Foundations of Artificial Intelligence

CS472/3

Lecture #24

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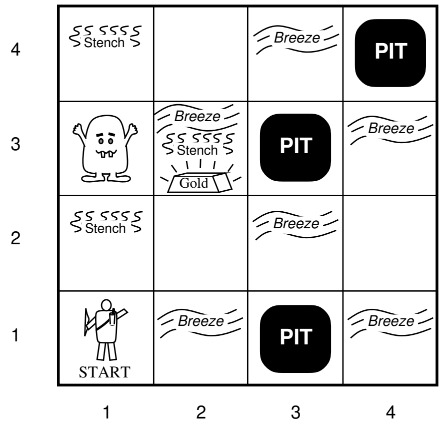
Today's Lecture

Knowledge Representation & Reasoning, cont.

Chapter 6 & 7, R&N.

Modeling Agent in Grid World



"Wumpus World" R&N, p154.

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Percept — five symbols.
E.g. [*Stench, Breeze, Glitter, None, None*]
Exercise in encoding. Important throughout AI (learning, planning etc.)

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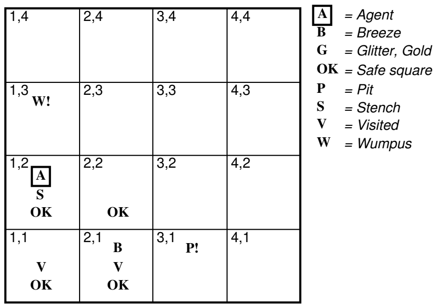

after three moves

$\neg S_{1,1}, \neg S_{2,1}, S_{1,2}, \neg B_{1,1}, B_{2,1}, \neg B_{1,2}$

S for "stench"; B for breeze.

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Rules for "relevant" squares:

R1: $\neg S_{1,1} \Rightarrow (\neg W_{1,1} \wedge \neg W_{1,2} \wedge \neg W_{2,1})$ becomes

R1a: $S_{1,1} \vee \neg W_{1,1}$ (for $\neg S_{1,1} \Rightarrow \neg W_{1,1}$)

R1b: $S_{1,1} \vee \neg W_{1,2}$ R1c: $S_{1,1} \vee \neg W_{2,1}$

R2a: $S_{2,1} \vee \neg W_{1,1}$ R2b: $S_{2,1} \vee \neg W_{2,1}$

R2c: $S_{2,1} \vee \neg W_{2,2}$ R2d: $S_{2,1} \vee \neg W_{3,1}$

R3a: $S_{1,2} \vee \neg W_{1,1}$ R3b: $S_{1,2} \vee \neg W_{1,2}$

R3c: $S_{1,2} \vee \neg W_{2,2}$ R3d: $S_{2,1} \vee \neg W_{1,3}$

R4: $\neg S_{1,2} \vee W_{1,3} \vee W_{1,2} \vee W_{2,2} \vee W_{1,1}$

R&N p. 174-175.

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Note many rule. E.g. just R3, gives up to 4 clauses **per square**.

Ex. First-order:

$\forall l_1, s, Smelly(l_1) \Rightarrow$

$(\exists l_2 At(Wumpus, l2, s) \wedge (l_2 = l_1 \vee Adjacent(l_1, l_2))$

How would you define $Adjacent$?

How about:

$\forall i, j, , s \;\; 1 \leq i, j \leq N \;.\; Smelly(i, j) \Rightarrow$

$(\exists k, l \;.\; -1 \leq k, l \leq 1 \quad At(Wumpus, i + k, j + l, s)$

What about epressiveness? What is implicitly used? Computation?

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"Finding the Wumpus"

What holds in Wumpus KB? (12 symbols — $S_{1,1}, S_{2,1}$ etc.

$2^{12} = 4096$, truth assignments

To prove: $W_{1,3}$

Use resolution.

Compare with section 6.5 R&N for inference rule approach.

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1) $\neg S_{1,1}$ (in KB / fact)
2) $\neg W_{1,1}$ (resolution with R1a)
3) $\neg S_{2,1}$ (in KB / fact)
4) $\neg W_{1,2}$ (resolution with R1b)
5) $\neg W_{2,2}$ (res with R2c)
6) $S_{1,2}$ (in KB / fact)
7) $W_{1,3} \vee W_{1,2} \vee W_{2,2} \vee W_{1,1}$
8) $W_{1,3} \vee W_{1,2} \vee W_{2,2}$
9) $W_{1,3} \vee W_{1,2}$
10) $W_{1,3}$
11) $\neg W_{1,3}$ (our assumption)
12) $\emptyset$ (contradiction: it follows $W_{1,3}$ **must be True.**)

Why do things this way?

Contrast with **simulation** approach.

Basic idea: axiomatic / knowledge-based / declarative approach
allows us a very large range of **queries / conclusions.**
Procedural (e.g., standard program, "simulation") would
require separate procedure for each possible question (almost).
Of course, getting the axioms / facts right can be tricky!
And, reasoning can be computationally very hard!

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So far, most success in a restricted context:
e.g. "expert systems" knowledge encoded in basic if-then rules
(similar to Horn sentences: $(p \wedge q \wedge r) \Rightarrow s$)
use forward / backward chaining (Section 9.4. R&N).
Also, more recently in **diagnosis**. (Xerox / NASA)

And, more specialized KR languages, e.g., frame-based systems
descriptin logics. (AT&T).
Tens of thousands of facts / thousands of frames ("objects").

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Modeling actions: Simple Reflex Agent

Directly connects percepts to actions:

$\forall s, b, u, c, t \quad \mathit{Percept}([s, b, \mathit{Glitter}, u, c], t) \Rightarrow \mathit{Action}(\mathit{Grab}, t)$

Or, more indirectly:

$\forall s, b, u, c, t \quad \mathit{Percept}([s, b, \mathit{Glitter}, u, c], t) \Rightarrow \mathit{AtGold}(t)$

$\forall t \quad \mathit{AtGold}(t) \Rightarrow \mathit{Action}(\mathit{Grab}, t)$

Why more flexible? *Limitations of reflex approach?*

Representing Change / Time

How did we represent change so far? E.g., in our (propositional) Wumpus world.

Agent would move around. Captured how?

We would add sentences to the KB.

Want more general / elegant approach.

For example: We want to make statements **about** possible changes in the world. (Why?)

Situation Calculus

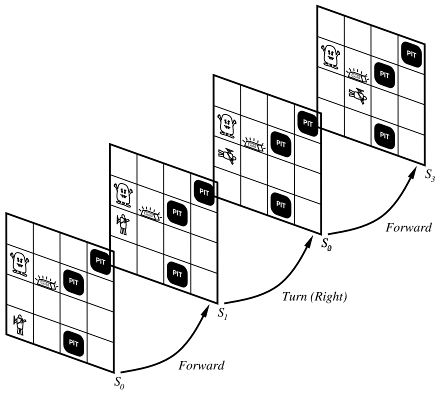
One approach: have time argument

We can be more concise, since we're only interested in when and how things **change**.

Focus on **"situations". ("snapshots")**

(John McCarthy 1963).

(Changing) World is represented by a series of *situations*.



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E.g.:

$At(Agent, [1, 1], S_0) \wedge At(Agent, [1, 2], S_1)$

"talking" about change / actions:

$Result(Forward, S_0) = S1$
$Result(Turn(Right), S_1) = S2$
$Result(Forward, S_2) = S3$

Is *Result* a relation or a function?
What about *Forward*?

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Effect Axioms

$Portable(Gold)$
$\forall s \quad AtGold(s) \Rightarrow Present(Gold, s)$
$\forall x, s \quad (Present(x, s) \land Portable(x)) \Rightarrow Holding(x, Result(Grab, s))$
$\forall x, s \quad \neg Holding(x, Result(Release, s))$

Does this work?

Frame Axioms

Need also to state what **doesn't** change!

$$\forall a, x, s \quad Holding(x, s) \land (a \neq Release)) \Rightarrow Holding(x, Result(a, x))$$

$$\forall a, x, s \quad (\neg Holding(x, s) \land (a \neq grab)) \Rightarrow \neg Holding(x, Result(a, x))$$

More compactly:

$\forall a, x, s \;\; Holding(x, Results(a, s)) \Leftrightarrow$
$\quad [(a = Grab \wedge Present(x, s) \wedge Portable(x))$
$\quad \vee (Holding(x, s) \wedge a \neq Release)]$

successor-state axioms: need to list all the ways in wich any predicate can become true / false.

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Frankly, representing and dealing with dynamic / changing is not a "strong point" of first-order logic.

- work on different logics:
  e.g. dynamic logic / nonmonotonic logic.

nonmon: long "struggle". Yale shooting problem (warn.: R):

`load gun / point gun / wait 5 seconds / fire gun`

question: target dead? about 100+ research papers . . ., since 1986; still not fully resolved.

first-order logic better at "static" information.

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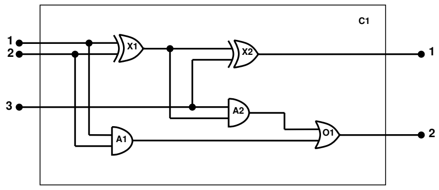
Another example: Electronic Circuits



Section 8.3 R&N.

Formalization

one-bit full adder: two inputs and a carry / one output and carry
 four gates: AND, OR, XOR and NOT.
Goal: analyze design to see if it matches specification.
Consider: circuits (gates and gate types), terminals, and signals.
 formalization — keep task in mind.
 e.g., for fault diagnosis: might want to specify "wires"
  could be broken... (e.g., $Wire(x, y)$)

Vocabulary

pick: functions / predicates / constants.

  constant symbols: X_1, X_2, etc.

  type gate: $Type(X_1) = XOR$, note XOR new constant.

    Alt.: $Type(X_1, XOR)$. Q. Advantage function?

  terminals: $Out(1, X_1), In(1, X_1), In(2, X_1)$.

connectivity: $Connected(Out(1, X_1), In(1, X_2))$.

  Note: we don't have to **name** the terminals explicity.

    the semantics of the function will assign some unique "object" to it.

    (Skolemization can bring back name.)

signal values: function $Signal(x)$, e.g., $Signal(In(1, X_1))$.

signal values: On and Off.

General Rules

how signals behave:

1) $\forall t_1, t_2 \;\; Connected(t_1, t_2) \Rightarrow Signal(t_1) = Signal(t_2)$

2a) $\forall t \;\; Signal(t) = On \vee Signal(t) = Off$

2b) $On \neq Off$

3) $\forall t_1, t_2 \;\;\; Connected(t_1, t_2) \Leftrightarrow Connected(t_2, t_1)$

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how gates behave:

4) $\forall g \;\; Type(g) = OR \Rightarrow$

$$Signal(Out(1, g)) = On \Leftrightarrow \exists n \;\; Signal(In(n, g) = On.$$

5) how AND?

6) $\forall g \;\; Type(g) = XOR \Rightarrow$

$$(Signal(Out(1, g)) = On \Leftrightarrow (Signal(In(1, g) \neq Signal(In(2, g))))$$

7) NOT, similarly.

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few rules (7): good ontology
clear rules: good vocabulary
what remains?

atomic facts — describing actual circuit under consideration.
types of gates:
$Type(X_1) = XOR, \;\; Type(X_2) = XOR, \;\; Type(A_1) = AND, \ldots$
conectivity:

$Connected(Out(1, X_1), \;\; In(1, X_2)),$
$Connected(In(1, C_1), \;\; In(1, X_1)),$
$Connected(Out(1, X_1), \;\; In(1, A_2))$
$Connected(In(1, C_1), \;\; In(1, A_1)),$

etc.

Queries

Our theory captures full behavior.

Can now ask many different queries about behavior etc.

E.g.

$\exists i_1, i_2, i_3 \;\; Signal(In(1, C_1)) = i_1 \wedge Signal(In(2, C_1)) = i_2 \wedge Signal(In_3, C_1)) = i_3$
$\wedge Signal(Out(1, C_1)) = Off \wedge Signal(Out(2, C_1)) = On$

A.: $(I_1 = On \wedge i_2 = On \wedge i_3 = Off) \vee$
$(I_1 = On \wedge i_2 = Off \wedge i_3 = On) \vee$
$(I_1 = Off \wedge i_2 = On \wedge i_3 = On)$

What is the advantage over direct simulation?

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Of course, formalization is somewhat facilitated by the "closeness" between logical formalisms and digital circuitry. Starting with Shannon, allows for very powerful design methods (but did not prevent Pentium bug...).

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