Announcement

- Homework 1 was posted to the web site yesterday
- Due one week from today
- Hand-in instruction on web site
- www.cs.illinois.edu/class/cs440
- Requires some consolidation thought
- Don't Wait

Admissibility of A* (cont)

2) $\forall n \in$ nodes

$h(n) \leq h^*(n)$

Informally: be optimistic
(or don't be pessimistic)
Why? Could you prove it?

Important General Principle:
Optimism Under Uncertainty

Does not depend on problem or tree!

Is "Uniform Cost" admissible?

We have:

A_1* with heuristic fcn h_1

A_2* with heuristic fcn h_2

A_1* and A_2* are admissible

Then we say

A_1* is *more informed* than A_2*

iff for all non-goal nodes n

$h_1(n) > h_2(n)$

"more informed" implies "guaranteed not to search more"

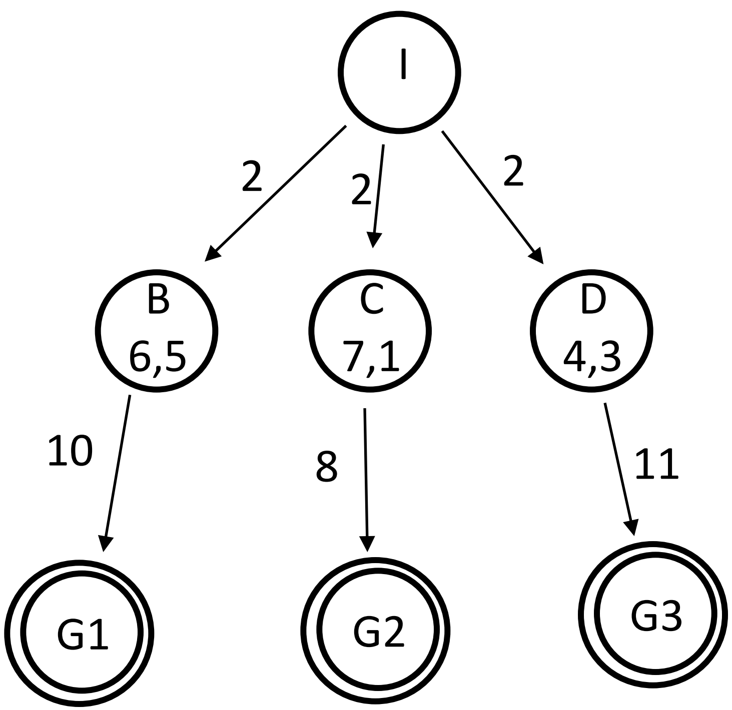
But what about this?

Three nodes B, C, D
two A* searches A_1 and A_2 with

		B	C	D
h^*		10	8	11
h_1	6	7	4	
h_2	5	1	3	

A_1 is more informed than A_2 but won't it search more?

	B	C	D	
h*		10	8	11
h_1	6	7	4	
h_2	5	1	3	



	A_1
n	q
-	(I)
I	(D_6 B_8 C_9)
D	(B C $G3_{13}$)
B	(C $G1_{12}$ G3)
C	($G2_{10}$ G1 G3)
G2	(G1 G3)

	A_2
n	q
-	(I)
I	(C_3 D_5 B_7)
C	(D B $G2_{10}$)
D	(B G2 $G3_{13}$)
B	(G2 $G1_{12}$ G3)
G2	(G1 G3)

Other Questions?

Linearity

Problem / World / System

Straight line / hyperplane

Linear = Easy

Superposition Principle:

Solve($G_1 \wedge G_2$, IS)

= Solve(G_1, IS) $\cup$ Solve(G_2, IS)

Is the world usually linear?

IS: $5, G_1: Lunch, G_2: Present

Search as Problem Solving assume linearity?

Exhaustive:

No

Hill Climbing:

Yes

Beam:

Yes, partially

Example

Suppose we want to build a house

Branching factor?

~50 (conservative)

Depth?

~1000 (small house)

Number of leaves in tree?

50^{1000}

$\cong 10^{1300}$

A fast computer - assume a TeraHz machine

1,000,000,000,000 or 10^{12} nodes/sec

Seconds in a year?

30,000,000 or 3×10^{7} sec/year

Age of the Universe?

14,000,000,000 or 1.4×10^{10} years

We can expand $4.2 \times 10^{29} < 10^{30}$ nodes

How informed must h be?

What fraction of nodes can we expand?

(assuming faster-than-possible computer, start at t=0, etc…)

Fraction: $10^{30} / 10^{1300}$

= 30/1300 or ~0.023?

NO!

$10^{30} / 10^{1300} = 10^{30-1300}$

10^{-1270} or

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Fraction Continued

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Fraction Continued

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What about parallelizing the search?

If each subatomic particle in the universe were a computer…

(there are about 10^{80} particles in the universe)

Things would not change much
(multi-core won't solve everything…)

Search: Algorithmic Complexity

- Why we avoid search
- Exponentials are mind-bogglingly BAD
- Easy problems can become difficult
- Difficult problems can become easy
- Key: Avoid search by representing / organizing / exploiting knowledge

World Model in Symbolic Logic

- States are decomposable into features
  - Properties & relations among objects in the state
  - Unlike search-type world model
- Inference
  - Come to know the goal through its features
  - Problem Solving by appreciating constraints
  - Explicit realization of what is already true
- Predicate Calculus as language for describing the world, its states, their features
- This is math...
- Logic-specific overload to “model” (disambiguate with context)

Text Decomposition

- Ch 7: Propositional Logic
  (aka Zeroth Order Logic)
- Ch 8: First Order Logic
- Ch 9: Inference
- [Ch 12: Knowledge Representation]

This organization can occlude the underlying conceptual structure; we will depart from it whenever convenient

Logic as Knowledge Representation

- Declarative (not procedural)
- Symbolic (not “sub-symbolic”)
- Well-defined componential semantics
- Interesting operations (e.g., inference) can be defined purely syntactically

- Does not naturally embrace uncertainty (this is its Achilles heel)

Inference

Apples are delicious things

Delicious things are edible

Therefore...

"I've eaten apples…yes! they are delicious and edible"

"Hold on, I've eaten apples. They *are* delicious, but they give me bad indigestion; they are *not* edible."

Philosophical / AI problem of "grounding"

Symbolic Logic offers a solution

Symbolic Inference

$A \Rightarrow B$

$B \Rightarrow C$

A

Therefore:

B

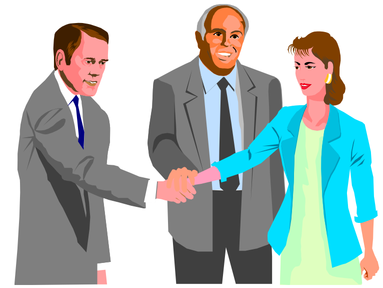
C

$A \Rightarrow C$

…

But what does "A" mean / stand for?

Universe / Universe of Discourse / Domain / ...



Objects are denoted by symbols:

Andy17 denotes

⇧

object constant symbol
constant symbol
object constant

Andy Smith
Age 23
Height 5’9”
...

For us, different object constants implies different objects and vice versa.

Mary Smith
Age 25
...

The symbol / object association is arbitrary:

Car54 denotes

Predicates / Relations are Denoted by Symbols

Married(Andy17, Car54)

Predicate Symbol

A particular relationship exists between the individuals

Predicates are n-ary

Meaning of a predicate is a (possibly infinite) set of n-tuples:
{(Joe23, Jill6), (Liz13, Fred972), …(Andy17, Car54)…}
here we used the symbols but really its their denotations

Functions are Denoted by Symbols

Father-of(Andy17)

Function Symbol

Another way of denoting an individual i.e., John3

Functions are n-ary

Meaning of a function is a (possibly infinite) set of n+1 tuples:
{(Joe23, Fred972), (Liz13, John3), …(Andy17, John3)…}

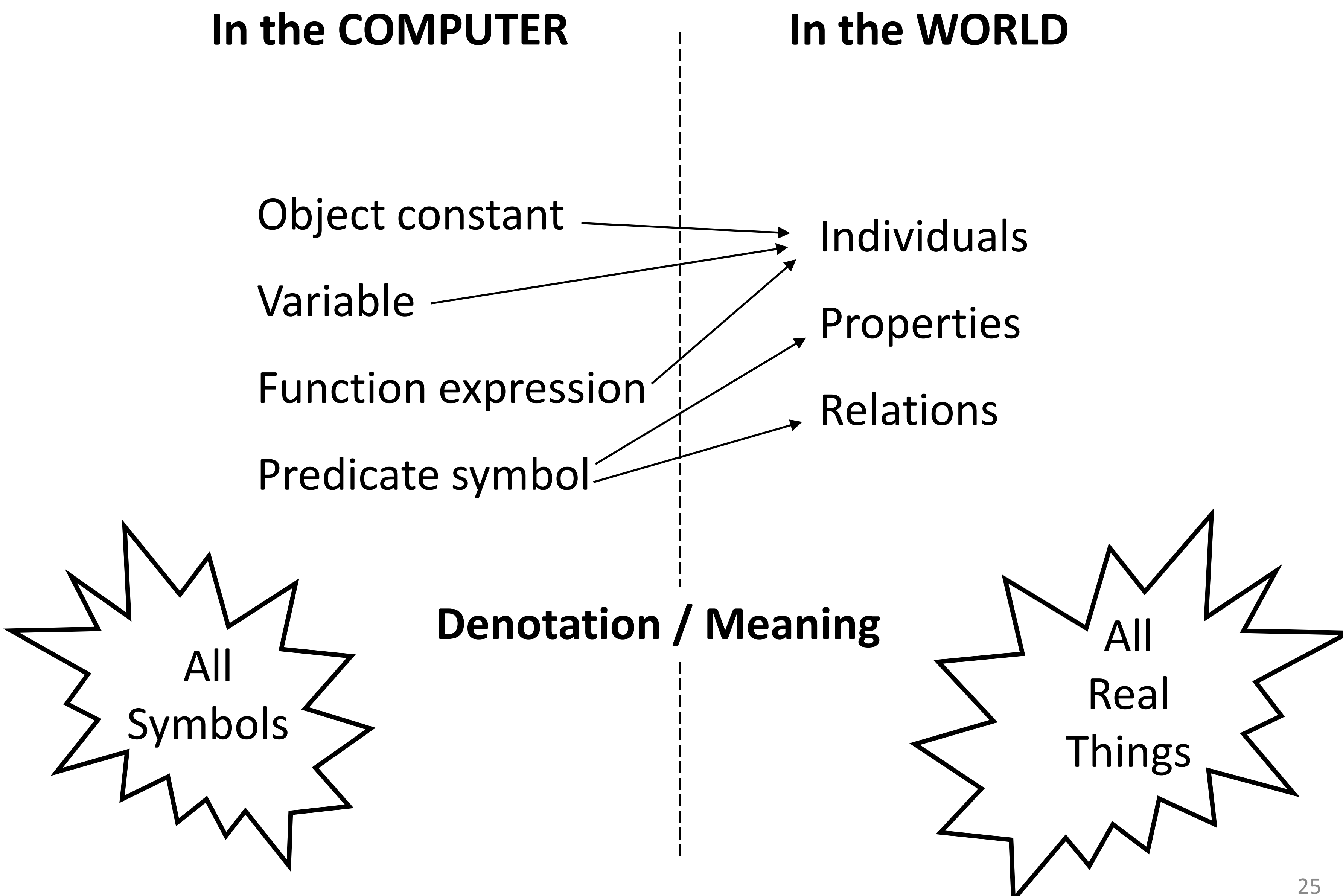
Variables - another type of symbol

- First Order
- Stand for individuals in the universe of discourse
- Not functions or relations
- Can be “free” or “bound”

“within the scope of a quantifier”
(NB: *NOT* a programming notion)

Important quantifiers

$\exists$	**existential**	**“there exists”**
$\forall$	**universal**	**“for all”**


In the COMPUTER
In the WORLD
Object constant
Variable
Function expression
Predicate symbol
Individuals
Properties
Relations
Denotation / Meaning
All Symbols
All Real Things

Logical Connectives

$\neg$	**negation**	**“not”**
$\wedge$	**conjunction**	**“and”**
$\vee$	**disjunction**	**“or”**
$\Rightarrow$	**implication**	**“implies”**
$\Leftrightarrow$	**equivalence**	**“if and only if”**

A *term* denotes an individual in the universe of discourse

- variable
- object constant
- function expression

A *function expression* is an n-ary function symbol with n terms as arguments

An *atom* (also atomic sentence, atomic WFF) is an n-ary predicate symbol with n terms as arguments

A *literal* is an atom or a negated atom

Well Formed Formulas WFFs

Atoms are WFFs

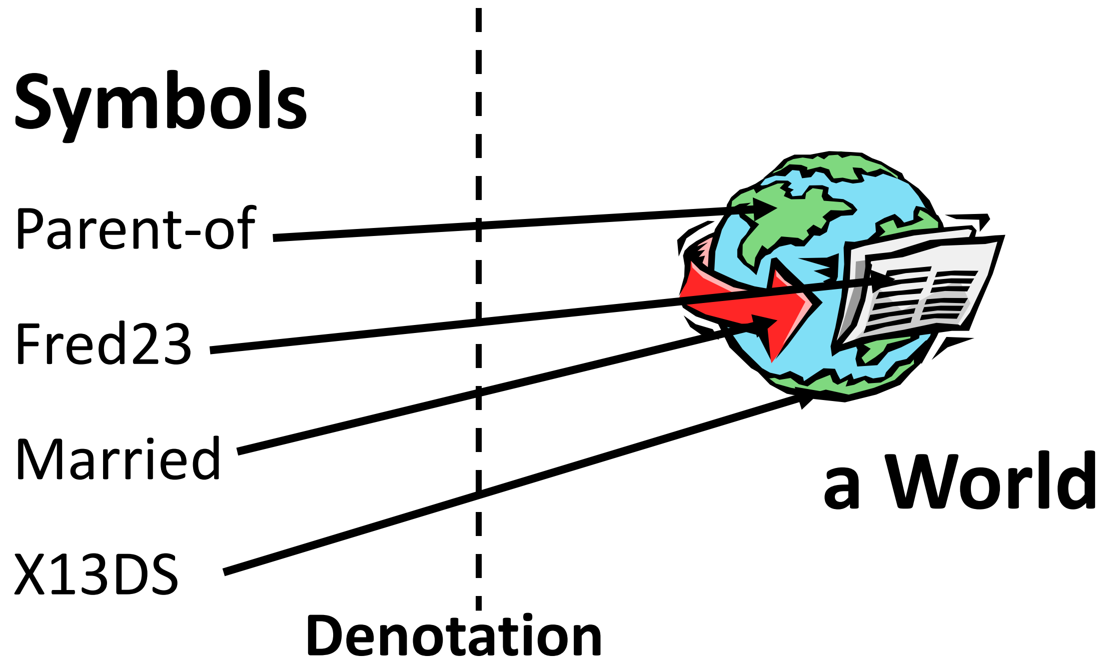
If Θ and Φ are WFFs then so are

$\forall x\ \Theta$	$\exists x\ \Theta$	$\neg\ \Theta$
$\Theta \wedge \Phi$	$\Theta \vee \Phi$	
$\Theta \Rightarrow \Phi$	$\Theta \Leftrightarrow \Phi$	

Logical implication $\Theta \Rightarrow \Phi$ is precisely $\neg\Theta \vee \Phi$
(*not* English implication!)

$\Theta \Leftrightarrow \Phi$ is precisely $(\Theta \Rightarrow \Phi) \wedge (\Phi \Rightarrow \Theta)$

$\vee$ “or” is inclusive



WFFs are *Truth Valuable* given a world and a denotational correspondence

WFF + denotation is a claim or assertion about the world

Claim holds or not (is true or false) depending on relations in the world

Examples

Some student is named “John”

$\exists x\, [Student(x) \wedge Name(x, \text{“John”})]$

Every student owns a computer

$\forall x\, [Student(x) \Rightarrow \exists y\, (Computer(y) \wedge Owns(x,y))]$

Scope of y

Scope of x

$\exists y\, [Computer(y) \wedge \forall x\, (Student(x) \Rightarrow Owns(x,y))]$

WFFs have different meanings

The English statement is ambiguous

More Examples

Birds fly.

Some birds fly.

Room 1404 Siebel is empty.

Some Ford is better than any Buick.

Someone on the basketball team is taller than anyone on the football team.

“Birds Fly”

$\forall x\ [\text{Bird}(x) \Rightarrow \text{Flies}(x)]$

$\forall x\ [B(x) \Rightarrow F(x)]$ where B means “is a bird” and F means “can fly”

We can also think about the meaning as
“There are no birds that cannot fly”

$\neg\exists x\ [\text{Bird}(x) \wedge \neg\text{Flies}(x)]$

These are equivalent: the two predicate calculus sentences have the same meaning although they look quite different.

Some birds fly.

$\exists x\ [Bird(x) \wedge Flies(x)]$

Note: in logic "some" traditionally means "at least one"

Room 1404 Siebel is empty. [taken to mean empty of people]

Really Bad: P

Poor: $Empty(Room1404SC)$

Better: $\forall x\ [Person(x) \Rightarrow Different(Location\text{-}of(x), Room1404SC)]$

Still Better: $\forall x\ \forall y\ [(Person(x) \wedge Location(y) \wedge At(x,y)) \Rightarrow Different(y, Room1404SC)]$

Completely Wrong: (why?)

$\forall x\ [Person(x) \Rightarrow At(x, \neg Room1404SC)]$

NOTE: functions (like Location-of) are partial…