

Knowledge base for the wumpus world

“Perception”

$\forall b, g, t \text{ Percept}([Smell, b, g], t) \Rightarrow Smelt(t)$

$\forall s, b, t \text{ Percept}([s, b, Glitter], t) \Rightarrow AtGold(t)$

Reflex: $\forall t \text{ AtGold}(t) \Rightarrow \text{Action}(Grab, t)$

Reflex with internal state: do we have the gold already?

$\forall t \text{ AtGold}(t) \wedge \neg Holding(Gold, t) \Rightarrow \text{Action}(Grab, t)$

Holding(Gold, t) cannot be observed

\Rightarrow keeping track of change is essential

Deducing hidden properties

Properties of locations:

$$\forall x, t \text{ At}(\text{Agent}, x, t) \wedge \text{Smelt}(t) \Rightarrow \text{Smelly}(x)$$

$$\forall x, t \text{ At}(\text{Agent}, x, t) \wedge \text{Breeze}(t) \Rightarrow \text{Breezy}(x)$$

Squares are breezy near a pit:

Diagnostic rule—infer cause from effect

$$\forall y \text{ Breezy}(y) \Rightarrow \exists x \text{ Pit}(x) \wedge \text{Adjacent}(x, y)$$

Causal rule—infer effect from cause

$$\forall x, y \text{ Pit}(x) \wedge \text{Adjacent}(x, y) \Rightarrow \text{Breezy}(y)$$

Neither of these is complete—e.g., the causal rule doesn't say whether squares far away from pits can be breezy

Definition for the *Breezy* predicate:

$$\forall y \text{ Breezy}(y) \Leftrightarrow [\exists x \text{ Pit}(x) \wedge \text{Adjacent}(x, y)]$$

Keeping track of change

Facts hold in *situations*, rather than eternally

E.g., *Holding(Gold, Now)* rather than just *Holding(Gold)*

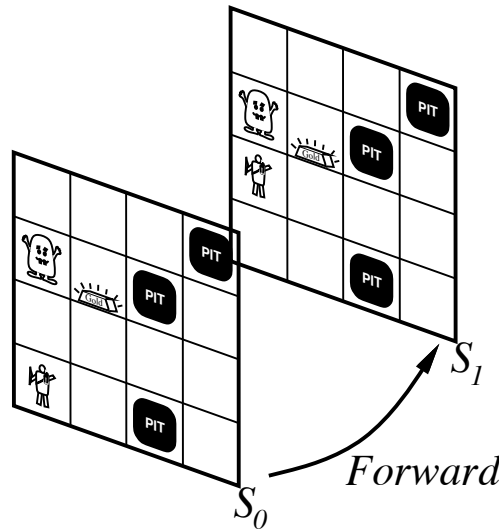
Situation calculus is one way to represent change in FOL:

Adds a situation argument to each non-eternal predicate

E.g., *Now* in *Holding(Gold, Now)* denotes a situation

Situations are connected by the *Result* function

Result(a, s) is the situation that results from doing *a* in *s*



Describing actions I

“Effect” axiom—describe changes due to action

$$\forall s \text{ AtGold}(s) \Rightarrow \text{Holding}(\text{Gold}, \text{Result}(\text{Grab}, s))$$

“Frame” axiom—describe **non-changes** due to action

$$\forall s \text{ HaveArrow}(s) \Rightarrow \text{HaveArrow}(\text{Result}(\text{Grab}, s))$$

Frame problem: find an elegant way to handle non-change

- (a) representation—avoid frame axioms
- (b) inference—avoid repeated “copy-overs” to keep track of state

Qualification problem: true descriptions of real actions require endless caveats—what if gold is slippery or nailed down or ...

Ramification problem: real actions have many secondary consequences—what about the dust on the gold, wear and tear on gloves, ...

Describing actions II

Successor-state axioms solve the representational frame problem

Each axiom is “about” a **predicate** (not an action per se):

$$\begin{aligned} P \text{ true afterwards} &\Leftrightarrow [\text{an action made } P \text{ true} \\ &\vee P \text{ true already and no action made } P \text{ false}] \end{aligned}$$

For holding the gold:

$$\begin{aligned} \forall a, s \text{ } Holding(Gold, Result(a, s)) &\Leftrightarrow \\ &[(a = Grab \wedge AtGold(s)) \\ &\vee (Holding(Gold, s) \wedge a \neq Release)] \end{aligned}$$

Making plans

Initial condition in KB:

$At(Agent, [1, 1], S_0)$

$At(Gold, [1, 2], S_0)$

Query: $Ask(KB, \exists s \text{ Holding}(Gold, s))$

i.e., in what situation will I be holding the gold?

Answer: $\{s / Result(Grab, Result(Forward, S_0))\}$

i.e., go forward and then grab the gold

This assumes that the agent is interested in plans starting at S_0 and that S_0 is the only situation described in the KB

Making plans: A better way

Represent **plans** as action sequences $[a_1, a_2, \dots, a_n]$

$PlanResult(p, s)$ is the result of executing p in s

Then the query $Ask(KB, \exists p \text{ Holding}(Gold, PlanResult(p, S_0)))$
has the solution $\{p/[Forward, Grab]\}$

Definition of $PlanResult$ in terms of $Result$:

$$\forall s \text{ } PlanResult([], s) = s$$

$$\forall a, p, s \text{ } PlanResult([a|p], s) = PlanResult(p, Result(a, s))$$

Planning systems are special-purpose reasoners designed to do this type of inference more efficiently than a general-purpose reasoner

Summary

First-order logic:

- objects and relations are semantic primitives
- syntax: constants, functions, predicates, equality, quantifiers

Increased expressive power: sufficient to define wumpus world

Situation calculus:

- conventions for describing actions and change in FOL
- can formulate planning as inference on a situation calculus KB