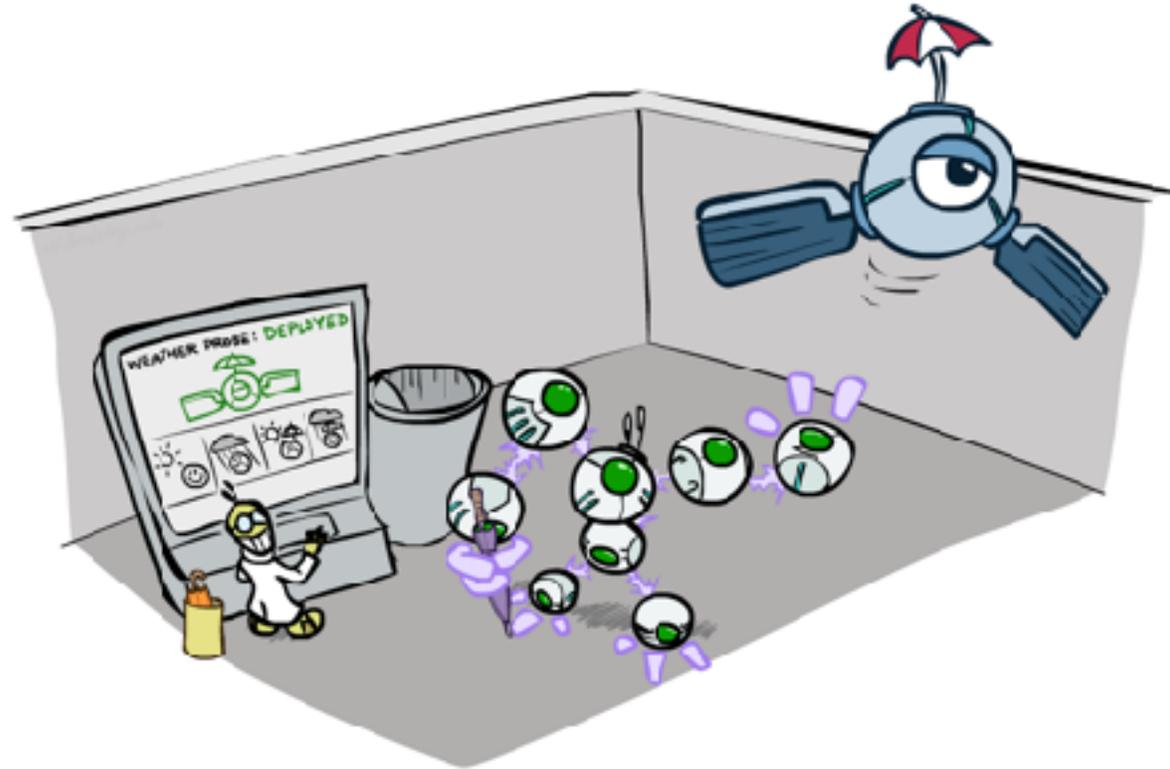


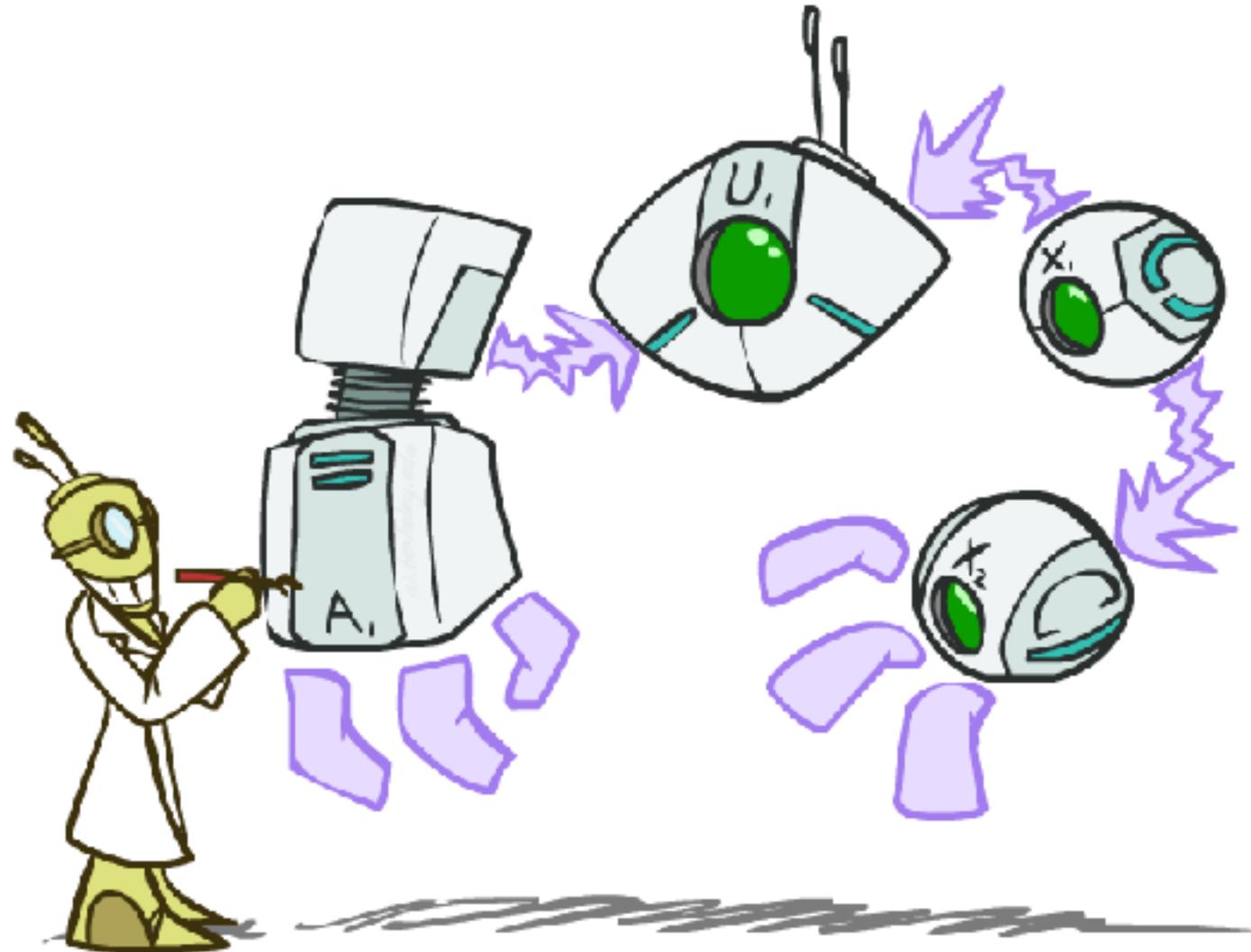
CS 383: Artificial Intelligence

Decision Networks and Value of Perfect Information

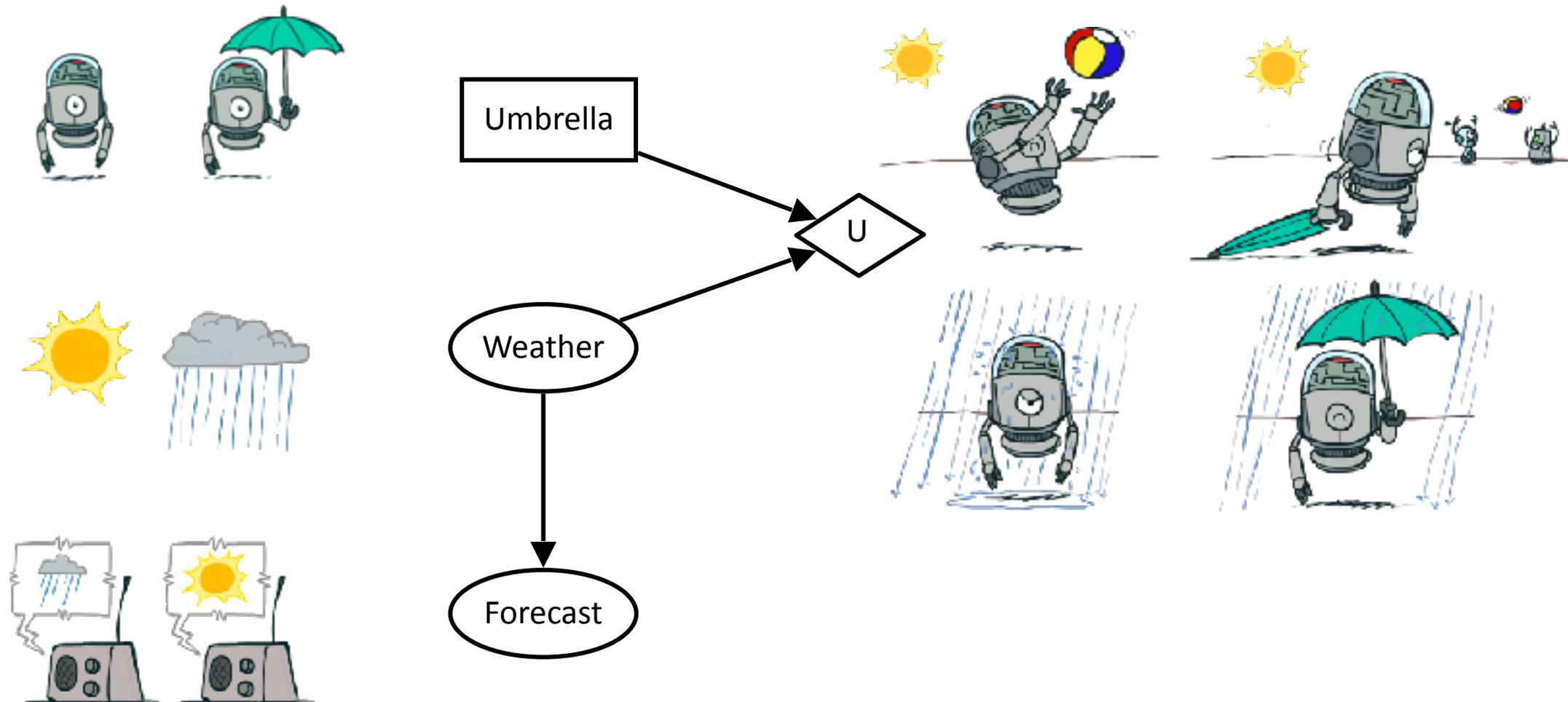


Prof. Scott Niekum — UMass Amherst

Decision Networks



Decision Networks



Decision Networks

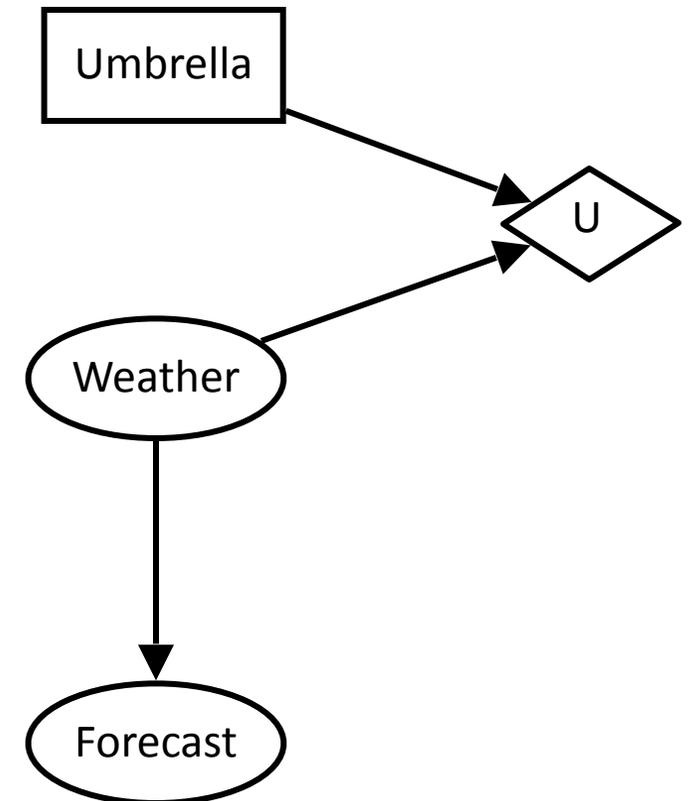
- **MEU: choose the action which maximizes the expected utility given the evidence**
- Can directly operationalize this with decision networks
 - Bayes nets with nodes for utility and actions
 - Lets us calculate the expected utility for each action

- **New node types:**

 ■ Chance nodes (just like BNs)

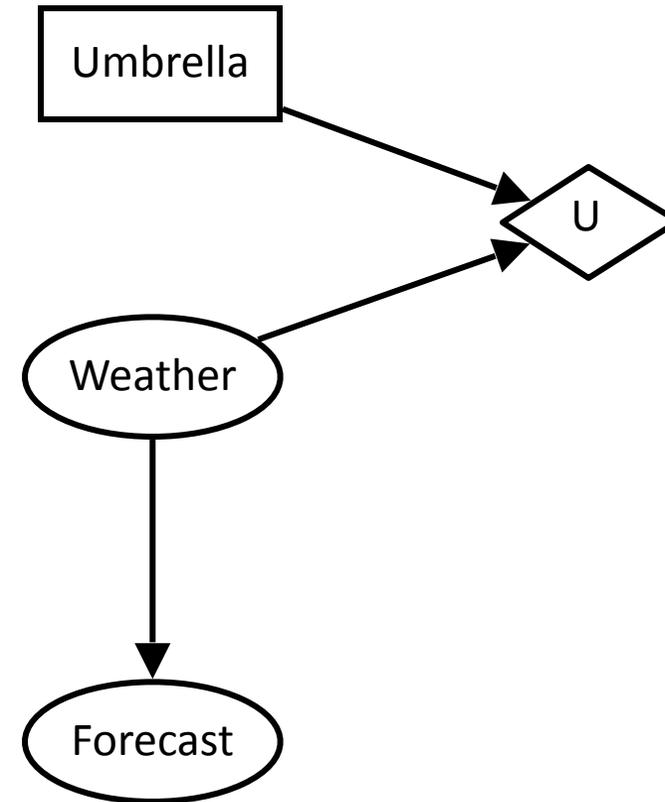
 ■ Actions (rectangles, cannot have parents, act as observed evidence)

 ■ 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

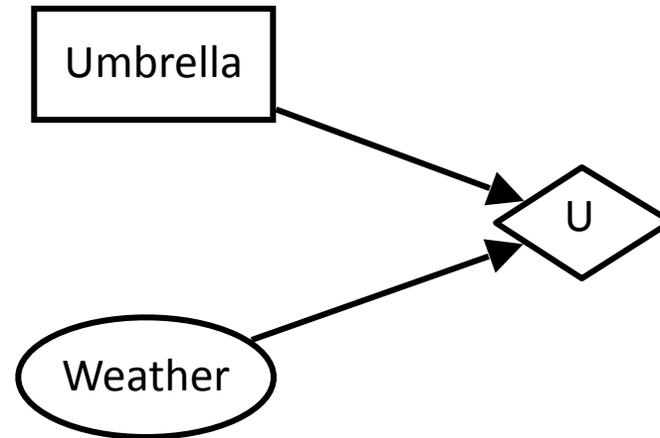
$$\begin{aligned} EU(\text{leave}) &= \sum_w P(w)U(\text{leave}, w) \\ &= 0.7 \cdot 100 + 0.3 \cdot 0 = 70 \end{aligned}$$

Umbrella = take

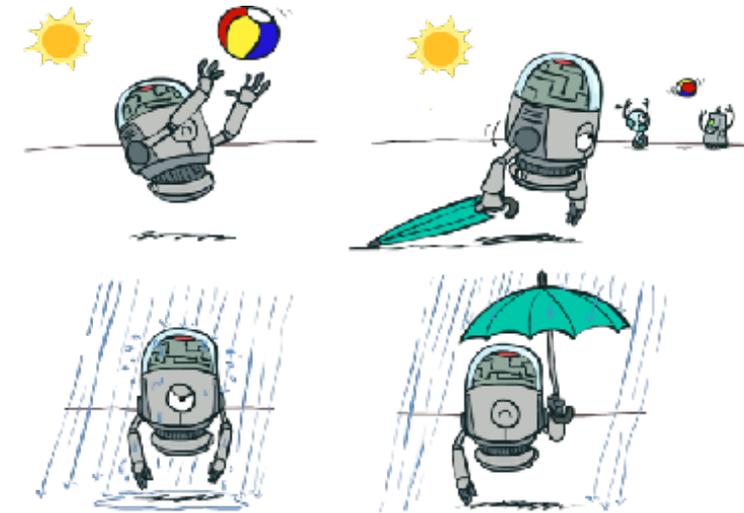
$$\begin{aligned} EU(\text{take}) &= \sum_w P(w)U(\text{take}, w) \\ &= 0.7 \cdot 20 + 0.3 \cdot 70 = 35 \end{aligned}$$

Optimal decision = leave

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

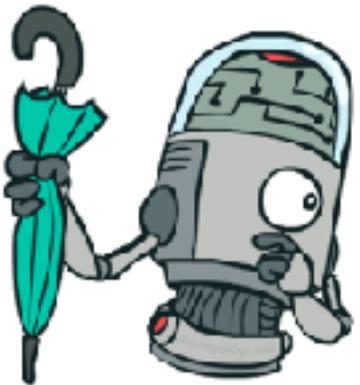
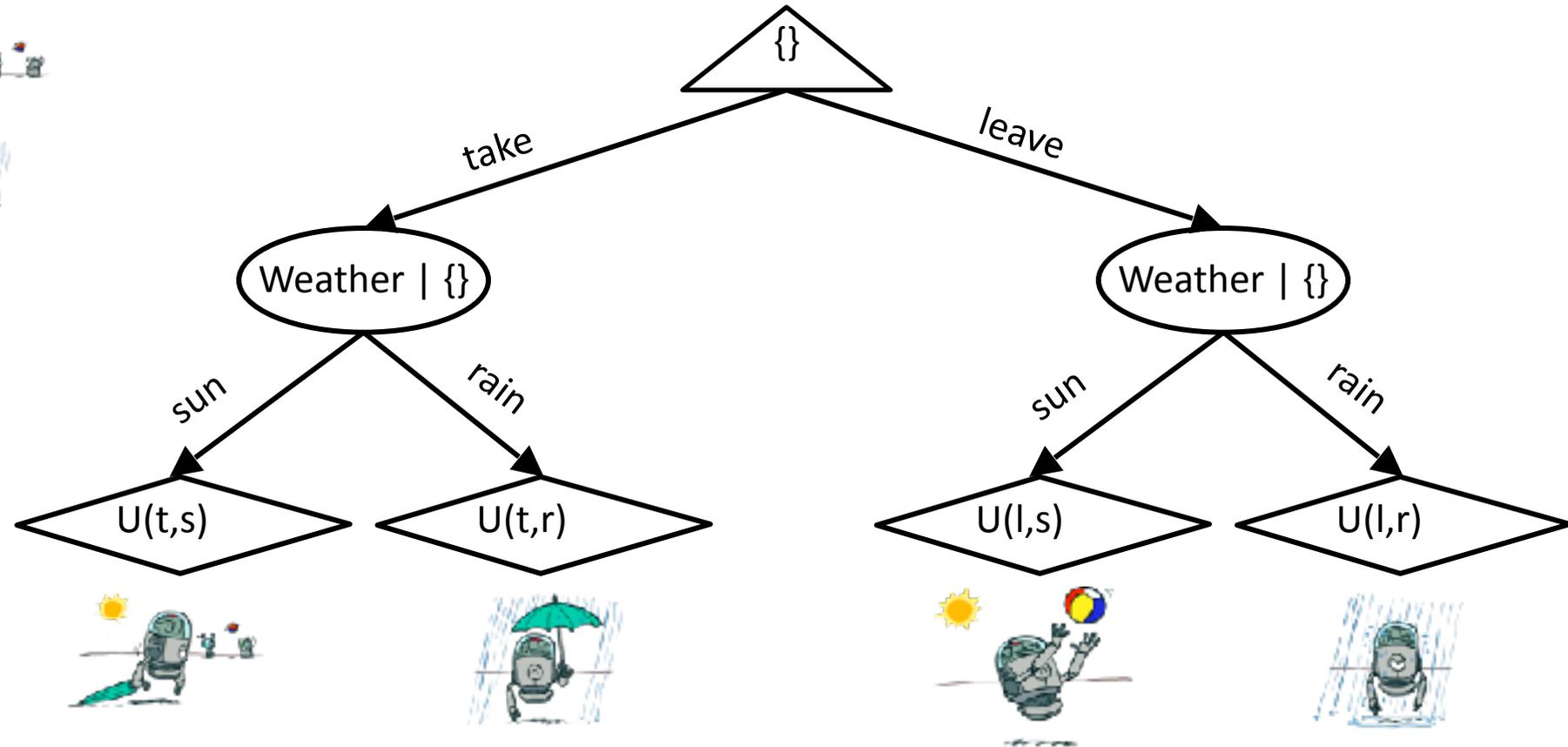
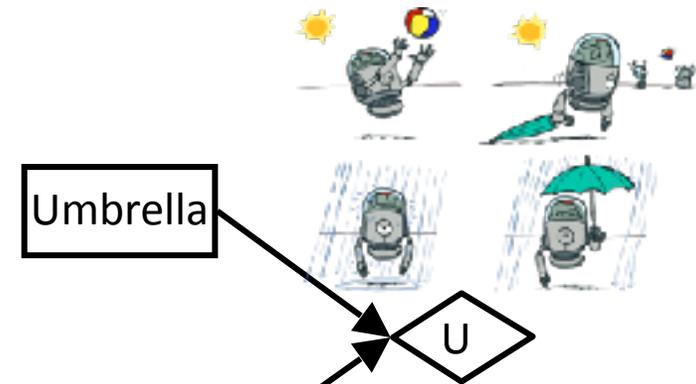


W	P(W)
sun	0.7
rain	0.3



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

Decisions as Outcome Trees



- Almost exactly like expectimax / MDPs
- What's changed?

Example: Decision Networks

Umbrella = leave

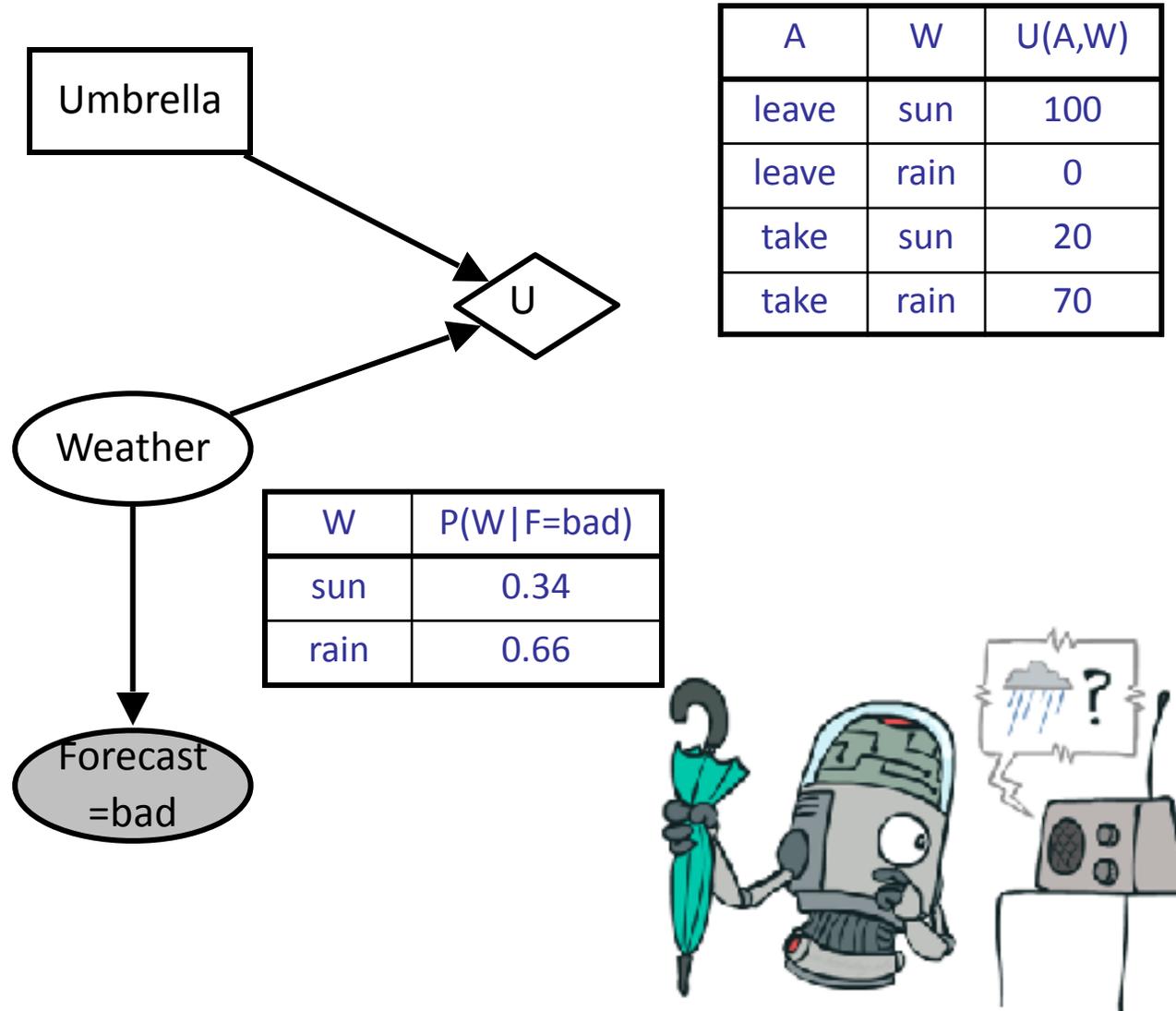
$$\begin{aligned} EU(\text{leave}|\text{bad}) &= \sum_w P(w|\text{bad})U(\text{leave}, w) \\ &= 0.34 \cdot 100 + 0.66 \cdot 0 = 34 \end{aligned}$$

Umbrella = take

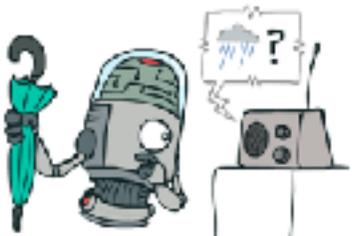
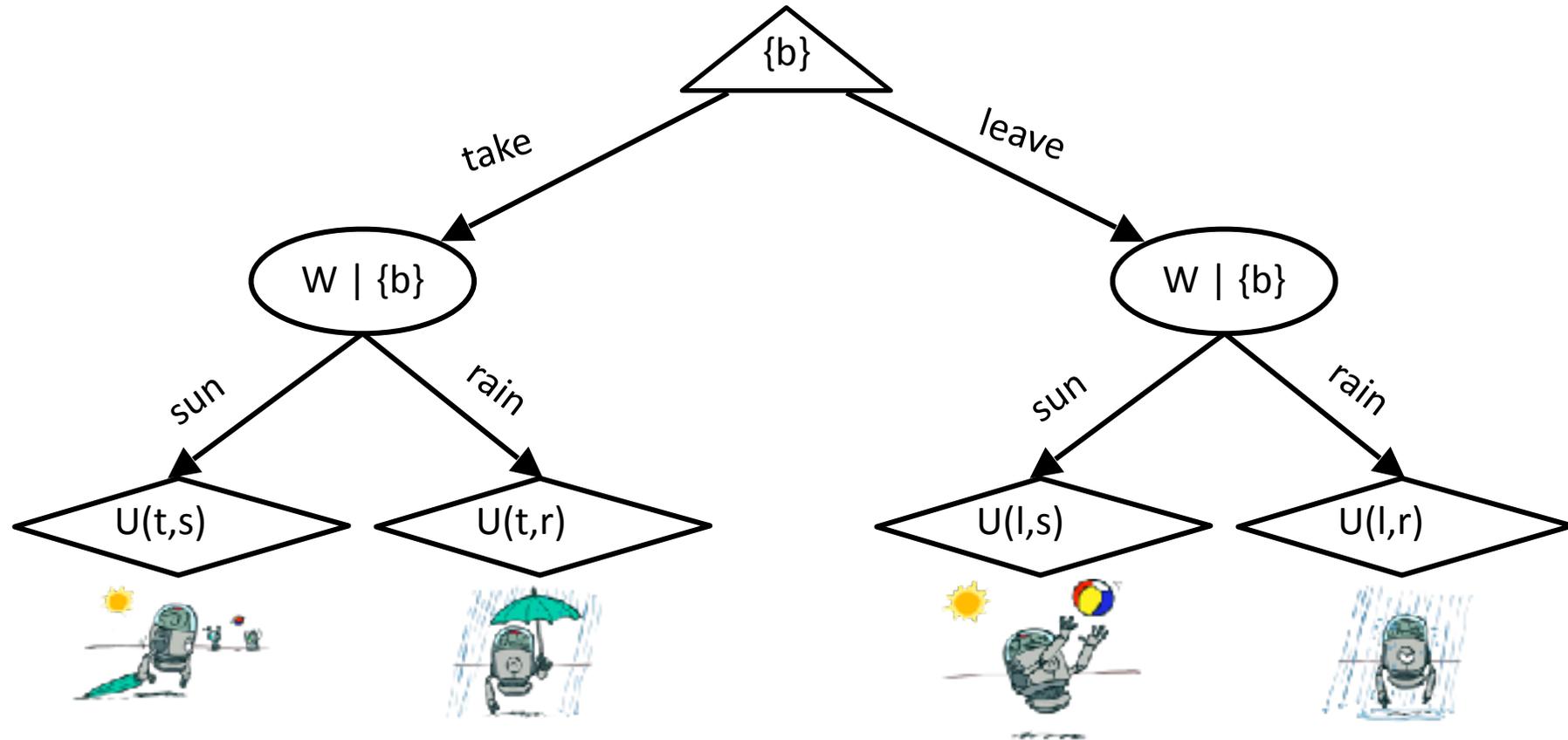
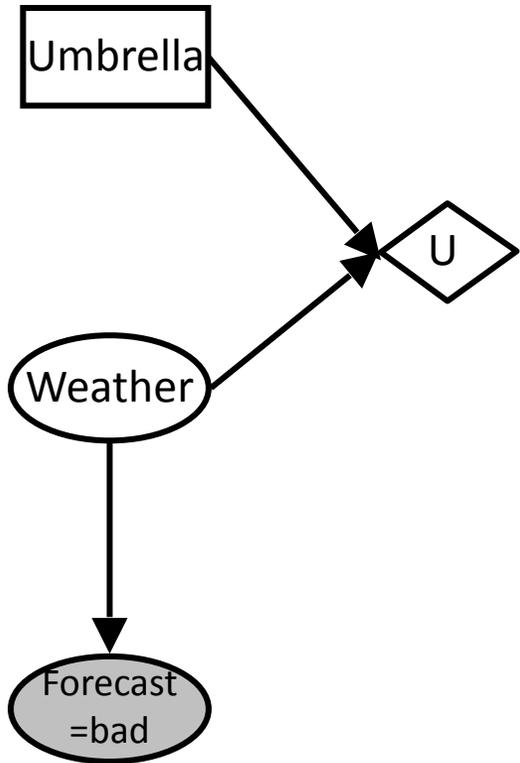
$$\begin{aligned} EU(\text{take}|\text{bad}) &= \sum_w P(w|\text{bad})U(\text{take}, w) \\ &= 0.34 \cdot 20 + 0.66 \cdot 70 = 53 \end{aligned}$$

Optimal decision = take

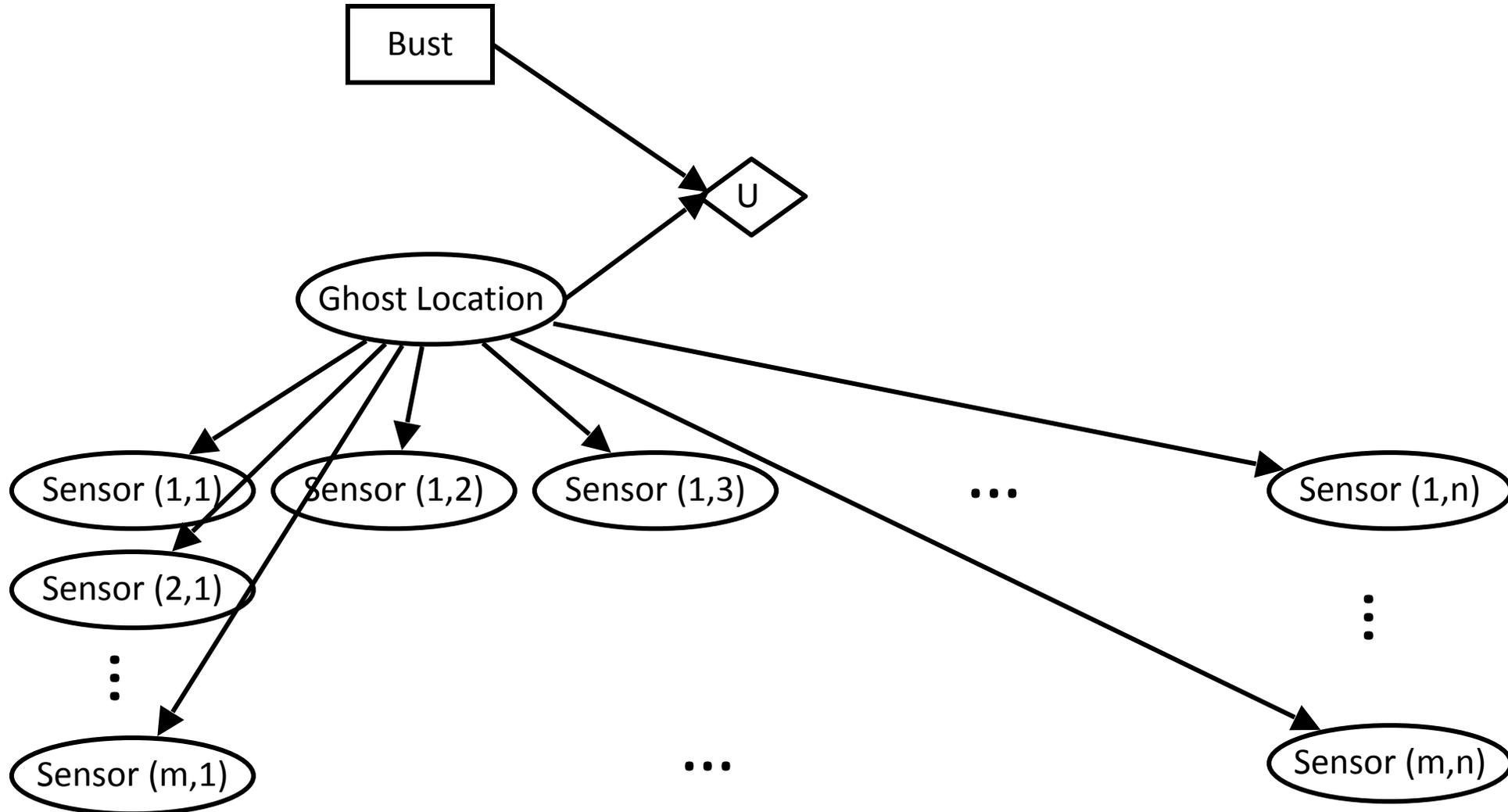
$$MEU(F = \text{bad}) = \max_a EU(a|\text{bad}) = 53$$



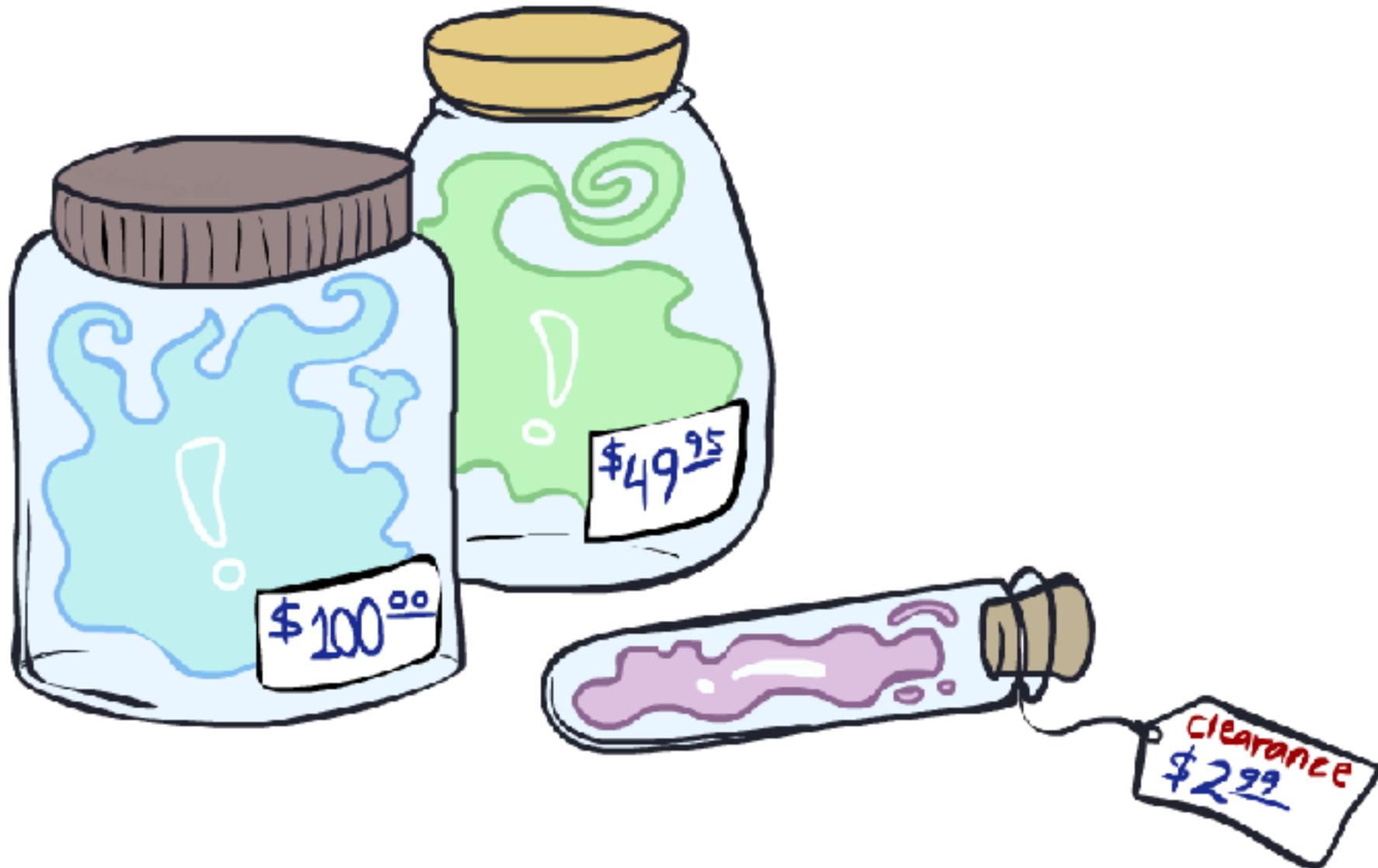
Decisions as Outcome Trees



Ghostbusters Decision Network

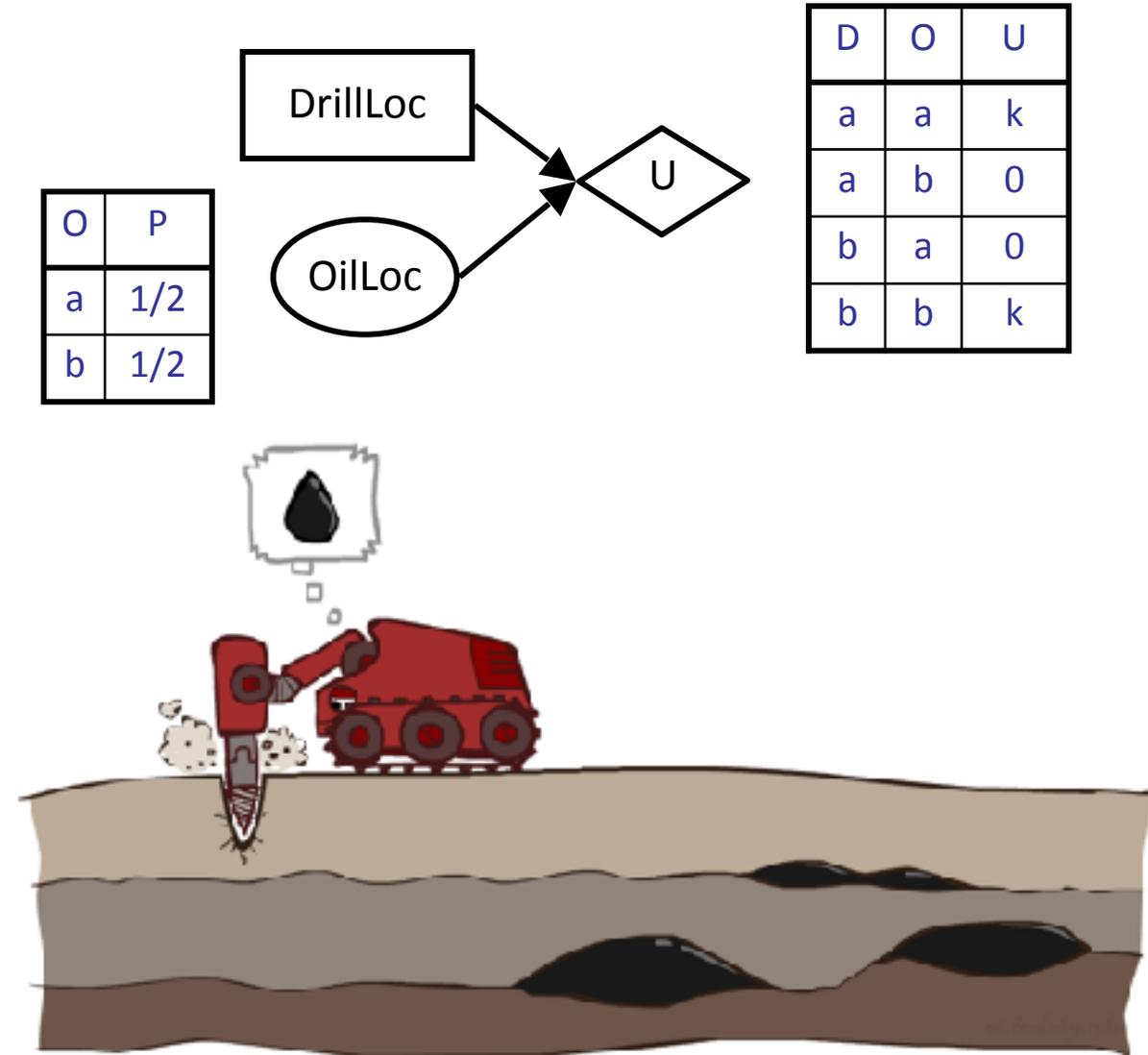


Value of Information



Value of Information

- Idea: compute value of acquiring evidence
 - Can be done directly from decision network
- 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

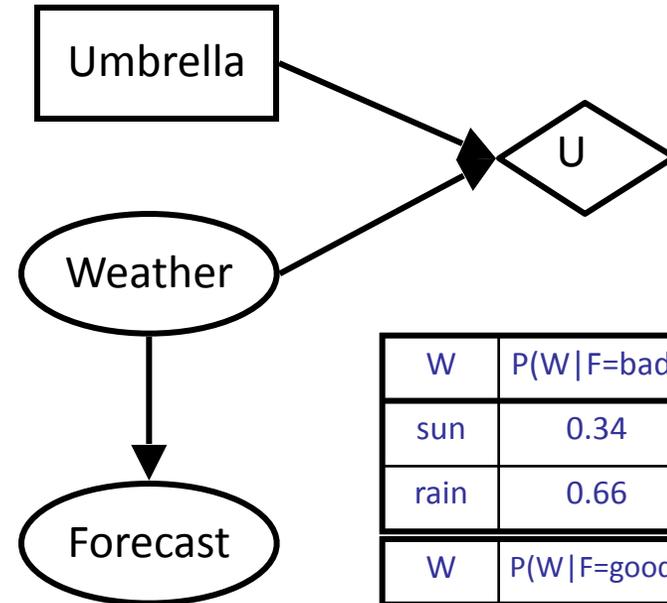
F	P(F)
good	0.59
bad	0.41



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

$$77.8 - 70 = 7.8$$

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

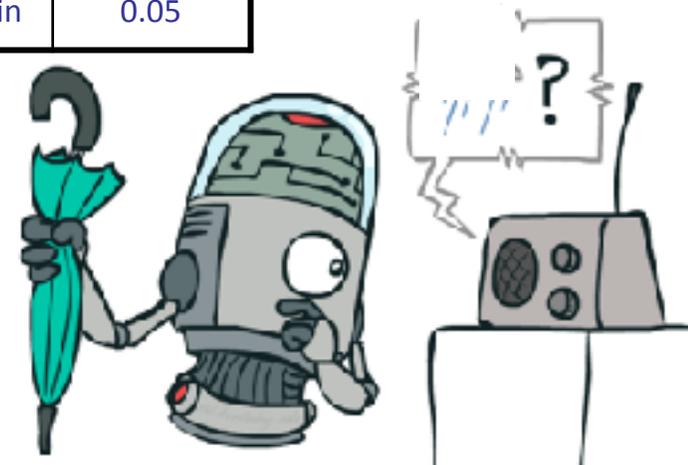


	A	W	U
leave	sun	100	0
take	sun	20	70

W	P(W F=bad)
sun	0.34
rain	0.66

W	P(W F=good)
sun	0.95
rain	0.05

W	P(W)
sun	0.7
rain	0.3



Value of Information

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

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

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

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

- 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:

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

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

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

VPI Properties

- Nonnegative

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



- Nonadditive

Typically (but not always):

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



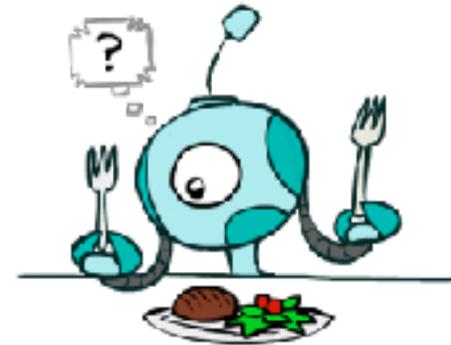
- Order-independent

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



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?



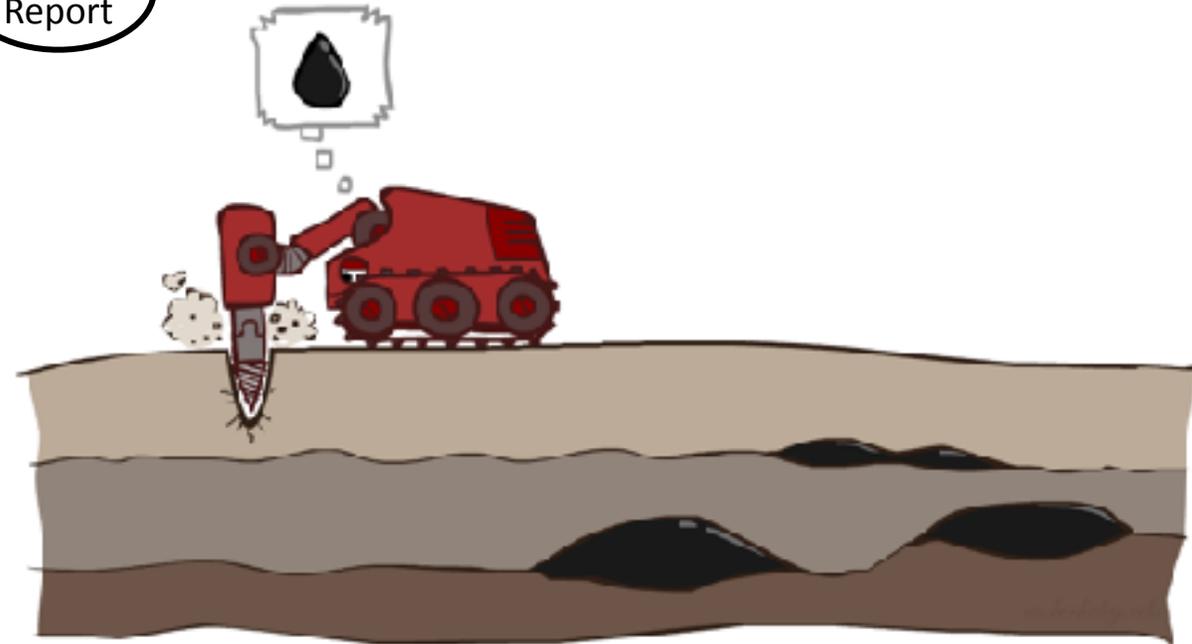
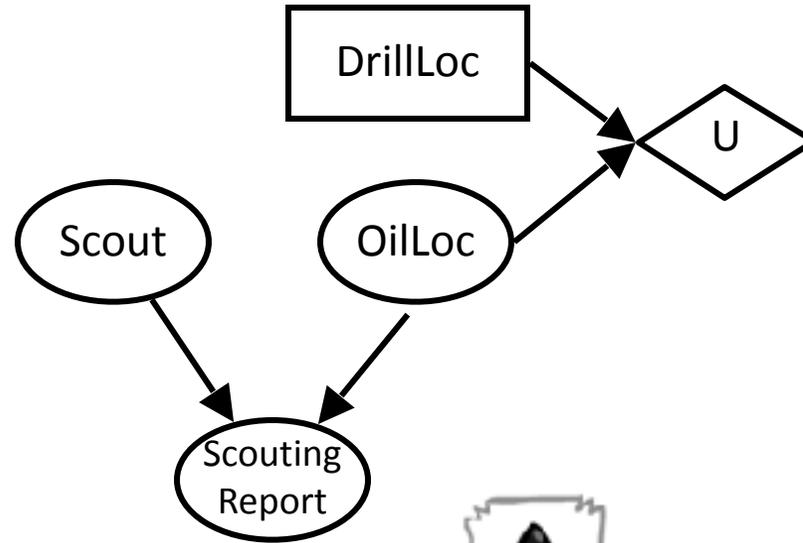
Value of Imperfect Information?



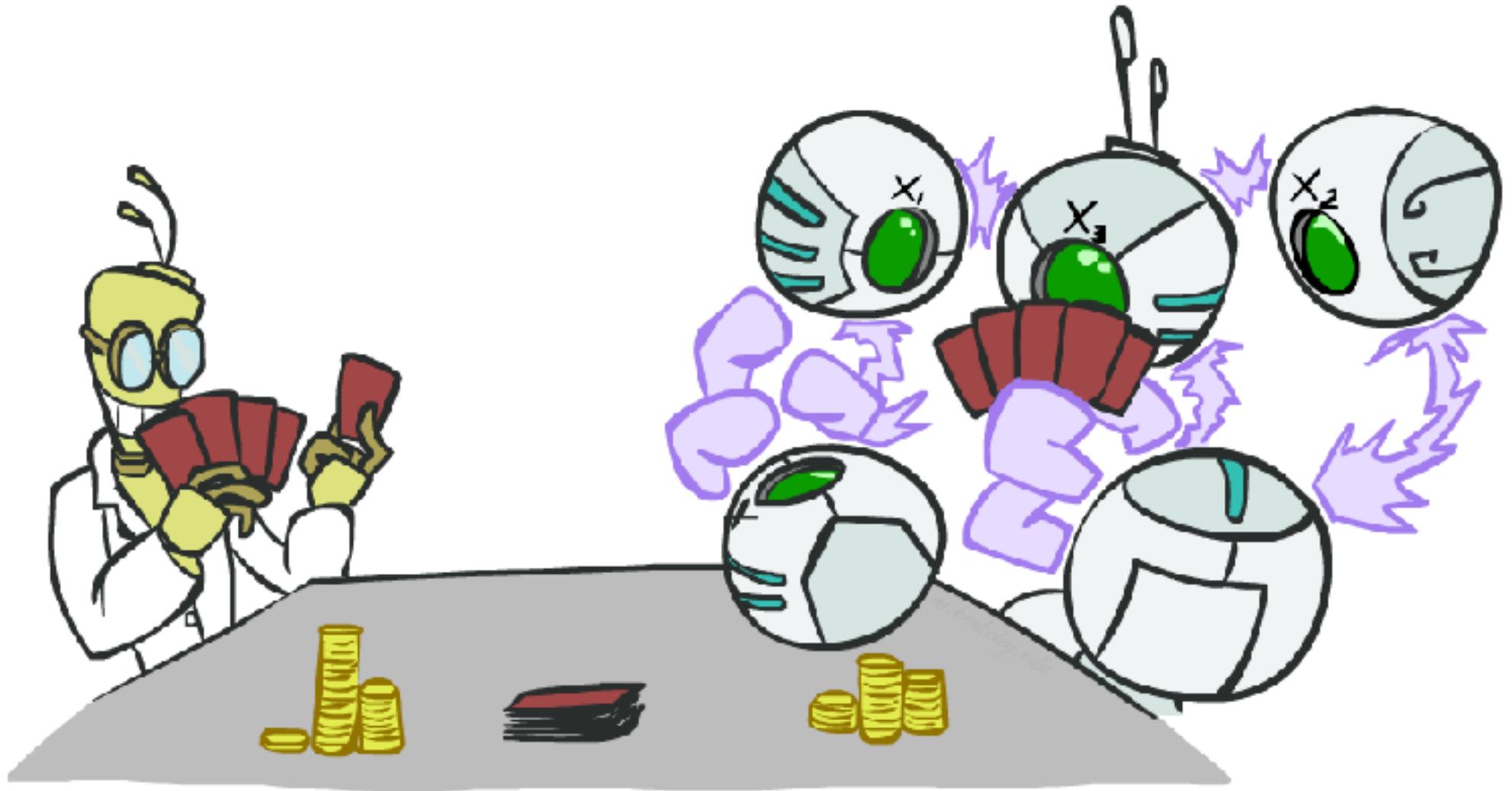
- No such thing
- Information corresponds to the observation of a node in the decision network
- If data is “noisy” that just means we don’t observe the original variable, but another variable which is a noisy version of the original one

VPI Question

- $VPI(\text{OilLoc}) = k/2$
- $VPI(\text{ScoutingReport}) ?$
- $VPI(\text{Scout}) ?$
- $VPI(\text{Scout} \mid \text{ScoutingReport}) ?$

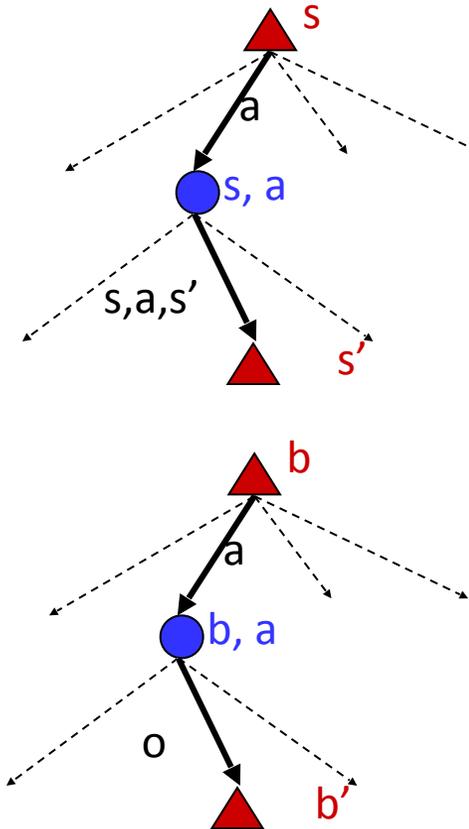


POMDPs



POMDPs

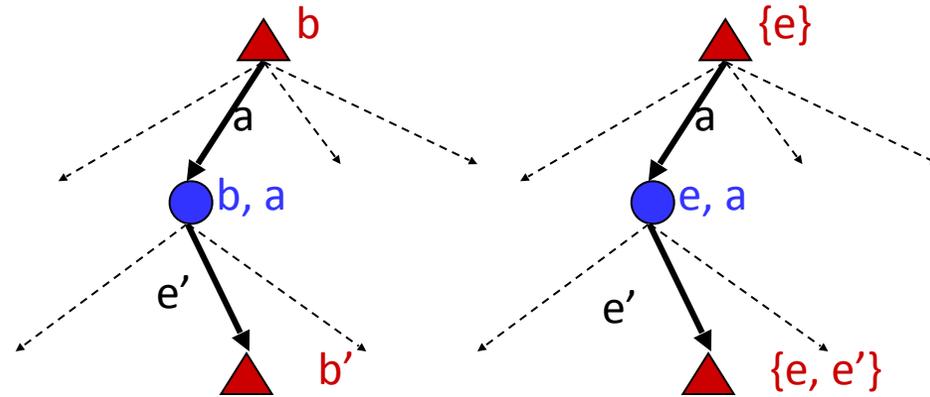
- MDPs have:
 - States S
 - Actions A
 - Transition function $P(s' | s, a)$ (or $T(s, a, s')$)
 - Rewards $R(s, a, s')$
- POMDPs add:
 - Observations O
 - Observation function $P(o | s)$ (or $O(s, o)$)
- POMDPs are MDPs over belief states b (distributions over S)



Example: Ghostbusters

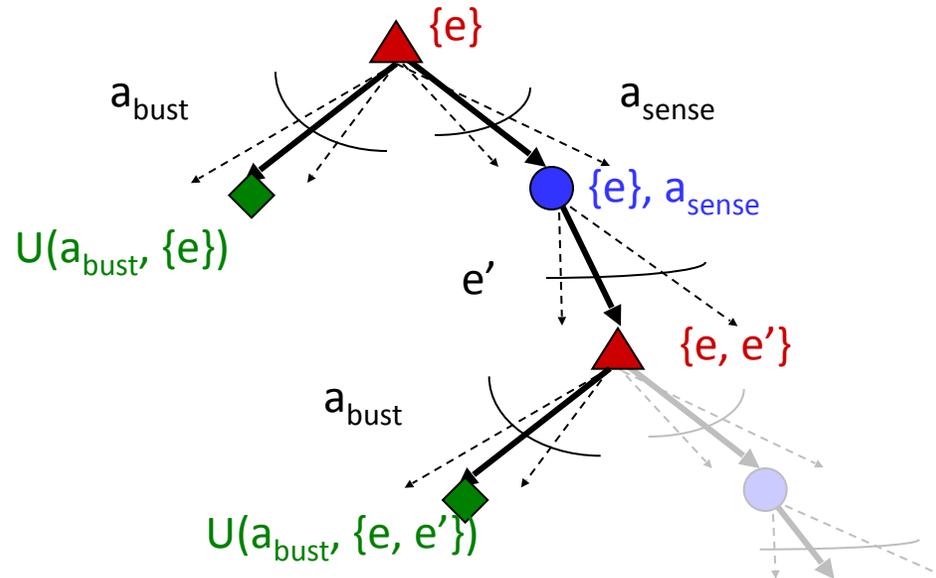
■ In (static) Ghostbusters:

- Belief state determined by evidence to date $\{e\}$
- Tree really over evidence sets
- Probabilistic reasoning needed to predict what new evidence will be gained, given past evidence and the action taken



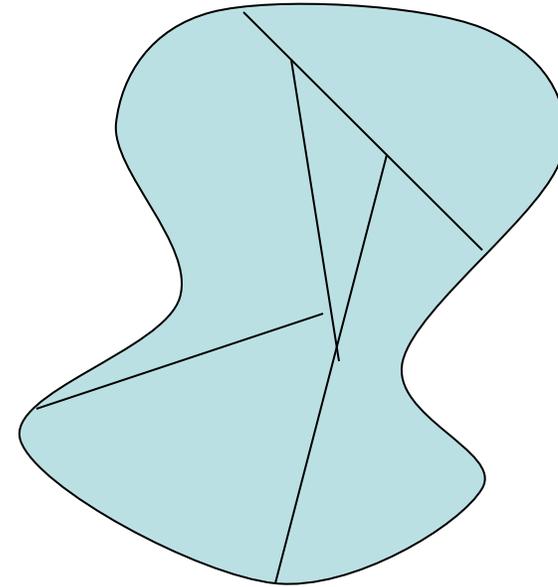
■ Solving POMDPs

- 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!

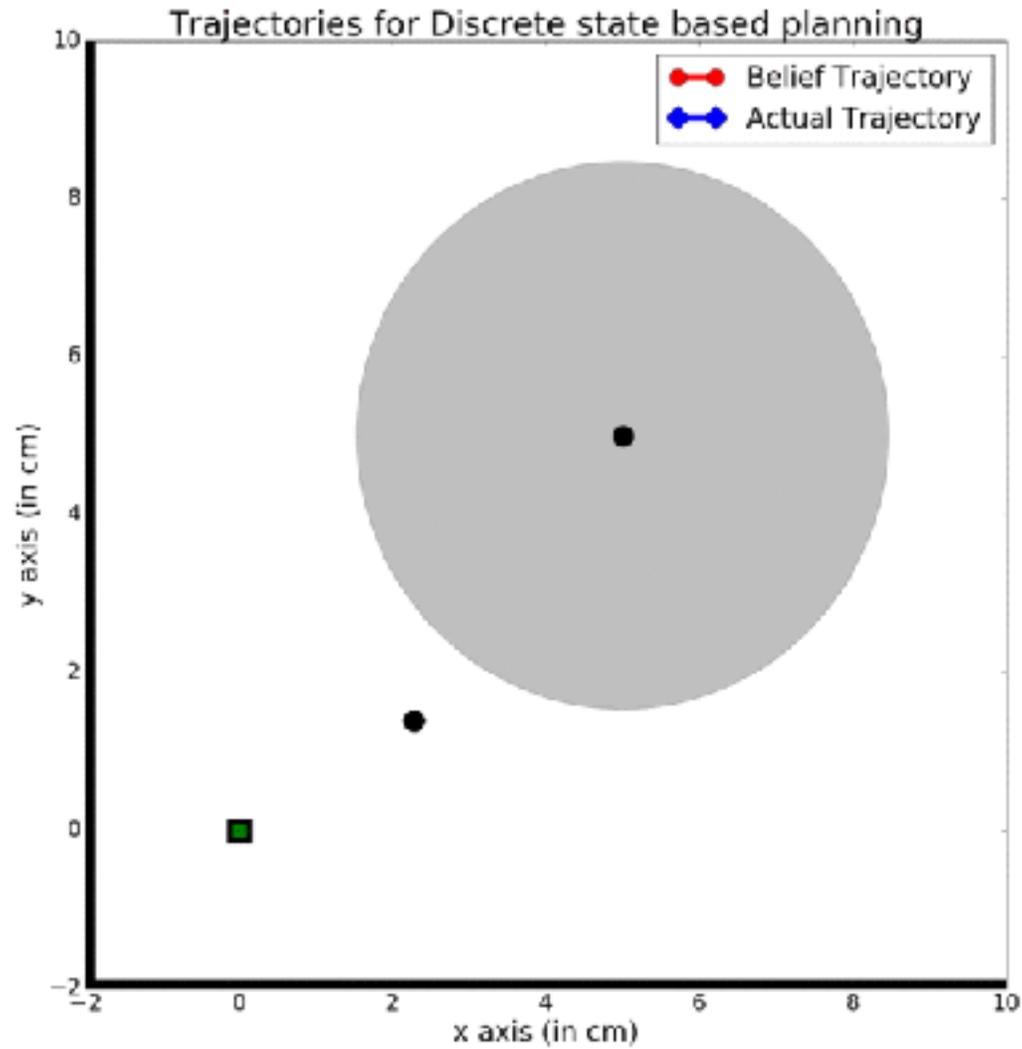


More Generally

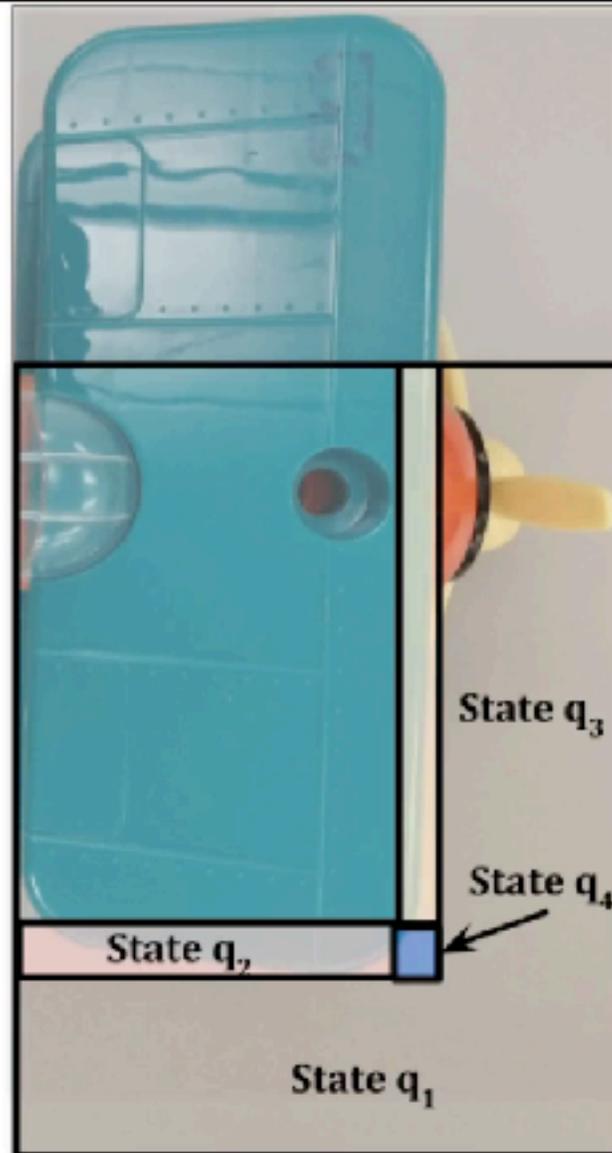
- General solutions map belief functions to actions
 - Can divide regions of belief space (set of belief functions) into policy regions (gets complex quickly)
 - Can build approximate policies using discretization methods
 - Can factor belief functions in various ways
- Overall, POMDPs are very (actually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



Hierarchical POMDP Planning

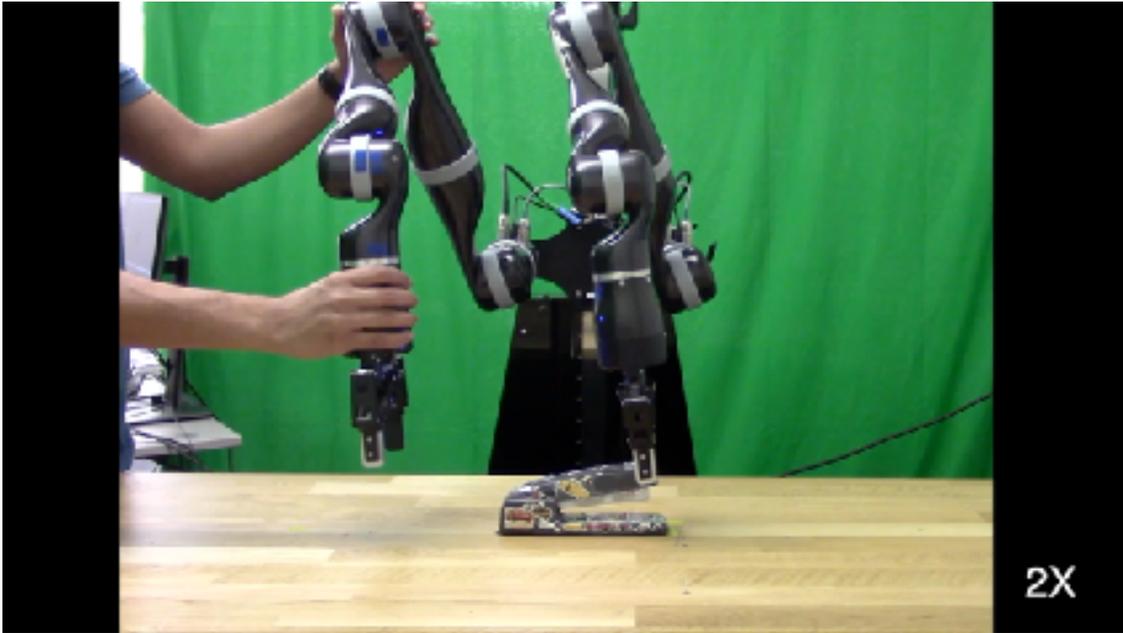


Hierarchical POMDP Planning



**Approximate Hybrid
Dynamics Model**

Hierarchical POMDP Planning



Teaching object dynamics



Execution of novel task