Foundations of Artificial Intelligence

CS472/3 — Fall 1999

Lecture #18 & 19

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Today's Lecture

K&R / Knowledge-Based Systems

Chapter 7 & 8, R&N.

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Example: N-Queens, first-order

- **1) no row with two queens**

  $$\forall i,j,k \;\; (1 \leq i,j,k \leq N) \;\; (Queen(i,j) \wedge Queen(i,k)) \Rightarrow (j = k)$$

- **2) no column with two queens**

  $$\forall i,j,k \;\; (1 \leq i,j,k \leq N) \;\; (Queen(j,i) \wedge Queen(k,i)) \Rightarrow (j = k)$$

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- **3) no diagonal with two queens**

  $$\forall i,j,k,l \;\; (1 \leq i,j,k,l \leq N) \;\; [(Queen(i,j) \wedge Queen(k,l) \wedge leftdiagonal(i,j,k,l)] \Rightarrow ((i = j) \wedge (k = l))$$

similarly for right diagonal.

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$$\forall i,j,k,l \ \ (1 \le i,j,k,l \le N)$$
$$leftdiagonal(i,j,k,l) \Leftrightarrow [(i-j)=(k-l)]$$

Similarly, for $rightdiagonal$

Complete?

- **4) at least one queen per row**

  $\forall i \ \exists j \ \ (1 \le i,j \le N) \ \ Queen(i,j)$

Note **finite domain:** finite propositional encoding exists.
Often be best for computer to reason with!

Interesting (first-order) consequence:

- at least one queen per column:
  $\forall i \ \exists j (1 \leq i, j \leq N) \ \ Queen(j, i)$

How do we know? How can we derive it automatically?

Simple Reflex Agent

Directly connects percepts to actions:
$\forall s, b, u, c, t \quad Percept([s, b, Glitter, u, c], t) \Rightarrow Action(Grab, t)$

Or, more indirectly:

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

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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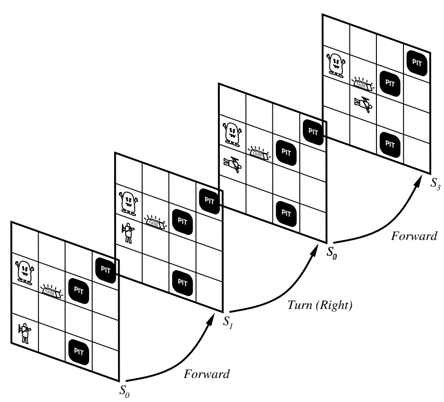

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E.g.:

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

"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

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

Does this work?

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Frame Axioms

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

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

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

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More compactly:

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

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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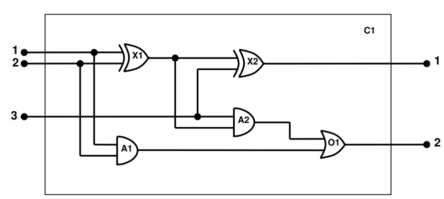
Another example: Electronic Circuits



Section 8.3 R&N.

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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., $Wire(x, y)$)

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

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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.

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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) $\forall t_1, t_2 \quad Connected(t_1, t_2) \Leftrightarrow Connected(t_2, t_1)$

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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?

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atomic facts — describing actual circuit under consideration.

types of gates:

$Type(X_1) = XOR$, $Type(X_2) = XOR$, $Type(A_1) = AND, ..$

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.

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Queries

Our theory captures full behavior.

Can now ask many different queries about behavior etc.

E.g.

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

A.: $(I_1 = On \land i_2 = On \land i_3 = Off) \lor$
$(I_1 = On \land i_2 = Off \land i_3 = On) \lor$
$(I_1 = Off \land i_2 = On \land i_3 = On)$

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...).