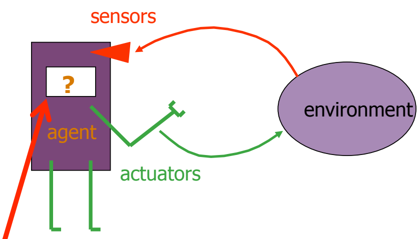
Knowledge Representation

CS151 Fall 2010
David Kauchak

Agent's knowledge representation

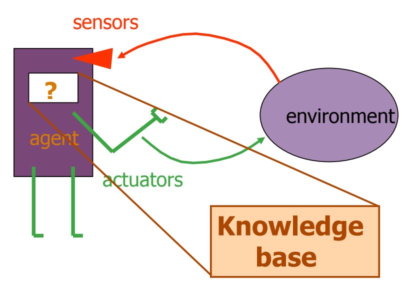


What have we seen so far for knowledge representation?

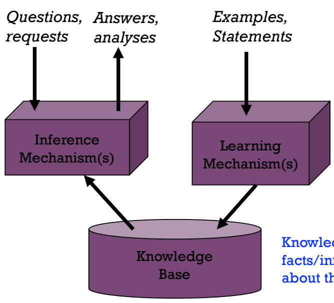
Agent's knowledge representation

- procedural
  - methods that encode how to handle specific situations
    - chooseMoveMancala()
    - driveOnHighway()
- model-based
  - bayesian network
  - neural network
  - decision tree
- Is this how people do it?

Knowledge-based agent



+ Knowledge-based approach



Knowledge base stores facts/information/rules about the world

+ What is in a knowledge base?

- Facts
  - Specific:
    - `Pomona College is a private college`
    - `Prof. Kauchak teaches at Pomona College`
    - `2+2 = 4`
    - `The answer to the ultimate question of life is 42`
  - General:
    - `All triangles have three sides`
    - `All tomatoes are red`
    - $n^2 = n * n$

+ Inference

- Given facts, we'd like to ask questions
  - Key: depending on how we store the facts, this can be easy or hard
  - People do this naturally (though not perfectly)
    - For computers, we need specific rules
- For example:
  - `Johnny likes to program in C`
  - `C is a hard programming language`
  - `Computer scientists like to program in hard languages`

  - What can we infer?

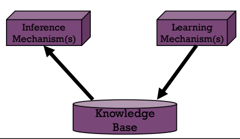
+ Inference

- For example:
  - Johnny likes to program in C
  - C is a hard programming language
  - Computer scientists like to program in hard languages
- **Be careful!**
  - we cannot infer that Johnny is a computer scientist
- What about now:
  - `All people who like to program in hard languages are computer scientists`

  - What can we infer?

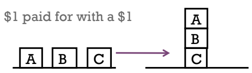
Creating a knowledge-based agent

- Representation: how are we going to store our facts?
- Inference: How can we infer information from our facts? How can we ask questions?
- Learning: How will we populate our facts?



Your turn

- Knowledge engineer
  - representation: how are you storing facts?
  - inference: how can you algorithmically query these facts?
  - learning: you provide the facts ☺
- Some problems to think about:
  - Give change for some purchase < $1 paid for with a $1
  - Block stacking problems
  - Wumpus world
  - How to make an omelette?
  - How early should I leave for my flight?
  - General reasoning agent (e.g. you)?



- Things to think about:
  - any approaches that you've seen previously useful?
  - what are the challenges?
  - what things are hard to represent?

Propositional logic

- Statements are constructed from propositions
- A proposition can be either true or false
- Statements are made into larger statements using connectives
- Example
  - `JohnnyLikesC = true`
  - `CisHard = true`
  - `CisHard ∧JohnnyLikesC => JohnnyIsCS`

Propositional logic

- Negation: not, ¬, ~
- Conjunction: and, ∧
- Disjunction: or, ∨
- Implication: implies, =>
- Biconditional: iff, <=>

Propositional logic

A	B	A⇒B
F	F	
F	T	
T	F	
T	T	

A	B	A⇔B
F	F	
F	T	
T	F	
T	T	

Propositional logic

A	B	A⇒B
F	F	T
F	T	T
T	F	F
T	T	T

A	B	A⇔B
F	F	T
F	T	F
T	F	F
T	T	T

A=>B ≡ ¬A∨B

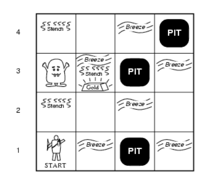
A<=>B ≡ (A=>B)∧(B=>A)

Inference with propositional logic

- There are many rules that enable new propositions to be derived from existing propositions
  - Modus Ponens: P=>Q, P, derive Q
  - deMorgan's law: ¬(A∧B), derive ¬A∨¬B

- View it as a search problem:
  - **starting state**: current facts/KB
  - **actions**: all ways of deriving new propositions from the current KB
  - **result**: add the new proposition to the KB/state
  - **goal**: when the KB/state contains the proposition we want

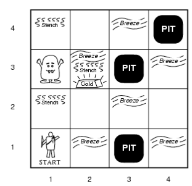
Propositional logic for Wumpus



How can we model Wumpus world using propositional logic? Is propositional logic a good choice?

Propositional logic for Wumpus

- Variable for each condition for each square
  - $breeze_{1,1}$ = false, $breeze_{1,2}$ = true, …
  - $breeze_{1,1}$ => $pit_{1,2}$ or $pit_{2,1}$, …



Have to enumerate all the states! Can't say if a square has a breeze then there is a pit next door

First order logic (aka predicate calculus)

- Uses objects (entities) and relations/functions
- Fixes two key problems with propositional logic
  - Adds relations/functions
    - `Likes(John, C)`
    - `isA(Obama, person)`
    - `isA(Obama, USPresident)`
    - `programsIn(John, C)`
  - This is much cleaner than:
    - `JohnLikeC`
    - `MaryLikesC`
    - `JohnLikesMary`
    - …

First order logic (aka predicate calculus)

- Quantifiers
  - "for all": written as an upside down 'A' - ∀
  - "there exists": written as a backwards 'E' - ∃
- For example:
  - `Johnny likes to program in C`
  - `C is a hard programming language`
  - `All people who like to program in hard languages are computer scientists`

$$likes(Johnny, C)$$

$$isHard(C)$$

$$\forall x\ \exists y\ likes(x,y) \wedge isHard(y) => isA(x, CS)$$

From text to logic

- There is a Pomona Student from Hawaii.
- Pomona students live in Claremont

More examples

- All purple mushrooms are poisonous
- No purple mushroom is poisonous
- Every CS student knows a programming language.
- A programming language is known by every CS student

How about…

$\forall x\ isA(x, Rose) \Rightarrow \exists y\ has(x,y) \wedge thorn(y)$

"Every rose has its thorn"

$\forall x\ \exists y$ isPerson(x) ∧ isPerson(y) => loves(x,y)

"Everybody loves somebody"

$\exists y\ \forall x$ isPerson(x) ∧ isPerson(y) => loves(x,y)

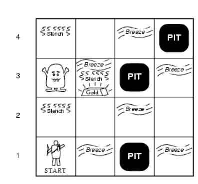
"There is someone that everyone loves"

$\forall x\ \exists y\ \exists$z isPerson(x) ∧ isPerson(y) ∧ isTime(z) => loves(x,y)

"Everybody loves somebody, sometime"

Now you try…

First-order logic for Wumpus



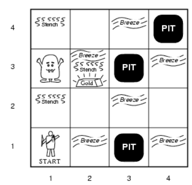
How can we model Wumpus world first order logic?

First-order logic for Wumpus

- A little tricky, but much more condensed

$$\forall s\ At(s) \wedge FeelBreeze(s) => Breezy(s)$$

$$\forall s\ Breezy(s) <=> \exists r\ Adjacent(s,r) \wedge Pit(r)$$



Inference with first-order logic

- Similar to predicate logic, can define as a search problem
- PROLOG is an example of an implementation of first-order logic

PROLOG

define a new method

```
change([H,Q,D,N,P]) :-
   member(H,[0,1,2]),
   member(Q,[0,1,2,3,4]),
   member(D,[0,1,2,3,4,5,6,7,8,9,10]),
   member(N,[0,1,2,3,4,5,6,7,8,9,10,
          11,12,13,14,15,16,17,18,19,20]),
   S is 50*H + 25*Q +10*D + 5*N,
   S =< 100,
   P is 100-S.
```

define range/possible values

facts

What would: change([0,2,3,4,6]) give us?

PROLOG

define a new method

```
change([H,Q,D,N,P]) :-
   member(H,[0,1,2]),
   member(Q,[0,1,2,3,4]),
   member(D,[0,1,2,3,4,5,6,7,8,9,10]),
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   S is 50*H + 25*Q +10*D + 5*N,
   S =< 100,
   P is 100-S.
```

define range/possible values

facts

no solution

PROLOG

define a new method

```
change([H,Q,D,N,P]) :-
   member(H,[0,1,2]),
   member(Q,[0,1,2,3,4]),
   member(D,[0,1,2,3,4,5,6,7,8,9,10]),
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   S =< 100,
   P is 100-S.
```

define range/possible values

facts

What would: change([0,2,3,2,P]) give us?

PROLOG

define a new method

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change([H,Q,D,N,P]) :-
   member(H,[0,1,2]),
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         11,12,13,14,15,16,17,18,19,20]),
   S is 50*H + 25*Q +10*D + 5*N,
   S =< 100,
   P is 100-S.
```

define range/possible values

facts

P=10 (we can make this work if P=10)

PROLOG

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define range/possible values

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What would: change([H,Q,D,N,P) give us?

PROLOG

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         11,12,13,14,15,16,17,18,19,20]),
   S is 50*H + 25*Q +10*D + 5*N,
   S =< 100,
   P is 100-S.
```

define range/possible values

facts

All possible ways of making change for $1!

PROLOG: N-Queens

```
solve(P) :-
    perm([1,2,3,4,5,6,7,8],P),
    combine([1,2,3,4,5,6,7,8],P,S,D),
    all_diff(S),
    all_diff(D).

combine([X1|X],[Y1|Y],[S1|S],[D1|D]) :-
    S1 is X1 +Y1,
    D1 is X1 -Y1,
    combine(X,Y,S,D).
combine([],[],[],[]).

all_diff([X|Y]) :-  \+member(X,Y), all_diff(Y).
all_diff([X]).
```

http://www.csupomona.edu/~jrfisher/www/prolog_tutorial/contents.html

Logic, the good and the bad

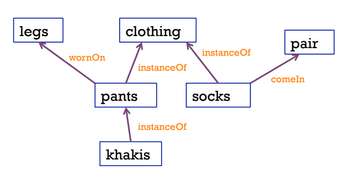
- Good:
  - Mathematicians have been working on it for a while
  - Logical reasoning is straightforward
    - tools (like PROLOG) exist to help us out
- Bad:
  - Dealing with exceptions is hard
    - not all tomatoes are red
    - sometimes our weather rock is wet, even though its not raining
  - Can be unintuitive for people
  - Going from language to logic is very challenging
  - Many restrictions on what you can do

Challenges

- General domain reasoning is hard!
  - ACTIONS
  - TIME
  - BELIEFS
- Chapt 12 in the book talks about a lot of these challenges
  - organizing objects into a hierarchy (shared/inherited properties… like inheritance in programming)
  - dealing with measurements
  - …
- At the end of the day, these don't work very well

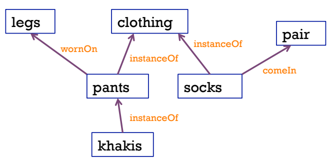
Ontology

- First-order logic states relationships between objects
- One easy way to represent a similar concept is with a graph
  - nodes are the objects
  - edges represent relationships between nodes
  - some of the quantifier capability is lost



Ontology

- Intuitive representation for people
- Can pose questions as graph traversals which is often more comfortable/efficient



Opencyc

- http://sw.opencyc.org/
- The good:
  - hundreds of thousands of terms
  - millions of relationships
  - includes proper nouns
  - includes links to outside information (wikipedia)
- The bad:
  - still limited coverage
  - limited/fixed relationships

WordNet

- http://wordnet.princeton.edu/
- The good:
  - 155K words
  - word senses (and lots of them)
  - part of speech
  - example usage
  - definitions
  - frequency information

  - some interesting uses already
    - word similarity based on graph distances
    - word sense disambiguation

WordNet

- The bad:
  - limited relationships
    - only "linguistic" relationships
    - hyponym (is-a)
    - hypernym (parent of is-a)
    - synonym
    - holonym (part/whole)
  - sometimes too many senses/too fine a granularity

Open mind common sense

- Use the intellect of the masses!
- http://openmind.media.mit.edu/
- The good:
  - much broader set of relationships
  - lots of human labeling
    - can collect lots of data
    - human labeled
    - reduces spam
  - more general statement engine

Open mind common sense

- The bad:
  - relies on the user
  - still a limited vocabulary
  - only scoring is voting
  - limited coverage in many domains

NELL

- NELL: Never-Ending Language Learning
  - http://rtw.ml.cmu.edu/rtw/
  - continuously crawls the web to grab new data
  - learns entities and relationships from this data
    - started with a seed set
    - uses learning techniques based on current KB to learn new information