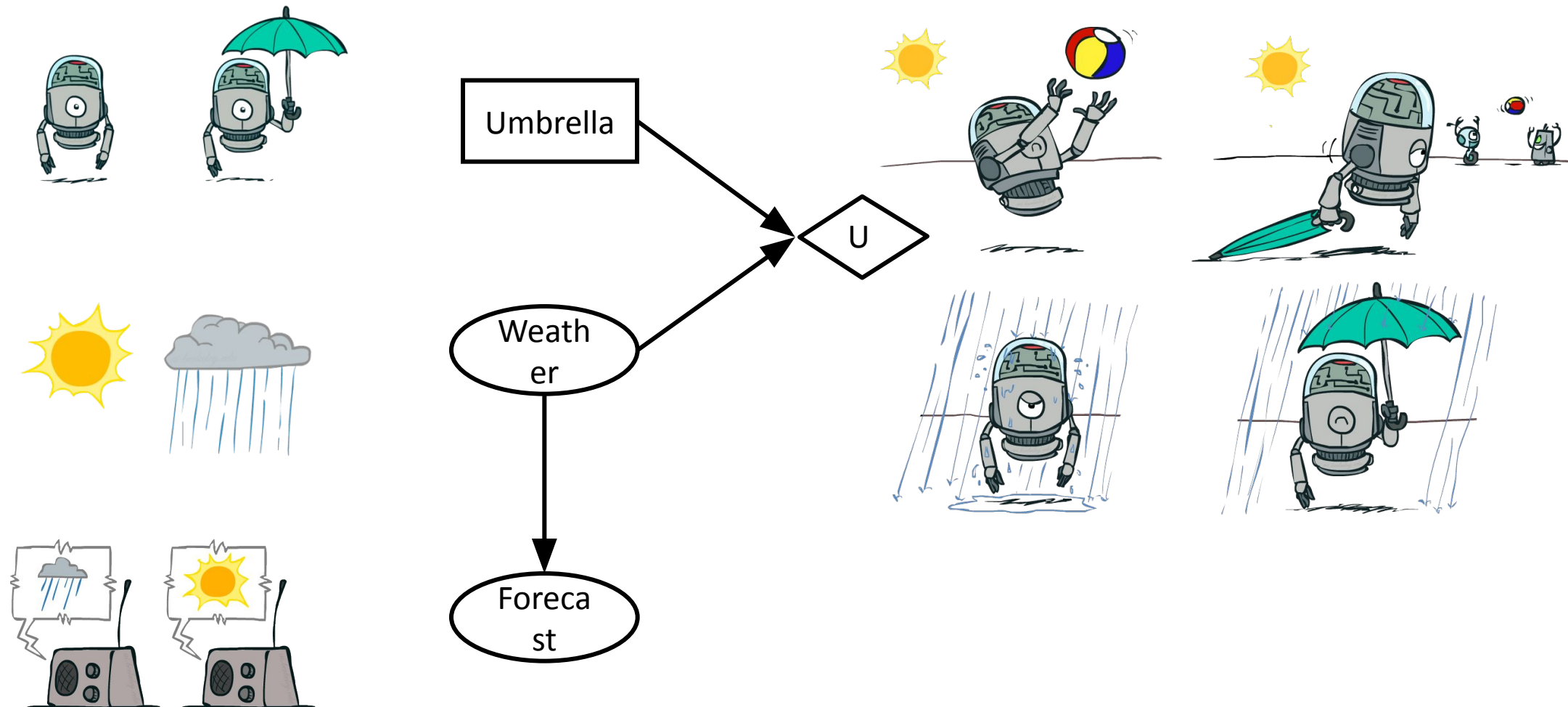
Decision Networks



Unused art



Decision Networks



Decision Networks

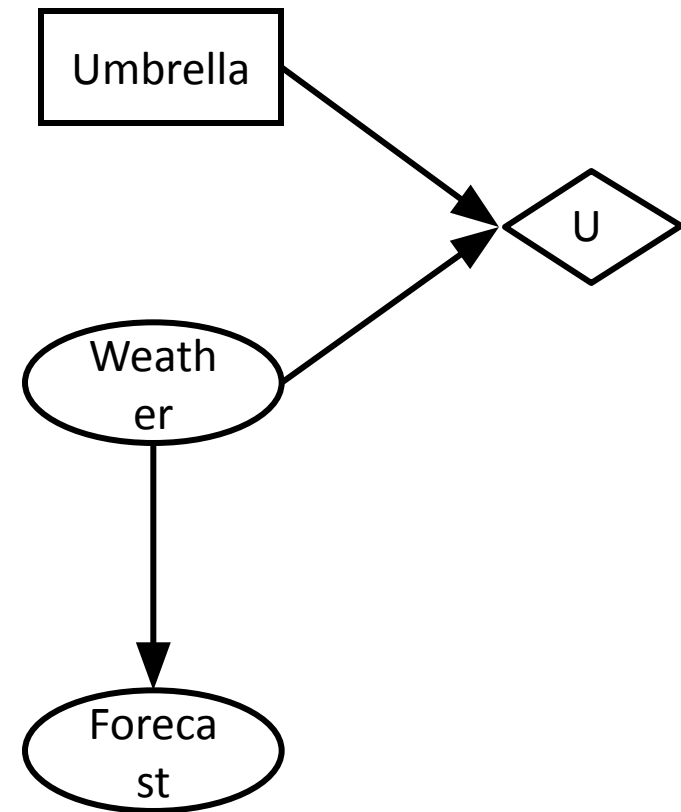
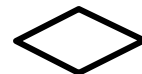
- **MEU: choose the action which maximizes the expected utility given the evidence**

- Can directly operationalize this with decision networks

- Bayes nets with nodes for utility and actions
- Lets us calculate the expected utility for each action

- New node types:

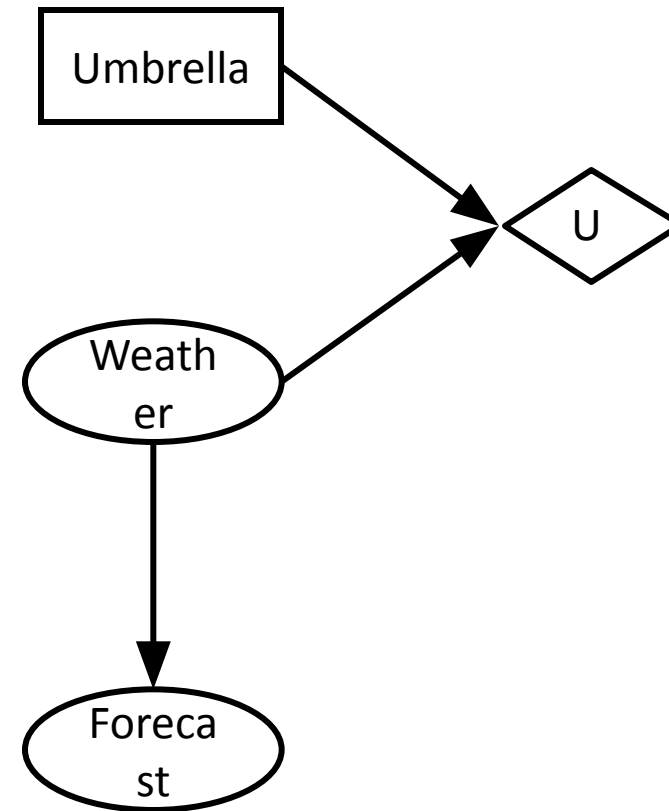
- Chance nodes (just like BNs)
- Actions (rectangles, cannot have parents, act as observed evidence. You choose these!)
- Utility node (diamond, depends on action and chance nodes)



Decision Networks

- Action selection

- Instantiate all evidence
- Set action node(s) each possible way
- Calculate posterior for all parents of utility node, given the evidence
- Calculate expected utility for each action
- Choose maximizing action



Decision Networks

Umbrella = leave

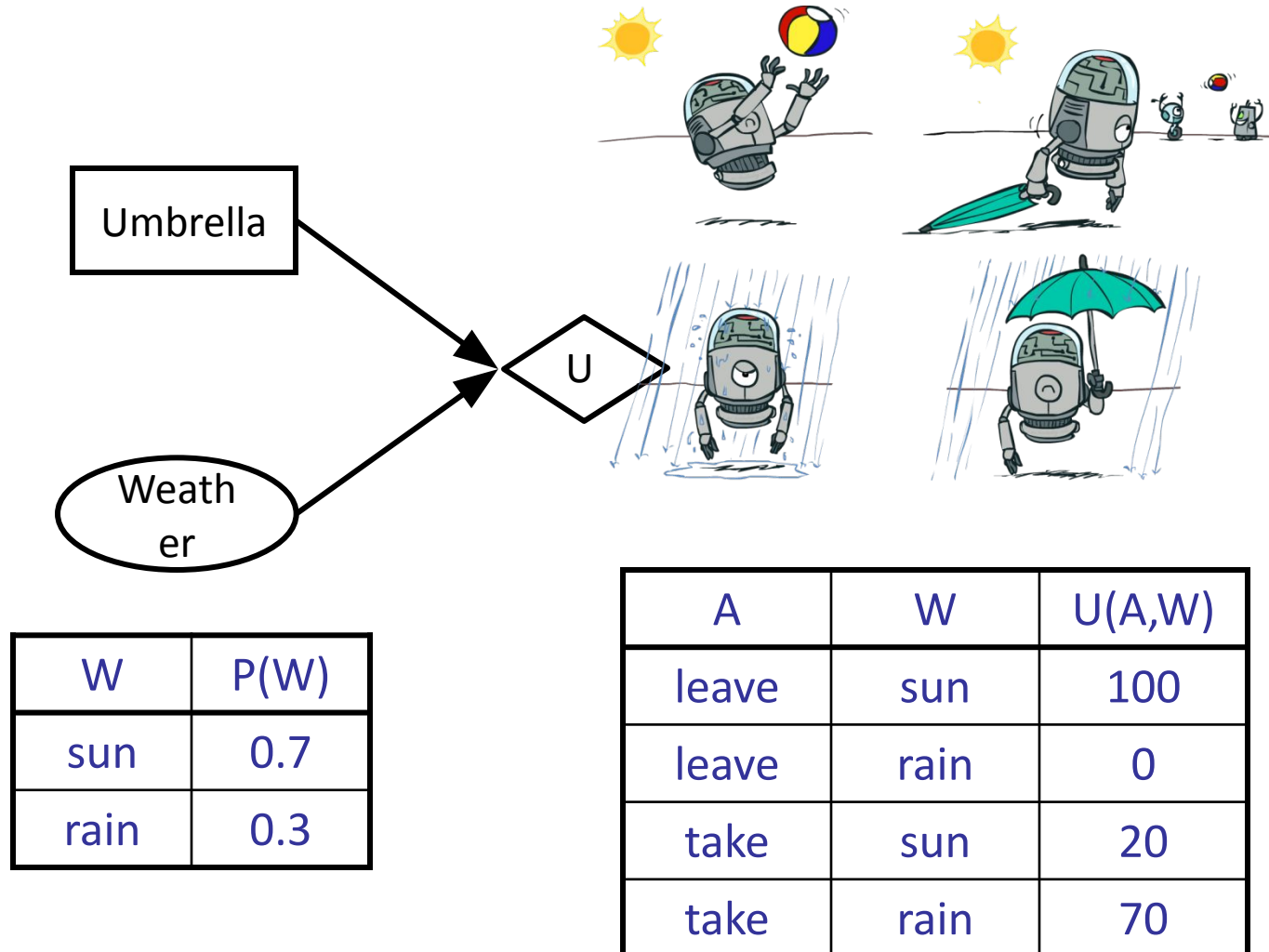
$$\begin{aligned} EU(\text{leave}) &= \sum_w P(w)U(\text{leave}, w) \\ &= 0.7 \cdot 100 + 0.3 \cdot 0 = 70 \end{aligned}$$

Umbrella = take

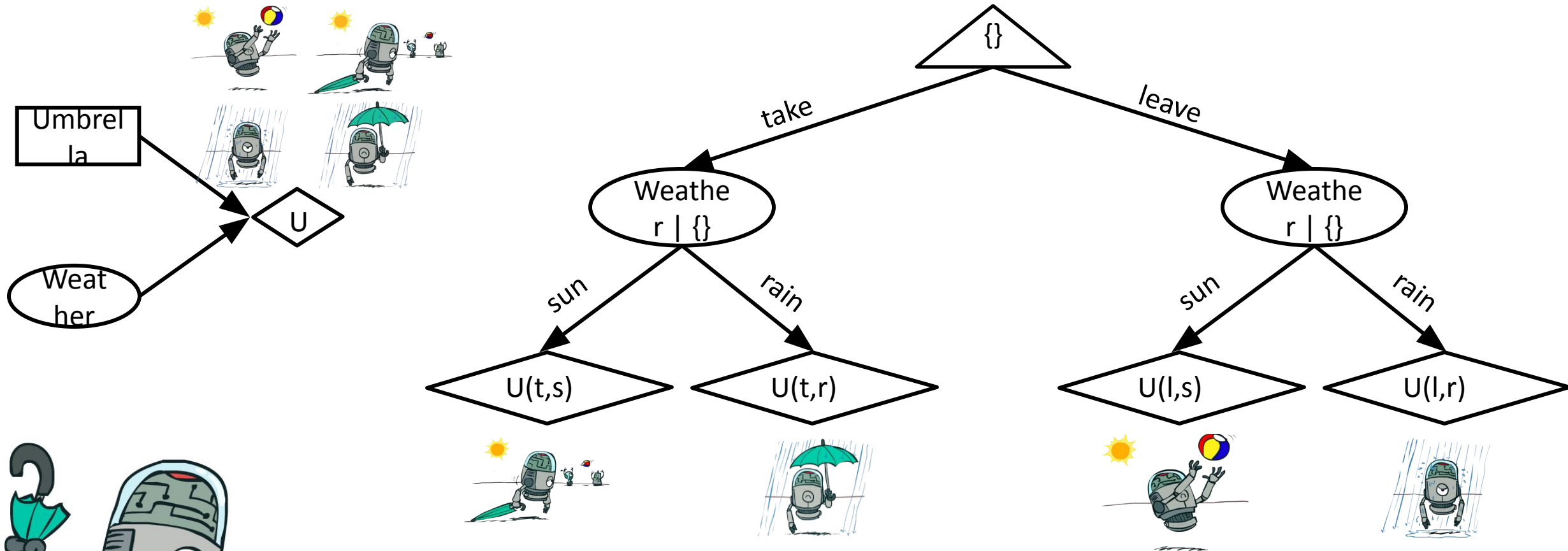
$$\begin{aligned} EU(\text{take}) &= \sum_w P(w)U(\text{take}, w) \\ &= 0.7 \cdot 20 + 0.3 \cdot 70 = 35 \end{aligned}$$

Optimal decision = leave

$$MEU(\emptyset) = \max_a EU(a) = 70$$



Decisions as Outcome Trees



- Almost exactly like expectimax / MDPs
- What's changed? The probabilities of chance nodes can be hard to compute / require Bayes net inference.

Example: Decision Networks

Umbrella = leave

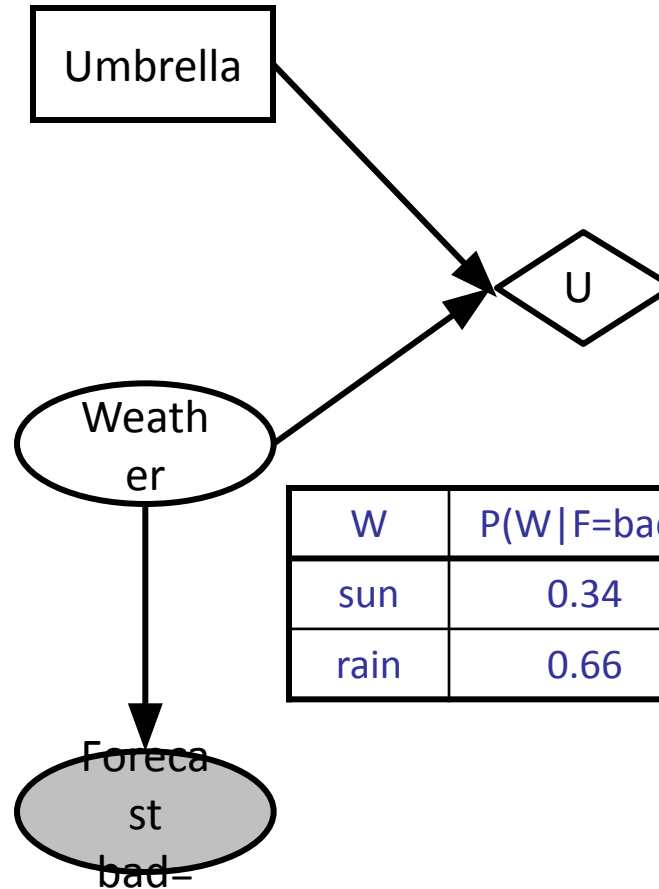
$$\begin{aligned} EU(\text{leave}|\text{bad}) &= \sum_w P(w|\text{bad})U(\text{leave}, w) \\ &= 0.34 \cdot 100 + 0.66 \cdot 0 = 34 \end{aligned}$$

Umbrella = take

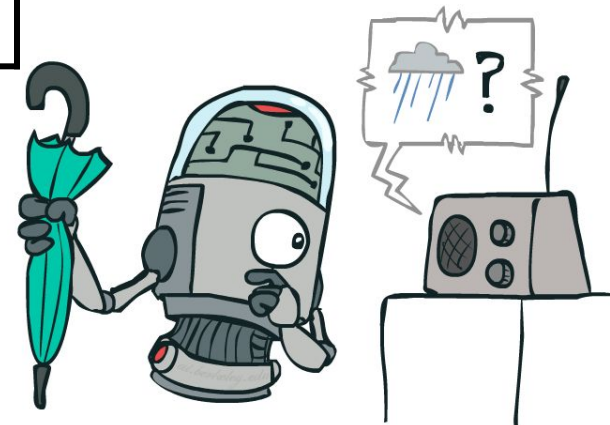
$$\begin{aligned} EU(\text{take}|\text{bad}) &= \sum_w P(w|\text{bad})U(\text{take}, w) \\ &= 0.34 \cdot 20 + 0.66 \cdot 70 = 53 \end{aligned}$$

Optimal decision = take

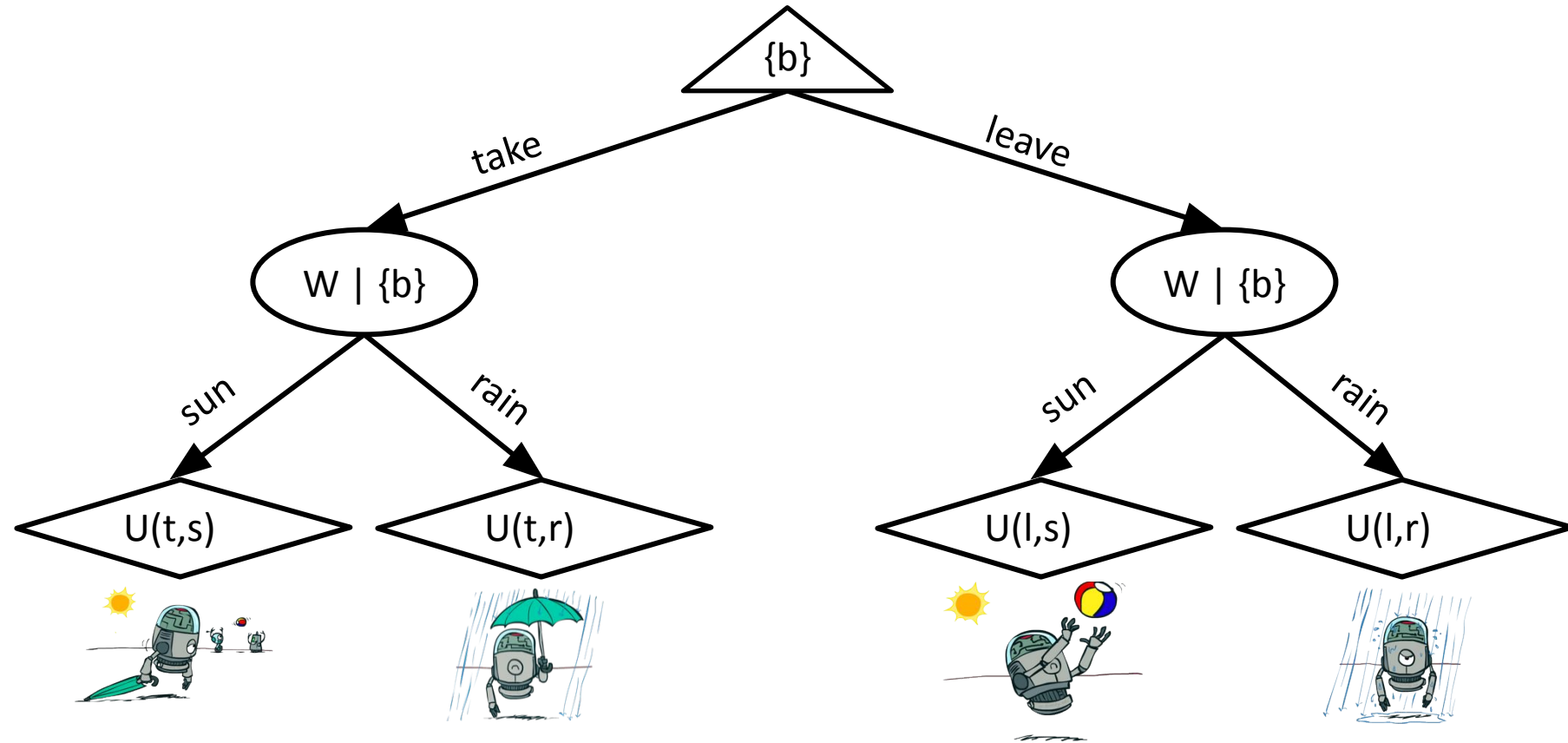
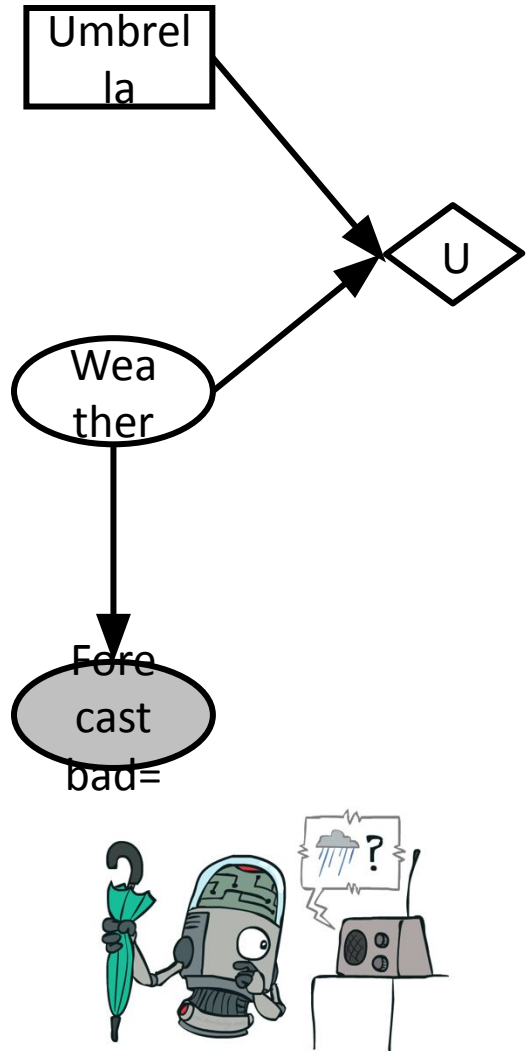
$$MEU(F = \text{bad}) = \max_a EU(a|\text{bad}) = 53$$



A	W	U(A,W)
leave	sun	100
leave	rain	0
take	sun	20
take	rain	70



Decisions as Outcome Trees

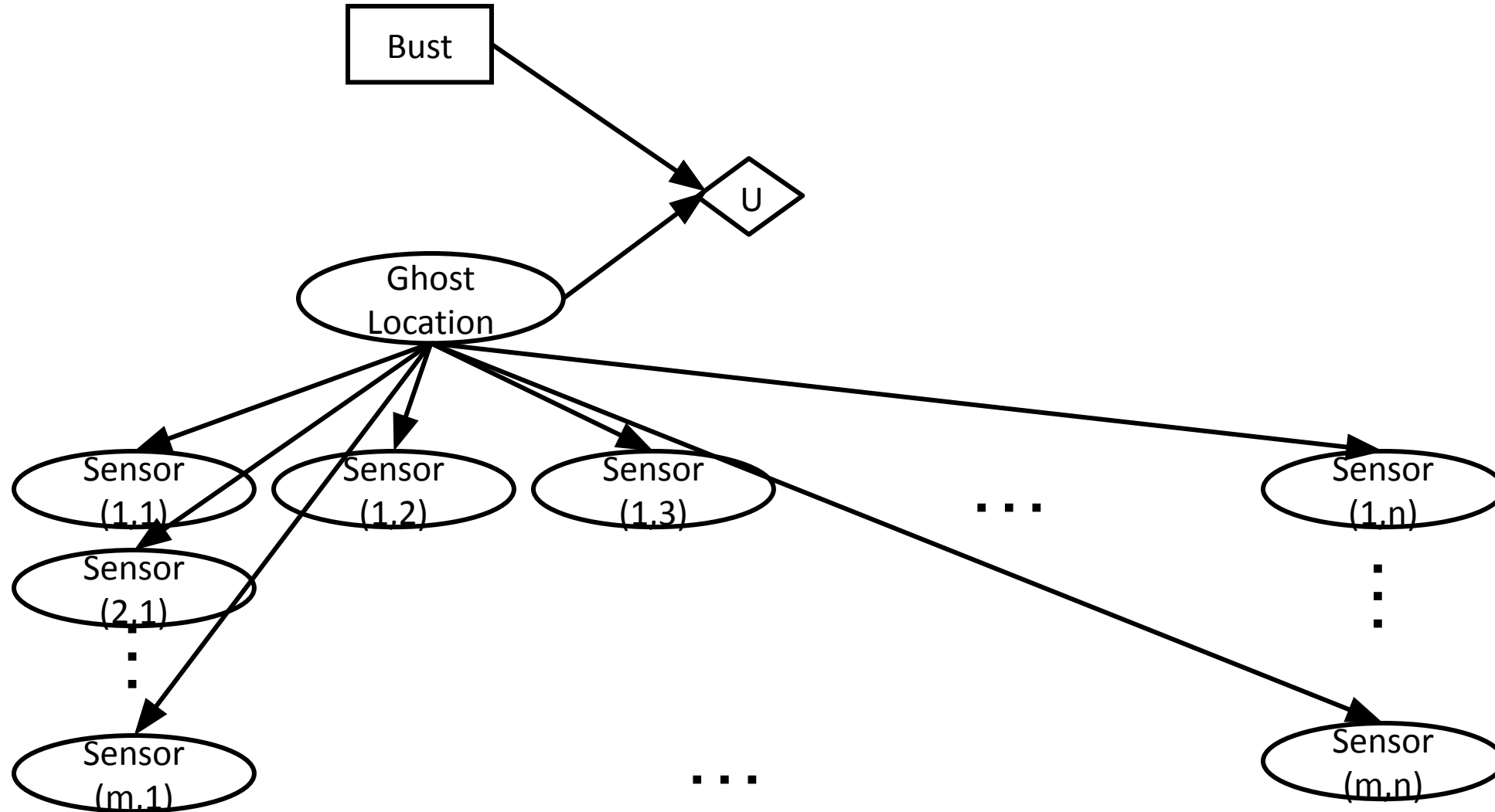


Video of Demo Ghostbusters with Probability

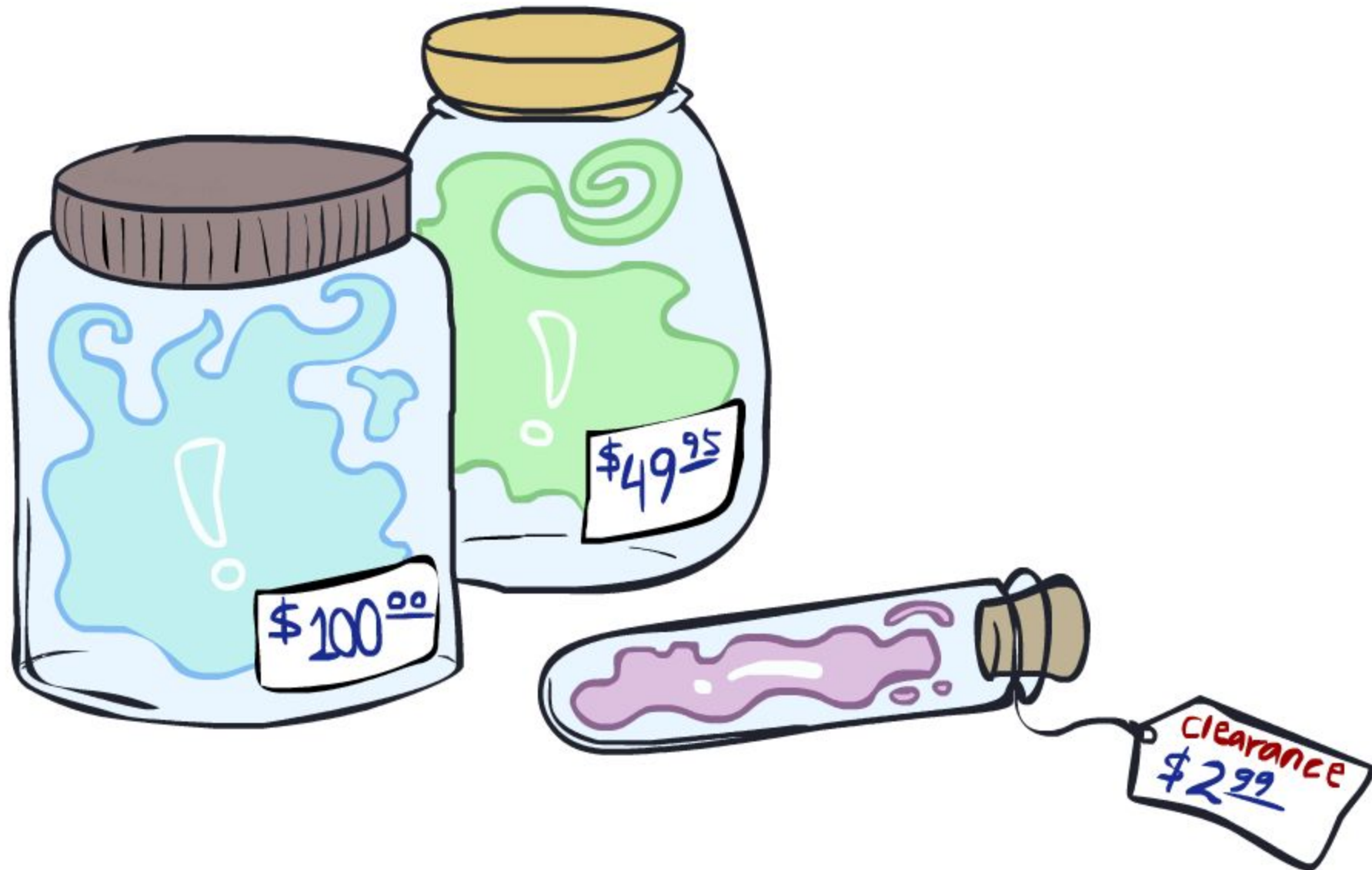


Ghostbusters Decision Network

Demo: Ghostbusters with probability

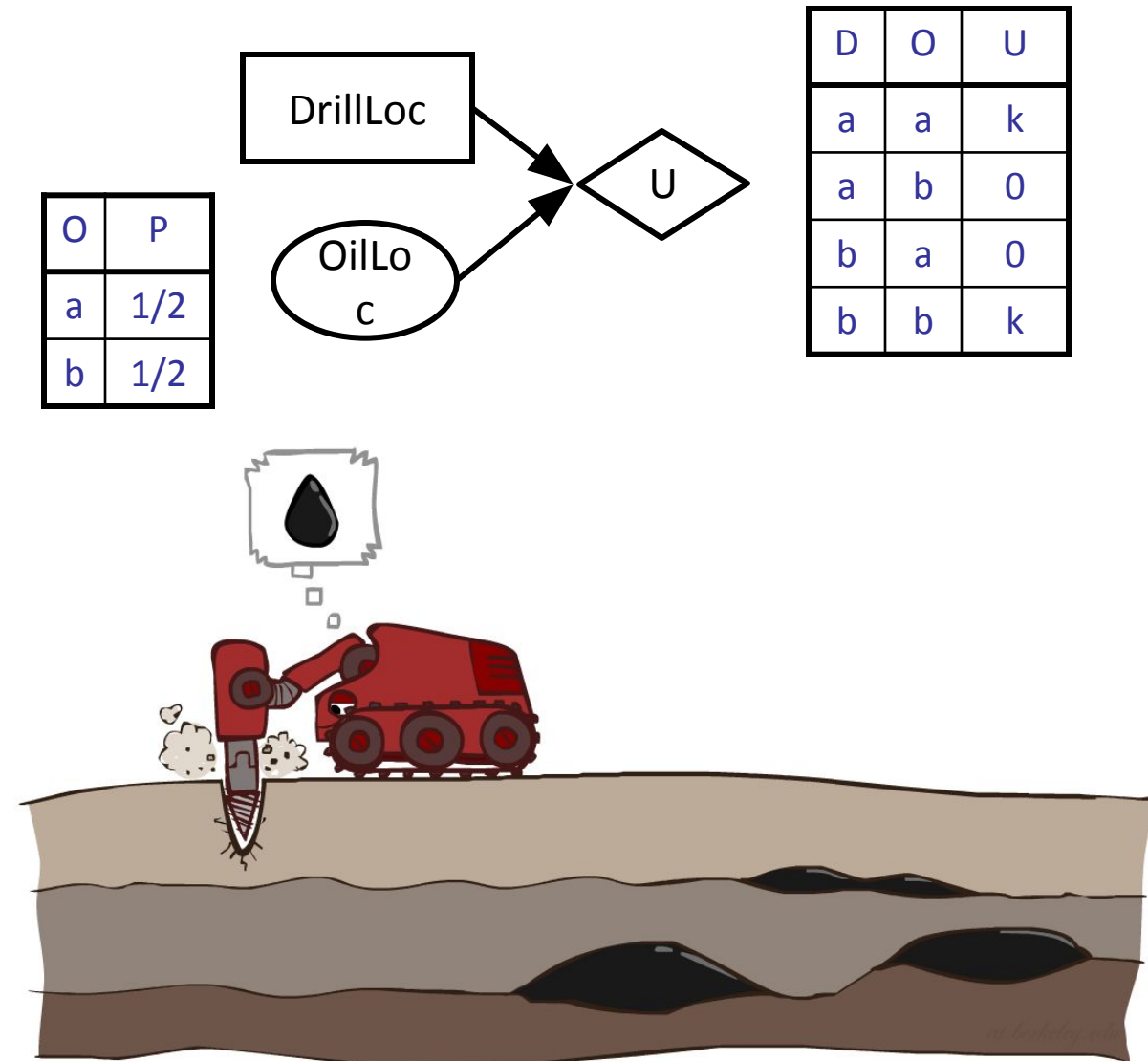


Value of Information



Value of Information

- Idea: compute value of acquiring evidence
 - Can be done directly from decision network
- Very simple example: buying oil drilling rights
 - Two blocks A and B, exactly one has oil, worth k
 - You can drill in one location
 - Prior probabilities 0.5 each, & mutually exclusive
 - Drilling in either A or B has $EU = k/2$, $MEU = k/2$
- Question: what's the value of information of O ?
 - Value of knowing which of A or B has oil
 - Value is expected gain in MEU from new info
 - Survey may say "oil in a" or "oil in b", prob 0.5 each
 - If we know OilLoc, MEU is k (either way)
 - Gain in MEU from knowing OilLoc?
 - $VPI(OilLoc) = k/2$
 - Fair price of information: $k/2$



VPI Example: Weather

MEU with no evidence

$$\text{MEU}(\emptyset) = \max_a \text{EU}(a) = 70$$

MEU if forecast is bad

$$\text{MEU}(F = \text{bad}) = \max_a \text{EU}(a|\text{bad}) = 53$$

MEU if forecast is good

$$\text{MEU}(F = \text{good}) = \max_a \text{EU}(a|\text{good}) = 95$$

Forecast distribution

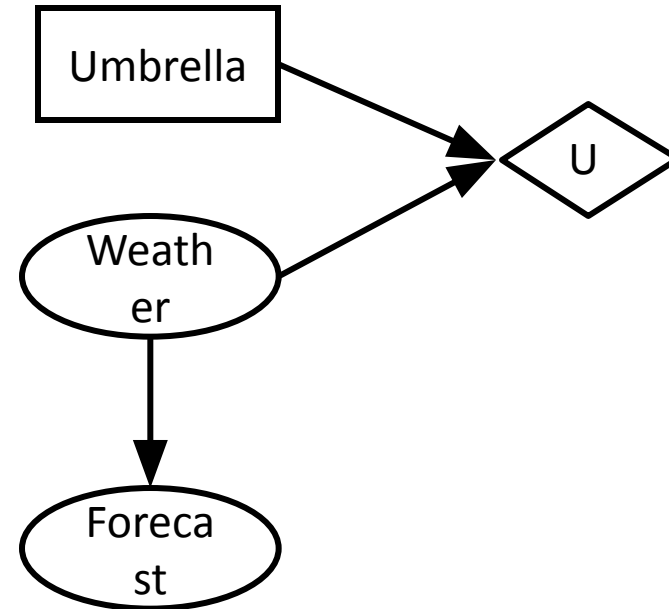
F	P(F)
good	0.59
bad	0.41



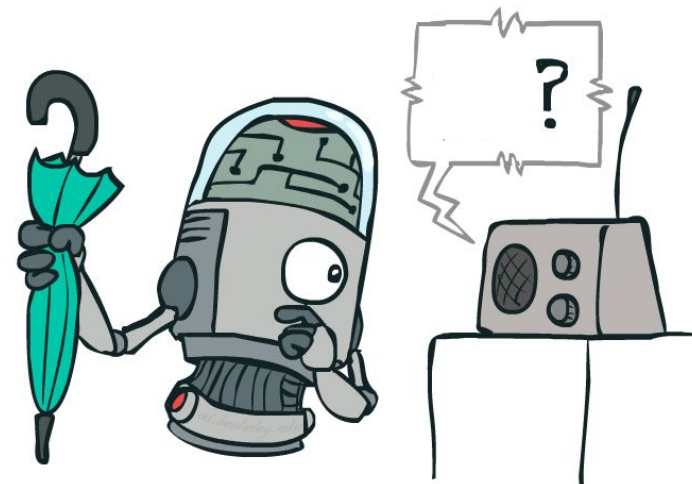
$$0.59 \cdot (95) + 0.41 \cdot (53) - 70$$

$$77.8 - 70 = 7.8$$

$$\text{VPI}(E'|e) = \left(\sum_{e'} P(e'|e) \text{MEU}(e, e') \right) - \text{MEU}(e)$$



A	W	U
leave	sun	100
leave	rain	0
take	sun	20
take	rain	70



Value of Information

- Assume we have evidence $E=e$. Value if we act now:

$$MEU(e) = \max_a \sum_s P(s|e) U(s, a)$$

- Assume we see that $E' = e'$. Value if we act then:

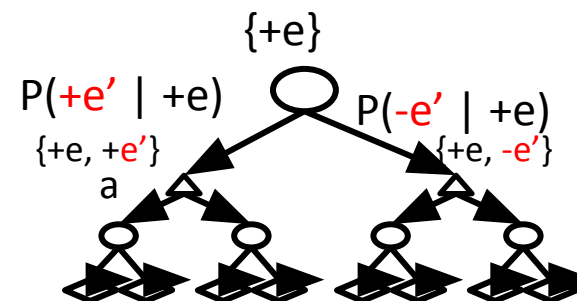
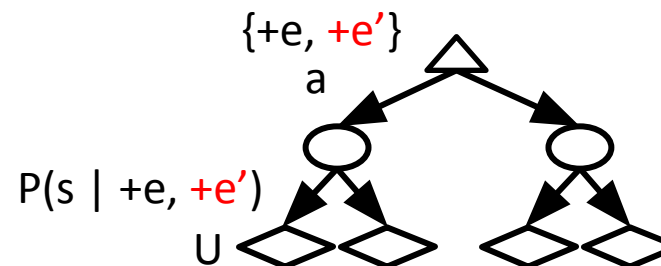
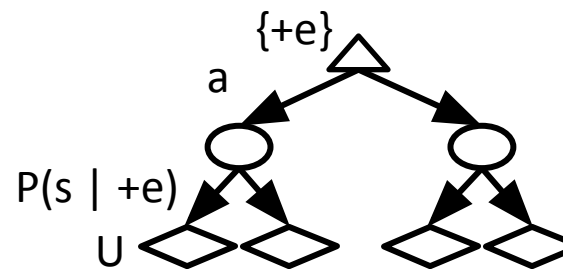
$$MEU(e, e') = \max_a \sum_s P(s|e, e') U(s, a)$$

- BUT E' is a random variable whose value is unknown, so we don't know what e' will be
- Expected value if E' is revealed and then we act:

$$MEU(e, E') = \sum_{e'} P(e'|e) MEU(e, e')$$

- Value of information: how much MEU goes up by revealing E' first then acting, over acting now:

$$VPI(E'|e) = MEU(e, E') - MEU(e)$$



VPI Properties

- Nonnegative

$$\forall E', e : \text{VPI}(E'|e) \geq 0$$



- Nonadditive

(think of observing E_j twice)

$$\text{VPI}(E_j, E_k|e) \neq \text{VPI}(E_j|e) + \text{VPI}(E_k|e)$$



- Order-independent

$$\begin{aligned} \text{VPI}(E_j, E_k|e) &= \text{VPI}(E_j|e) + \text{VPI}(E_k|e, E_j) \\ &= \text{VPI}(E_k|e) + \text{VPI}(E_j|e, E_k) \end{aligned}$$



Is VPI ever negative for *humans*?

- We aren't perfectly rational creatures
 - Would you want to know the day you will die?
 - What everyone around you is thinking?
 - That you carry an (actionable) genetic mutation?
 - That you carry an (unactionable) genetic mutation?

Is VPI ever negative for *humans*?

The New York Times



VOICES

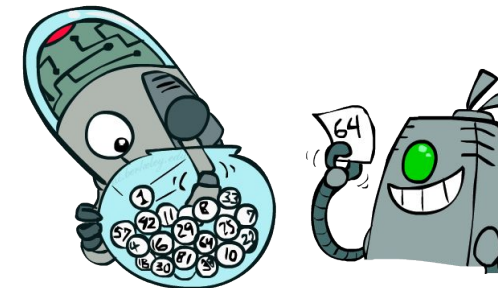
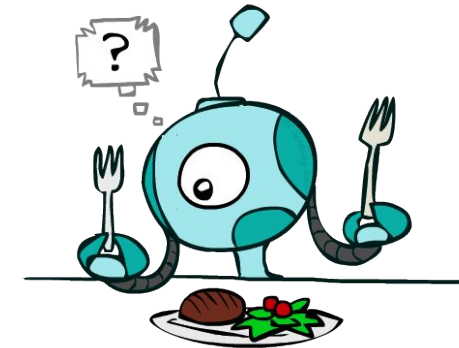
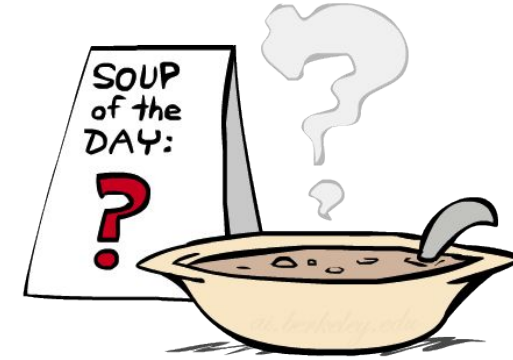
Knowing You Carry a Cancer Gene

BY EMMA PIERSON DECEMBER 31, 2012 3:21 PM 109

“At Stanford, I study artificial intelligence, in which math is used to resolve these sorts of dilemmas. My teachers claim that gaining information never hurts. It can be proved mathematically that a robot with more information never makes worse decisions. But we are not robots. Our eyes don’t filigree the world with coordinates and probabilities, and they can be blinded by tears.”

Quick VPI Questions

- The soup of the day is either clam chowder or split pea, but you wouldn't order either one. What's the value of knowing which it is?
- There are two kinds of plastic forks at a picnic. One kind is slightly sturdier. What's the value of knowing which?
- You're playing the lottery. The prize will be \$0 or \$100. You can play any number between 1 and 100 (chance of winning is 1%). What is the value of knowing the winning number?



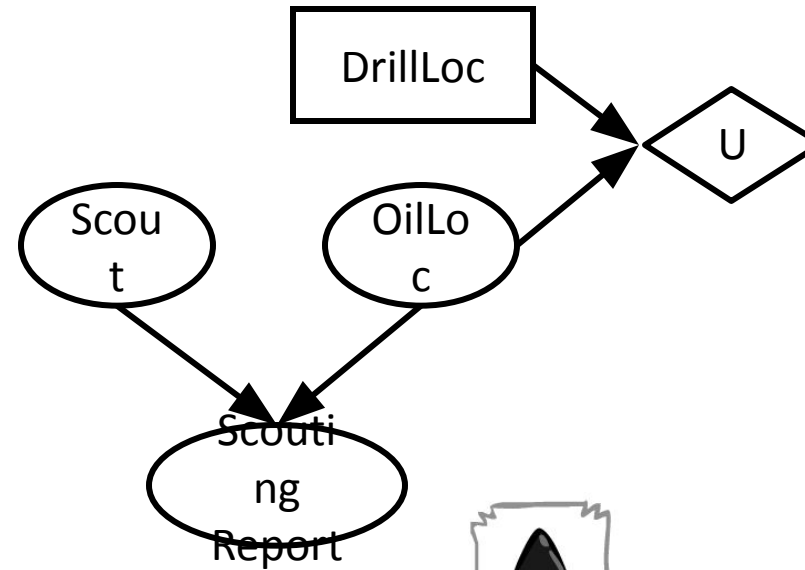
Value of Imperfect Information?



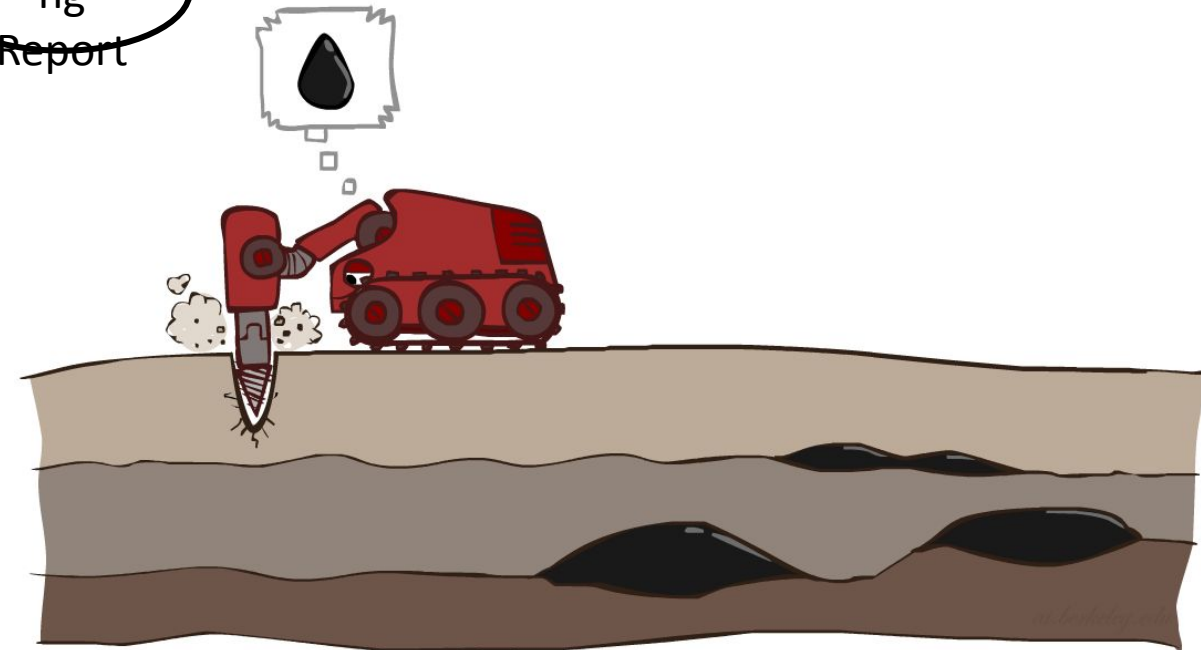
- No such thing (as we formulate it)
- Information corresponds to the observation of a node in the decision network
- If data is “noisy” that just means we don’t observe the original variable, but another variable which is a noisy version of the original one

VPI Question

- VPI(OilLoc) ?
- VPI(ScoutingReport) ?
- VPI(Scout) ?
- VPI(Scout | ScoutingReport) ?



- Generally:
 If $\text{Parents}(U) \perp\!\!\!\perp Z \mid \text{CurrentEvidence}$
 Then $\text{VPI}(Z \mid \text{CurrentEvidence}) = 0$

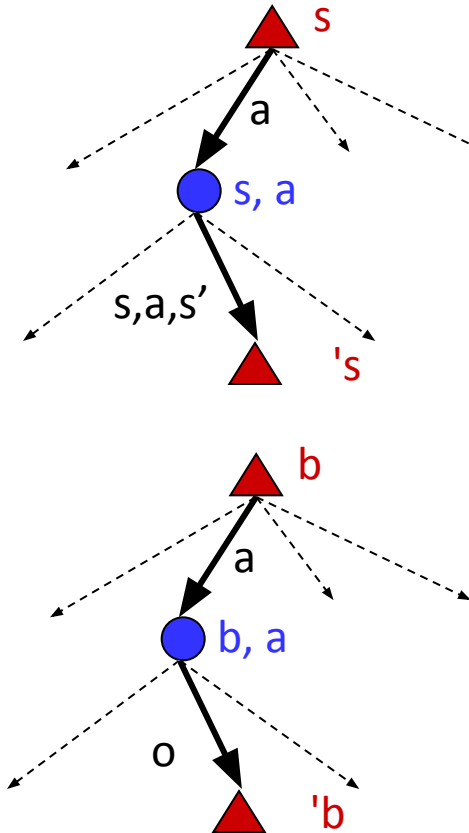


POMDPs



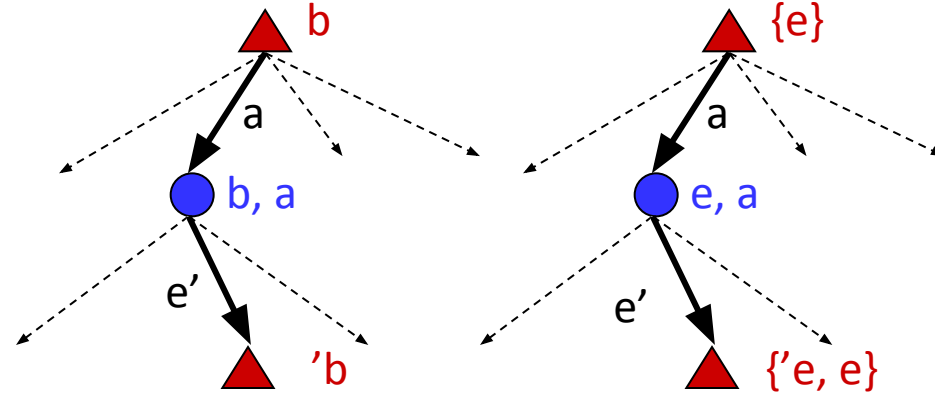
POMDPs

- MDPs have:
 - States S
 - Actions A
 - Transition function $P(s' | s, a)$ (or $T(s, a, s')$)
 - Rewards $R(s, a, s')$
- POMDPs add:
 - Observations O
 - Observation function $P(o | s)$ (or $O(s, o)$)
- One way to think of POMDPs: MDPs over belief states b (distributions over S)
- Alternately, state in POMDP: evidence you have observed so far
- We'll be able to say more in a few lectures

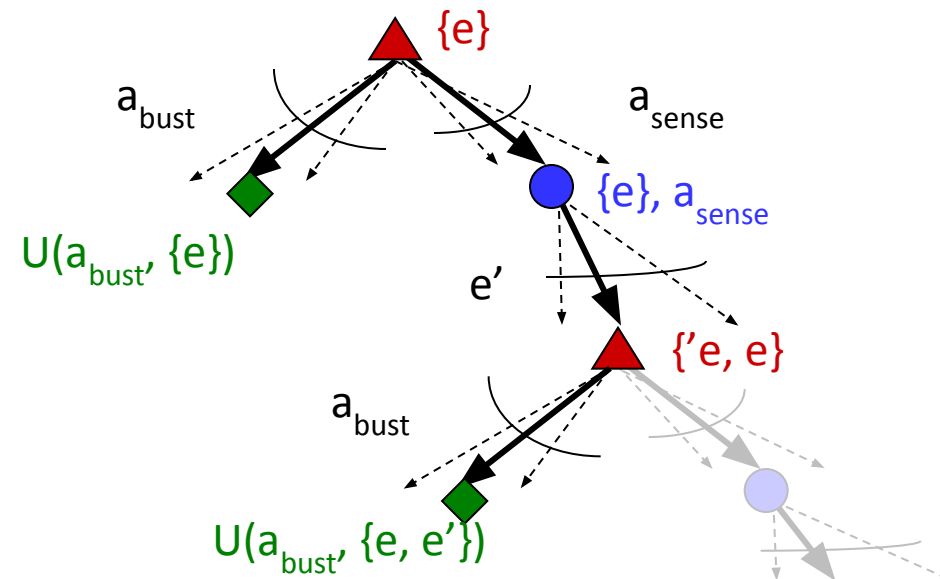


Example: Ghostbusters

- In (static) Ghostbusters:
 - Belief state determined by evidence to date $\{e\}$
 - Tree really over evidence sets
 - Probabilistic reasoning needed to predict new evidence given past evidence



- Solving POMDPs
 - One way: use truncated expectimax to compute approximate value of actions
 - What if you only considered busting or one sense followed by a bust?
 - You get a VPI-based agent!



Video of Demo Ghostbusters with VPI



More Generally*

- General solutions map belief functions to actions
 - Can divide regions of belief space (set of belief functions) into policy regions (gets complex quickly)
 - Can build approximate policies using discretization methods
 - Can factor belief functions in various ways
- Overall, POMDPs are very (actually PSPACE-) hard
- Most real problems are POMDPs, and we can rarely solve them in their full generality

