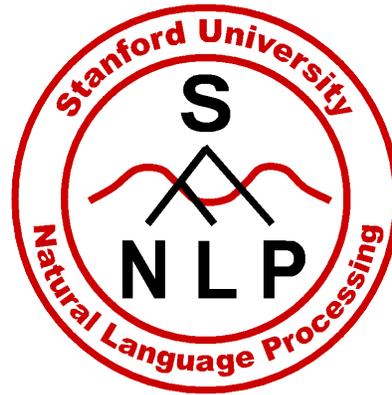


# Computational Semantics



CS224N 2011

Bill MacCartney

(Based on slides by Chris Manning, who in turn borrowed some slides from Mary Dalrymple, Jason Eisner, and Jim Martin)



# Why computational semantics?

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- Obvious high-level applications
  - Summarization
  - Translation
  - Question answering
  - Information access
  - Talking to your pet robot
  - Speech user interfaces
- The next generation of intelligent applications need deeper semantics than we have seen so far
  - Often you must understand well to be able to act



# Shallow vs. deep semantics

- We can do more than one might have thought without deep linguistic analysis
  - This is *the* lesson of the last two decades
- But we can't do everything we would like:
  - Not all tasks can ignore higher structure
  - Unsuitable if new text must be generated
  - Unsuitable if machine must act rather than relying on user to interpret material written by the author of the document
- You get what you pay for:
  - Cheap, fast, low-level techniques are appropriate in domains where speed and volume are more important than accuracy
  - More computationally expensive, higher-level techniques are appropriate when high-quality results are required



# MSN Search: Which is the largest African country?

A screenshot of a Mozilla Firefox browser window displaying MSN search results. The browser's address bar shows the URL: http://search.msn.com/results.aspx?q=Which+is+the+largest+African+country%3F. The search bar contains the query "Which is the largest African country?" and has a "Search" button and a "Near Me" button. The results section is titled "Web Results" and shows "1-10 of 1,555,823 containing Which is the largest African country? (0.11 seconds)". The first result is an "Answer" from Encarta: "Answer: **Sudan (country)**, republic in northeastern Africa, the largest country of the African continent. It is bounded on the north by Egypt; on the east by the...". Below this are three other search results with blue underlined titles: "Africa Safaris, Tours, Holidays and Travel Guide for each African ...", "Southern African Development Community Country Analysis Brief", and "The Inquirer - New England's Largest African American Newspaper". The browser's status bar at the bottom shows "Done".



# Live Search: Which is the largest African country?

A screenshot of a web browser window displaying search results from Live Search. The browser's address bar shows the URL "http://search.live.com/results.aspx?q=Which+is+the+largest+Afric". The search bar contains the query "Which is the largest African country?". The results page shows several entries, including "African facts and figures" from www.africaguide.com, "South Africa - Wikipedia, the free encyclopedia" (noting it as the 25th-largest country), "Central African Republic - Wikipedia, the free encyclopedia" (noting it as the 43rd-largest country), and "Southern African Development Community Country Analysis Brief" from www.eia.doe.gov. The browser interface includes navigation buttons (Back, Forward, Reload, Stop), a search bar, and a bookmarks icon.



# Bing: Which is the largest African country?

A screenshot of a web browser displaying a Bing search results page. The browser's address bar shows the search query: 'http://www.bing.com/search?q=Which+is+the+largest+African+country%3F&amp;g'. The search bar contains the text 'Which is the largest African country?'. Below the search bar, there are several search results. The first result is from Wikipedia, titled 'Africa - Wikipedia, the free encyclopedia', with a snippet stating 'Africa's largest country is Sudan, and its smallest country is the Seychelles, an archipelago off the east coast. [51] The smallest nation on the continental mainland is The Gambia.' The second result is from WikiAnswers, titled 'WikiAnswers - What is the largest country in Africa', with a snippet stating 'Sudan is the largest country in Africa. Note: There are comments associated with this question. See the discussion page to add to the conversation. This answer is closed to ...'. The third result is from Wikipedia, titled 'Portal:Africa/Countries/Selected country - Wikipedia, the free ...', with a snippet stating 'Algeria (Arabic : الجزائر , Al Jaza'ir, Berber :, Dzayer), officially the People's Democratic Republic of Algeria, is the second largest country on the African ...'. The fourth result is titled 'African facts and figures' with a snippet stating '... eastern Africa, the largest country of the African continent. Sudan has a total area of 2,505,800 sq km (967,490 sq mi). Smallest Country'. On the left side of the page, there are sections for 'RELATED SEARCHES' and 'SEARCH HISTORY'. The 'RELATED SEARCHES' section includes links like 'Largest Country in Africa', 'Largest African Desert', 'Best African Country', 'Largest European Country', 'Largest City in North Africa', 'Smallest Country in North Africa', 'Facts on Central Africa', and 'Facts on East Africa'. The 'SEARCH HISTORY' section includes 'Which is the largest African...' and 'Canon PowerShot'.



# Google: Which is the largest African country?

A screenshot of a web browser window showing a Google search result. The browser's address bar contains the URL 'http://www.google.com/search?client=safari&amp;rls=en&amp;q=Which+is+the+largest' and the search query 'Which is the largest Africa'. The search results page displays the Google logo, the search query 'Which is the largest African country', and the number of results 'About 3,740,000 results (0.33 seconds)'. The first search result is titled 'Africa - Wikipedia, the free encyclopedia' and includes a snippet: 'Nevertheless, White Africans remain an important minority in many African states. The African country with the largest White African population is South ...'. Other search results include 'List of African countries and territories - Wikipedia, the free ...' and 'African facts and figures' from 'www.africaguide.com'. The browser's tab bar shows several open tabs, including 'symbolic...', 'CS 224N ...', 'jiwon yu...', 'Overvie...', 'The Stan...', 'Parasol ...', and 'Which is ...'. The browser's navigation bar includes links for 'Web', 'Images', 'Videos', 'Maps', 'News', 'Shopping', 'Gmail', and 'more'. The browser's status bar at the bottom says 'Display a menu'.



# Live Search: What is the capital of Sudan?

A screenshot of a web browser window displaying search results from Live Search. The browser's address bar shows the URL "http://search.live.com/results.aspx?q=What+is+the+...". The search bar contains the query "What is the capital of Sudan?". The search results are displayed on a blue background with a search bar and navigation tabs for "Web", "Images", "News", "Maps", "Classifieds", and "More". The top result is "Sudan Capital: Khartoum" with a link to "en.wikipedia.org/wiki/Juba%2C\_Sudan". Below this, there is a snippet of text from Wikipedia about Juba, Sudan, and another snippet about the capital of Sudan, Khartoum. The browser window also shows several open tabs, including "CS 224N / Ling 280 Sy...", "Live Search: What is th...", and "What is the currency o...".



# MSN Search: Which countries does the Danube flow through?

A screenshot of a Mozilla Firefox browser window displaying MSN search results. The browser's address bar shows the URL: http://search.msn.com/results.aspx?q=Which+countries+does+the+Danube+flow+. The search bar contains the query "Which countries does the Danube flow through?" and a "Search" button. The results section is titled "Web Results" and shows "1-10 of 16,590 containing Which countries does the Danube flow through? (0.10 seconds)". Three search results are visible, each with a blue link title "Danube River" and a snippet of text. The first result snippet says "... and the only major European river to flow from West to East. It takes its source ... the Romanian coast. Along its way, the Danube flows through nine countries (Germany, Austria, Slovakia, Hungary ...". The second result snippet says "... down this river. The Danube, through its rich history, remains ... of Yugoslavia. On the Danube, different countries have built dams and ... level. After all, the Danube does provide a major ...". The third result snippet says "... only major European river to flow from west to east. It rises ... where the Danube Delta is. The Danube is an important international waterway. It flows through ten countries ( Austria , Bulgaria , Croatia ...". Each result includes a green link to the source page and a "Cached page" link. The browser's status bar at the bottom shows "Done".



# MSN Search: What are the capitals of the countries bordering the Baltic?

The screenshot shows a Mozilla Firefox browser window displaying MSN Search results. The search query is "What are the capitals of the countries bordering the Baltic?". The results page shows 1-10 of 4,928 results. The first two results are from "CIA - The World Factbook -- Germany" and "CIA - The World Factbook -- Sweden". The third result is from "2004" and discusses the position of developing countries. The browser's address bar shows the URL: http://search.msn.com/results.aspx?q=What+are+the+capitals+of+the+countries+bordering+the+Baltic+Sea. The browser's menu bar includes File, Edit, View, Go, Bookmarks, Tools, and Help. The browser's toolbar includes a search bar with the text "msn search" and a "Go" button. The browser's status bar shows "Done".

MSN Search: What are the capitals of the countries bordering the Baltic? - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

http://search.msn.com/results.aspx?q=What+are+the+capitals+of+the+countries+bordering+the+Baltic+Sea

Symboli... Symboli... BBC NE... CS 224... NLP Tree (S... NLP cl-sema... NLP cv05.p... Compu... Google ... MSN S...

Web News Images Desktop Encarta

What are the capitals of the countries bordering the Baltic? Search Near Me

+Search Builder Settings Help Español

## Web Results

1-10 of 4,928 containing **What are the capitals of the countries bordering the Baltic?** (0.11 seconds)

### [CIA - The World Factbook -- Germany](#)

... Top of Page Location: Central Europe, **bordering** the **Baltic** Sea and the North Sea, between the Netherlands ... boundaries: total: 3,621 km border **countries**: Austria 784 km, Belgium 167 km, Czech Republic ...

[www.capitals.com/geos/gm.html](http://www.capitals.com/geos/gm.html) [Cached page](#)

### [CIA - The World Factbook -- Sweden](#)

... Top of Page Location: Northern Europe, **bordering** the **Baltic** Sea, Gulf of Bothnia, Kattegat, and Skagerrak ... boundaries: total: 2,205 km border **countries**: Finland 586 km, Norway 1,619 km Coastline ...

[www.capitals.com/geos/sw.html](http://www.capitals.com/geos/sw.html) [Cached page](#)

[Show more results from "www.capitals.com"](#).

### [2004](#)

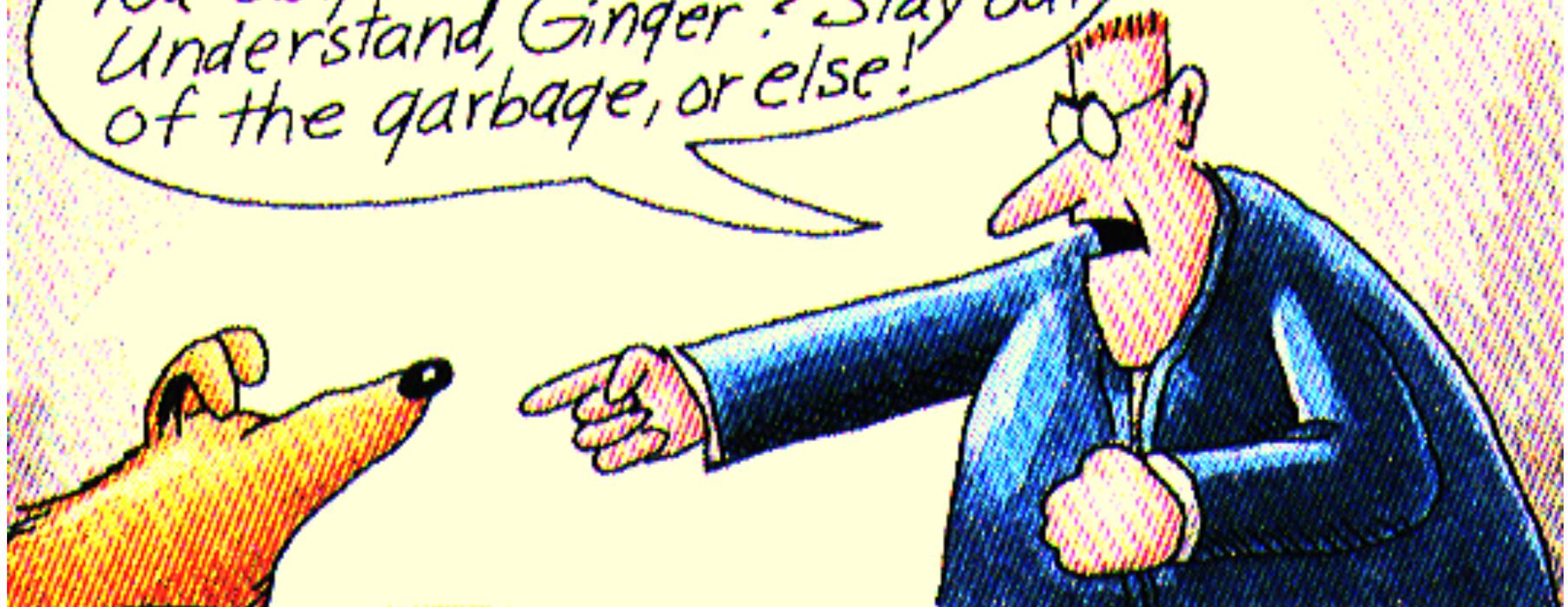
... into consideration the position of developing **countries**. The Protocol will enter into force once ... sale (including sale in markets in nations **bordering** the Convention area) of bluefin tuna less ...

[www.nmfs.noaa.gov/sfa/international/InternationalAgreements/04InternationalAgreements.pdf](http://www.nmfs.noaa.gov/sfa/international/InternationalAgreements/04InternationalAgreements.pdf) [Cached page](#) PDF file

Done

# What we say to dogs

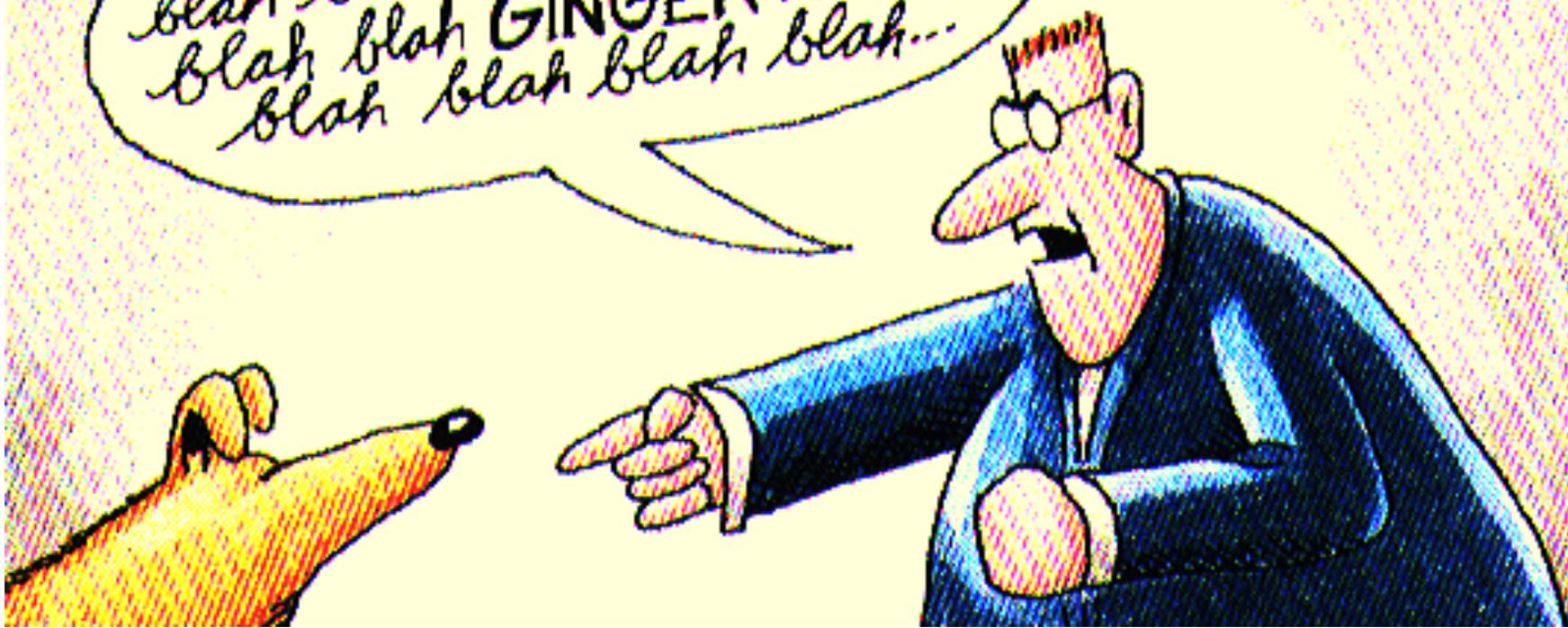
Okay, Ginger! I've had it!  
You stay out of the garbage!  
Understand, Ginger? Stay out  
of the garbage, or else!



# What they hear

Lynn

blah blah GINGER blah  
blah blah blah blah  
blah blah GINGER blah  
blah blah blah blah...





# Chat-80: doing precise semantics

- Developed between 1979 and 1982 by Fernando Pereira and David Warren; became Pereira's dissertation
- Proof-of-concept natural language interface to database system
- Used in projects: e.g. Shoptalk (Cohen et al. 1989), a natural language and graphical interface for decision support in manufacturing
- Even used in an AppliedNLP-2000 conference paper! [Asking about train routes and schedules]
- Source code in /afs/ir/class/cs224n/src/chat/
  - sadly, I've failed to get it to actually run ☹



# Things you could ask...

---

- What is the total area of countries south of the Equator and not in Australasia?
- What is the average area of the countries in each continent?
- Is there more than one country in each continent?
- What are the countries from which a river flows into the Black\_Sea?
- Which country bordering the Mediterranean borders a country that is bordered by a country whose population exceeds the population of India?



# The CHAT-80 Database

```
% Facts about countries.
% country(Country,Region,Latitude,Longitude,
%       Area (sqmiles), Population,
%       Capital,Currency)
country(andorra,southern_europe,42,-1,179,
       25000,andorra_la_villa,franc_peseta).
country(angola,southern_africa,-12,-18,481351,
       5810000,luanda,?).
country(argentina,south_america,-35,66, 1072067,
       23920000,buenos_aires,peso).

capital(C,Cap) :- country(C,_,_,_,_,_,Cap,_).
```



# The CHAT-80 Grammar

```
/* Sentences */
sentence(S) --> declarative(S), terminator(.) .
sentence(S) --> wh_question(S), terminator(?) .
sentence(S) --> yn_question(S), terminator(?) .
sentence(S) --> imperative(S), terminator(!) .

/* Noun Phrase */
np(np(Agmt, Pronoun, []), Agmt, NPCase, def, _, Set, Nil) -->
  {is_pp(Set)},
  pers_pron(Pronoun, Agmt, Case),
  {empty(Nil), role(Case, decl, NPCase)}.

/* Prepositional Phrase */
pp(pp(Prep, Arg), Case, Set, Mask) -->
  prep(Prep),
  {prep_case(NPCase)},
  np(Arg, _, NPCase, _, Case, Set, Mask).
```



# Chat-80 trace (small)

Question: What is the capital of  
Australia?

Parse: 0.0sec.

whq

\$VAR

1

s

np

3+sin

wh(B)

[]

verb(be,active,pres+fin,

[],pos)

arg

dir

np

3+sin

np\_head

det(the(sin))

[]

capital

pp

prep(of)

np

3+sin

name

(australia)

[]

[]

Semantics: 0.0sec.

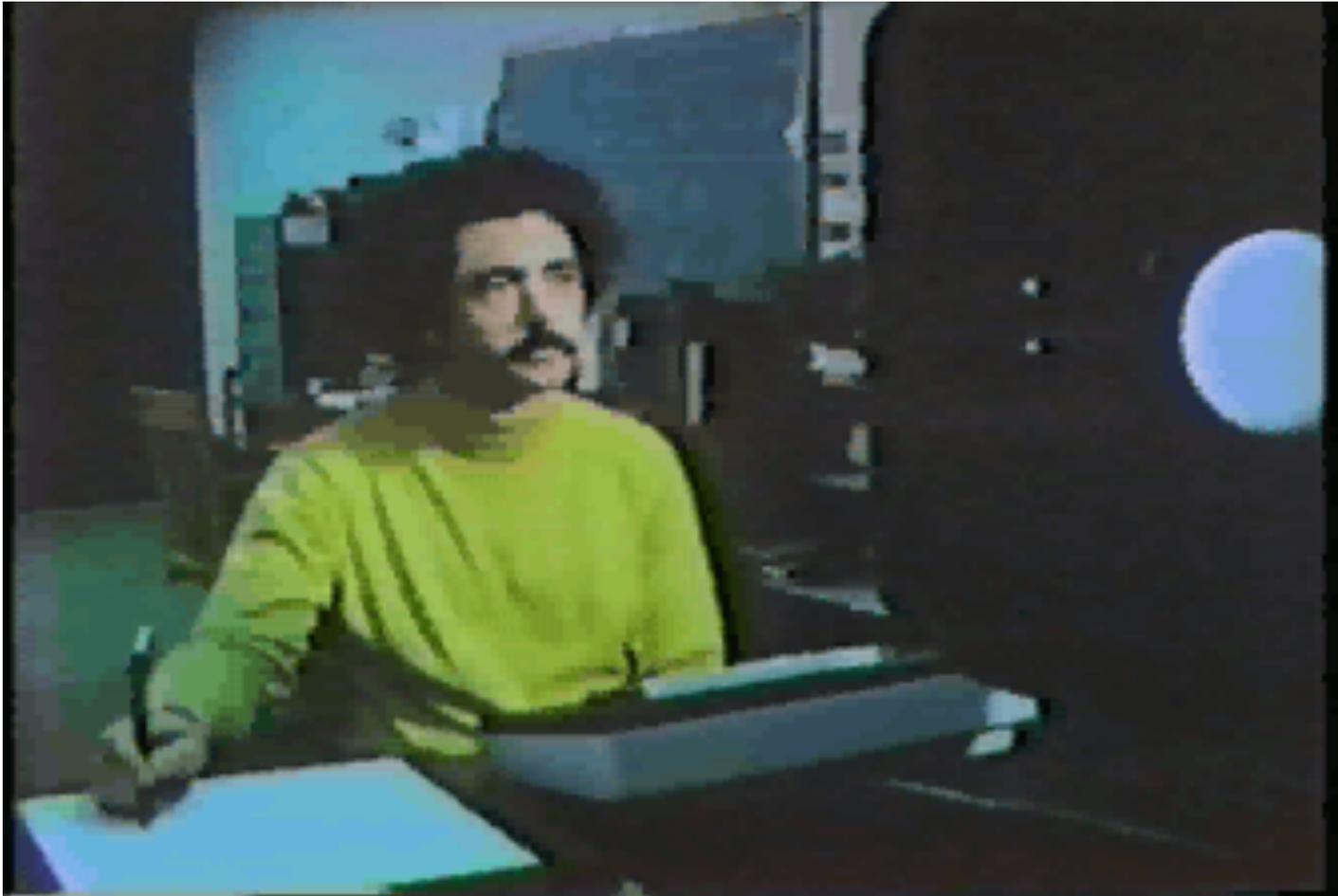
answer([B]) :-

capital(australia,B)

canberra.



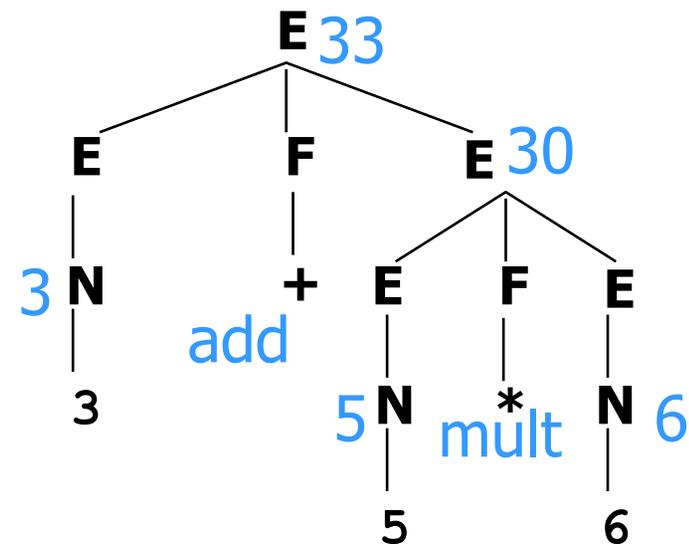
# SHRDLU





# Programming Language Interpreter

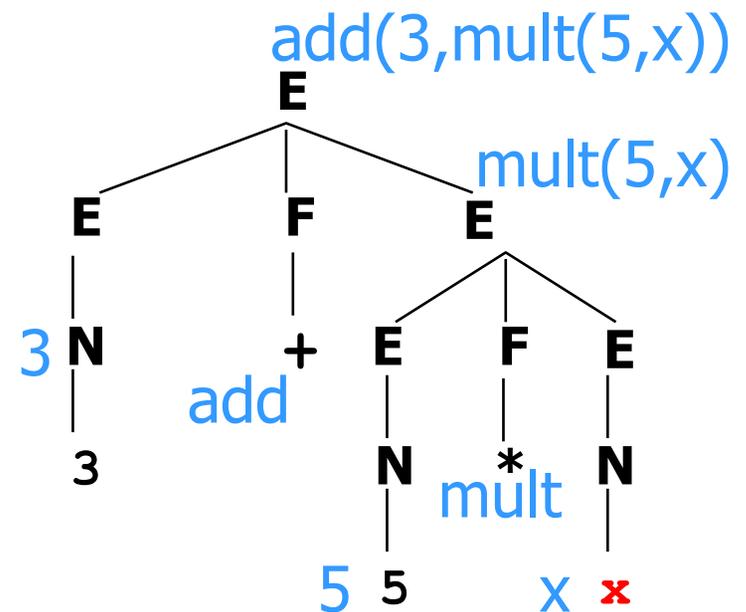
- What is meaning of  $3+5*6$ ?
- First parse it into  $3+(5*6)$
- Now give a meaning to each node in the tree (bottom-up)





# More complex meanings

- How about  $3+5*x$ ?
- Don't know  $x$  at compile time
- “Meaning” at a node is a piece of code, not a number
- Form is “rule-to-rule” translation
  - We provide a way to form the semantics of each parent in terms of the semantics of the children





# What Counts as Understanding?

- A somewhat difficult philosophical question
- We understand if we can respond appropriately
  - “throw axe at dwarf”
- We understand a statement if we can determine its truth
- We understand a statement if we can use it to answer questions [similar to above – requires reasoning]
  - **Easy:** John ate pizza. What was eaten by John?
- Understanding is the ability to translate
  - English to Chinese? requires deep understanding?? String transduction!
  - English to **logic**? deepest - the definition we'll use!
    - all humans are mortal =  $\forall x [\text{human}(x) \Rightarrow \text{mortal}(x)]$
- We assume we have logic-manipulating rules to tell us how to act, draw conclusions, answer questions ...



# Roadmap

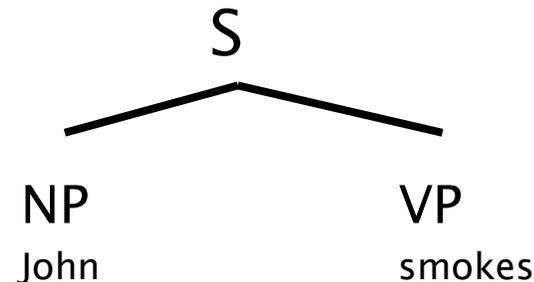
---

- Today:
  - Look at some sentences and phrases
  - What would be reasonable logical representations for them?
  - Get some idea of compositional semantics
- Next class:
  - How can we build those representations?
- Another course (somewhere in AI, hopefully):
  - How can we reason with those representations?
- Last lectures:
  - Lexical semantics (representing word meaning)
  - Question answering/semantic search/textual entailment



# (Formal/Compositional) Computational Semantics

- Sentences: “John smokes.”  
“Everyone who smokes snores.”
- Syntactic Analyses:



- Semantics Construction: smoke(j)
  - Logic as meaning representation language
- Inference:  $\forall x.\text{smoke}(x) \rightarrow \text{snore}(x), \text{smoke}(j)$   
 $\Rightarrow \text{snore}(j)$



# Logic: Some Preliminaries

## Three major kinds of objects

1. Booleans (Bool)
  - Roughly, the semantic values of (declarative) sentences
2. Individuals/Entities (Ind)
  - Values of NPs, i.e., objects
  - Maybe also other types of entities, like times
3. Functions of various types
  - A function returning a boolean is called a “predicate”
    - e.g., `frog(x)`, `green(x)`
    - A predicate defines a set of individuals that satisfy it
    - A one argument predicate is called a “property”
  - More complex functions return other functions!
  - Some functions take other functions as arguments!
    - (Higher order functions.)



# Logic: Lambda Terms

- Lambda terms:
  - A way of writing “anonymous functions”
    - No function header or function name
    - But defines the key thing: **behavior** of the function
    - Just as we can talk about 3 without naming it “x”
  - Let `square =  $\lambda p. p * p$`
  - Equivalent to `int square(p) { return p * p; }`
  - But we can talk about  `$\lambda p p * p$`  without naming it
  - Format of a lambda term:  `$\lambda$  variable . expression`



# Logic: Lambda Terms

- Lambda terms:
  - Let  $\text{square} = \lambda p \ p * p$
  - Then  $\text{square}(3) = (\lambda p \ p * p)(3) = 3 * 3$
  - **Note:  $\text{square}(x)$  isn't a function! It's just the value  $x * x$ .**
  - But  $\lambda x \ \text{square}(x) = \lambda x \ x * x = \lambda p \ p * p = \text{square}$   
(proving that these functions are equal – and indeed they are, as they act the same on all arguments: what is  $(\lambda x \ \text{square}(x))(y)$ ?)
- Let  $\text{even} = \lambda p \ (p \bmod 2 == 0)$  a predicate: returns true/false
- $\text{even}(x)$  is true if  $x$  is even
- How about  $\text{even}(\text{square}(x))$ ?
- $\lambda x \ \text{even}(\text{square}(x))$  is true of numbers with even squares
  - Just apply rules to get  $\lambda x \ (\text{even}(x * x)) = \lambda x \ (x * x \bmod 2 == 0)$
  - This happens to denote the same predicate as  $\text{even}$  does



# Logic: Multiple Arguments

- All lambda terms have one argument
- But we can fake multiple arguments ...
- Suppose we want to write `times(5,6)`
- Remember: `square` can be written as  $\lambda x.\text{square}(x)$
- Similarly, `times` is equivalent to  $\lambda x.[\lambda y.\text{times}(x,y)]$
- **Claim that `times(5)(6)` means same as `times(5,6)`**
  - $\text{times}(5) = (\lambda x.\lambda y.\text{times}(x,y)) (5) = \lambda y.\text{times}(5,y)$ 
    - If this function weren't anonymous, what would we call it?
  - $\text{times}(5)(6) = (\lambda y \text{ times}(5,y))(6) = \text{times}(5,6)$
- Referred to as “**currying**”



# Logic: Interesting Constants

- We have “constants” that name some of the entities and functions (e.g., `times`):
  - `GeorgeWBush` - an entity
  - `red` - a predicate on entities
    - holds of just the red entities: `red(x)` is true if `x` is red!
  - `loves` - a predicate on 2 entities
    - `loves(GeorgeWBush, LauraBush)`
    - *Question:* What does `loves(LauraBush)` denote?
- Constants used to define meanings of words
- Meanings of phrases will be built from the constants



# Logic: Interesting Constants

- Generalized Quantifiers
- **most** – a predicate on 2 predicates on entities
  - **most(pig, big)** = “most pigs are big”
    - Equivalently, **most( $\lambda x$  pig(x),  $\lambda x$  big(x))**
  - returns true if most of the things satisfying the first predicate also satisfy the second predicate
- similarly for other quantifiers
  - **all(pig, big)** (equivalent to  $\forall x$  pig(x)  $\Rightarrow$  big(x))
  - **exists(pig, big)** (equivalent to  $\exists x$  pig(x) AND big(x))
  - can even build complex quantifiers from English phrases:
    - “between 12 and 75”; “a majority of”; “all but the smallest 2”



# Quantifier Order

- Groucho Marx celebrates quantifier order ambiguity:
  - In this country a woman gives birth every 15 min.  
Our job is to find that woman and stop her.
  - $\exists \text{woman } (\forall 15 \text{min gives-birth-during}(\text{woman}, 15 \text{min}))$
  - $\forall 15 \text{min } (\exists \text{woman gives-birth-during}(15 \text{min}, \text{woman}))$
  - Surprisingly, both are possible in natural language!
  - Which is the joke meaning?
    - (where it's always the same woman)



## In the Background: Model Theory

- $\forall x.(\text{bird}(x) \rightarrow \text{love}(s,x))$  is a string again!
- Mathematically precise model representation, e.g.:  $\{\text{cat}(s), \text{bird}(t), \text{love}(s,t), \text{granny}(g), \text{own}(g,s), \text{own}(g,t)\}$
- Inspect formula w.r.t. to the model: Is it true?
- Inferences can extract information: Is anyone not owned by Granny?



# Compositional Semantics

- We've discussed what semantic representations should look like.
- **But how do we get them from sentences???**
- **First** - parse to get a syntax tree.
- **Second** - look up the semantics for each word.
- **Third** - build the semantics for each constituent
  - Work from the bottom up
  - The syntax tree is a "recipe" for how to do it
- **Principle of Compositionality**
  - The meaning of a whole is derived from the meanings of the parts, via composition rules



# A simple grammar of English

(in Definite Clause Grammar, DCG, form - as in Prolog)

sentence --> noun\_phrase, verb\_phrase.

noun\_phrase --> proper\_noun.

noun\_phrase --> determiner, noun.

verb\_phrase --> verb, noun\_phrase.

Proper\_noun --> [John]

Proper\_noun --> [Mary]

determiner --> [the]

determiner--> [a]

verb --> [ate]

verb --> [kissed]

noun --> [cake]

noun --> [lion]



## Extending the grammar to check number agreement between subjects and verbs

$S \rightarrow NP(\text{Num}), VP(\text{Num})$ .

$NP(\text{Num}) \rightarrow \text{Proper\_noun}(\text{Num})$ .

$NP(\text{Num}) \rightarrow \text{det}(\text{Num}), \text{noun}(\text{Num})$ .

$VP(\text{Num}) \rightarrow \text{verb}(\text{Num}), \text{noun\_phrase}(\_)$ .

$\text{Proper\_noun}(s) \rightarrow [\text{Mary}]$ .

$\text{det}(s) \rightarrow [\text{the}]$ .

$\text{det}(p) \rightarrow [\text{the}]$ .

$\text{noun}(s) \rightarrow [\text{lion}]$ .

$\text{noun}(p) \rightarrow [\text{lions}]$ .

$\text{verb}(s) \rightarrow [\text{eats}]$ .

$\text{verb}(p) \rightarrow [\text{eat}]$ .



# A simple DCG grammar with semantics

sentence(SMeaning) --> noun\_phrase(NPMeaning),  
verb\_phrase(VPMeaning), {combine (NPMeaning,  
VPMeaning, SMeaning)}.

verb\_phrase(VPMeaning) --> verb(Vmeaning),  
noun\_phrase(NPMeaning), {combine (NPMeaning,  
VMeaning, VPMeaning)}.

noun\_phrase (NPMeaning) --> name(NPMeaning).

name(john) --> [john].

verb( $\lambda x$ .jumps(x)) --> [jumps]

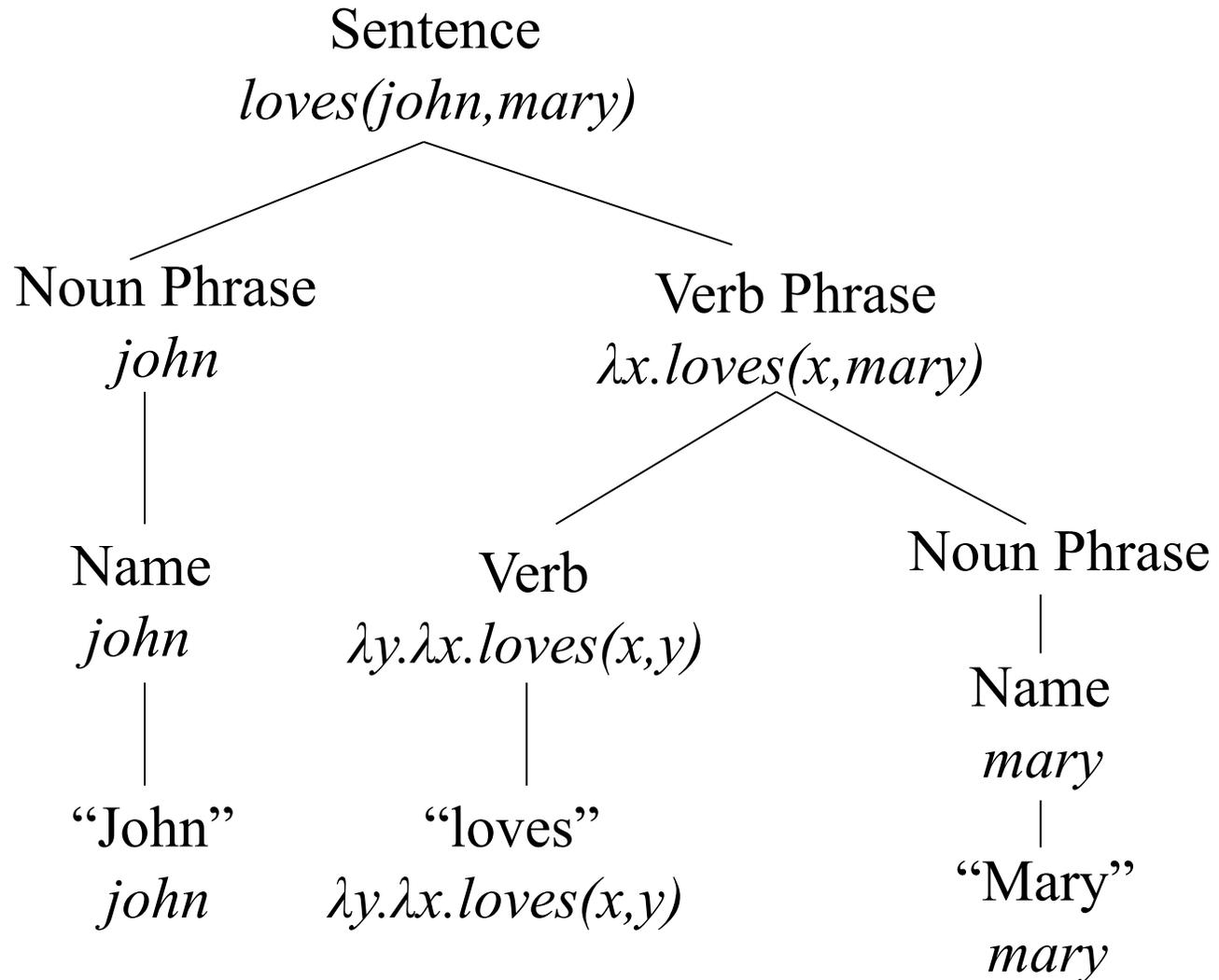
name(mary) --> [mary].

verb( $\lambda y$ . $\lambda x$ .loves(x,y)) --> [loves]

Combine(X, Y, Z) --> apply(Y, X, Z)



# Parse tree with associated semantics





# In detail: Beta-Reduction

---

$(\lambda y \lambda x. \text{love}(x, y))[\text{mary}][\text{john}]$

$\beta \Rightarrow (\lambda x. \text{love}(x, \text{mary}))[\text{john}]$

$\beta \Rightarrow \text{love}(\text{john}, \text{mary})$



# Quiz question!

Suppose the *give* relation is:  $\text{give}(\text{giver}, \text{gift}, \text{recipient})$

And suppose the order of syntactic composition for

*Sue gave Boris a cat*

is:  $[\text{Sue} [[\text{gave Boris}] \text{a cat}]]$

What is the correct lambda expression for *give*?

- A.  $\lambda x. \lambda y. \lambda z. \text{give}(x, y, z)$
- B.  $\lambda y. \lambda x. \lambda z. \text{give}(x, y, z)$
- C.  $\lambda z. \lambda y. \lambda x. \text{give}(x, y, z)$
- D.  $\lambda x. \lambda z. \lambda y. \text{give}(x, y, z)$
- E.  $\lambda z. \lambda x. \lambda y. \text{give}(x, y, z)$



# Formal Compositional Semantics ...

- **Richard Montague**  
(1930-1971)
- *“... I reject the contention that an important theoretical difference exists between formal and natural languages ...”*





# Augmented CFG Rules

- We can also accomplish this just by attaching semantic formation rules to our syntactic CFG rules

$$A \rightarrow \alpha_1 \dots \alpha_n \quad \{f(\alpha_1.sem, \dots, \alpha_n.sem)\}$$

- This should be read as the semantics we attach to A can be computed from some function applied to the semantics of A's parts.
- The functions/operations permitted in the semantic rules are restricted, falling into two classes
  - Pass the semantics of a daughter up unchanged to the mother
  - Apply (as a function) the semantics of one of the daughters of a node to the semantics of the other daughters



# How do things get more complex? (The former) GRE analytic section

- Six sculptures – C, D, E, F, G, H – are to be exhibited in rooms 1, 2, and 3 of an art gallery.
  - Sculptures C and E may not be exhibited in the same room.
  - Sculptures D and G must be exhibited in the same room.
  - If sculptures E and F are exhibited in the same room, no other sculpture may be exhibited in that room.
  - At least one sculpture must be exhibited in each room, and no more than three sculptures may be exhibited in any room.
- If sculpture D is exhibited in room 3 and sculptures E and F are exhibited in room 1, which of the following may be true?
  1. Sculpture C is exhibited in room 1.
  2. Sculpture H is exhibited in room 1.
  3. Sculpture G is exhibited in room 2.
  4. Sculptures C and H are exhibited in the same room.
  5. Sculptures G and F are exhibited in the same room.



# Scope Needs to be Resolved!

*At least one sculpture must be exhibited in each room.*

The same sculpture in each room?

*No more than three sculptures may be exhibited in any room.*

**Reading 1:** For every room, there are no more than three sculptures exhibited in it.

**Reading 2:** Only three or less sculptures are exhibited ( the rest are not shown).

**Reading 3:** Only a certain set of three or less sculptures may be exhibited in any room ( for the other sculptures there are restrictions in allowable rooms).

- Some readings will be ruled out by being uninformative or by contradicting other statements
- Otherwise we must be content with distributions over scope-resolved semantic forms



# An alternative: Semantic Grammars

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- A problem with traditional linguistic grammars is that they don't necessarily reflect the semantics in a straightforward way
- You can deal with this by...
  - Fighting with the grammar
    - Complex lambdas and complex terms, etc.
  - Rewriting the grammar to reflect the semantics
    - And in the process give up on some syntactic niceties
    - known as "Semantic grammars"
      - Simple idea, dumb name



# Semantic Grammar

- The term semantic grammar refers to the motivation for the grammar rules
  - The technology (plain CFG rules with a set of terminals) is the same as we've been using
  - The good thing about them is that you get exactly the semantic rules you need
  - The bad thing is that you need to develop a new grammar for each new domain
- Typically used in conversational agents in constrained domains
  - Limited vocabulary
  - Limited grammatical complexity
  - Syntactic parsing can often produce all that's needed for semantic interpretation even in the face of "ungrammatical" input - write fragment rules



# Lifer Semantic Grammars

- Example domain—access to DB of US Navy ships

S → <present> the <attribute> of <ship>

<present> → what is | [can you] tell me

<attribute> → length | beam | class

<ship> → the <shipname>

<shipname> → kennedy | enterprise

<ship> → <classname> class ships

<classname> → kitty hawk | lafayette

- Example inputs recognized by above grammar:

*can you tell me the class of the Enterprise*

*what is the length of Kitty Hawk class ships*

- Many categories are not "true" syntactic categories
- Words are recognized by their context rather than category (e.g. *class*)
- Recognition is strongly directed
- Strong direction useful for error detection and correction

- G. Hendrix, E. Sacerdoti, D. Sagalowicz, and J. Slocum. 1978. Developing a natural language interface to complex data. *ACM Transactions on Database Systems* 3:105-147



# Semantic Grammars Summary

- Advantages:
  - Efficient recognition of limited domain input
  - Absence of overall grammar allows pattern-matching possibilities for idioms, etc.
  - No separate interpretation phase
  - Strength of top-down constraints allows powerful ellipsis mechanisms
    - What is the length of the Kennedy? The Kittyhawk?*
- Disadvantages:
  - Different grammar required for each new domain
  - Lack of overall syntax can lead to "spotty" grammar coverage
    - E.g. fronting possessive in "<attribute> of <ship>" to <ship> 's <attribute> doesn't imply fronting in "<rank> of <officer>"
  - Difficult to develop grammars past a certain size
  - Suffers from fragility

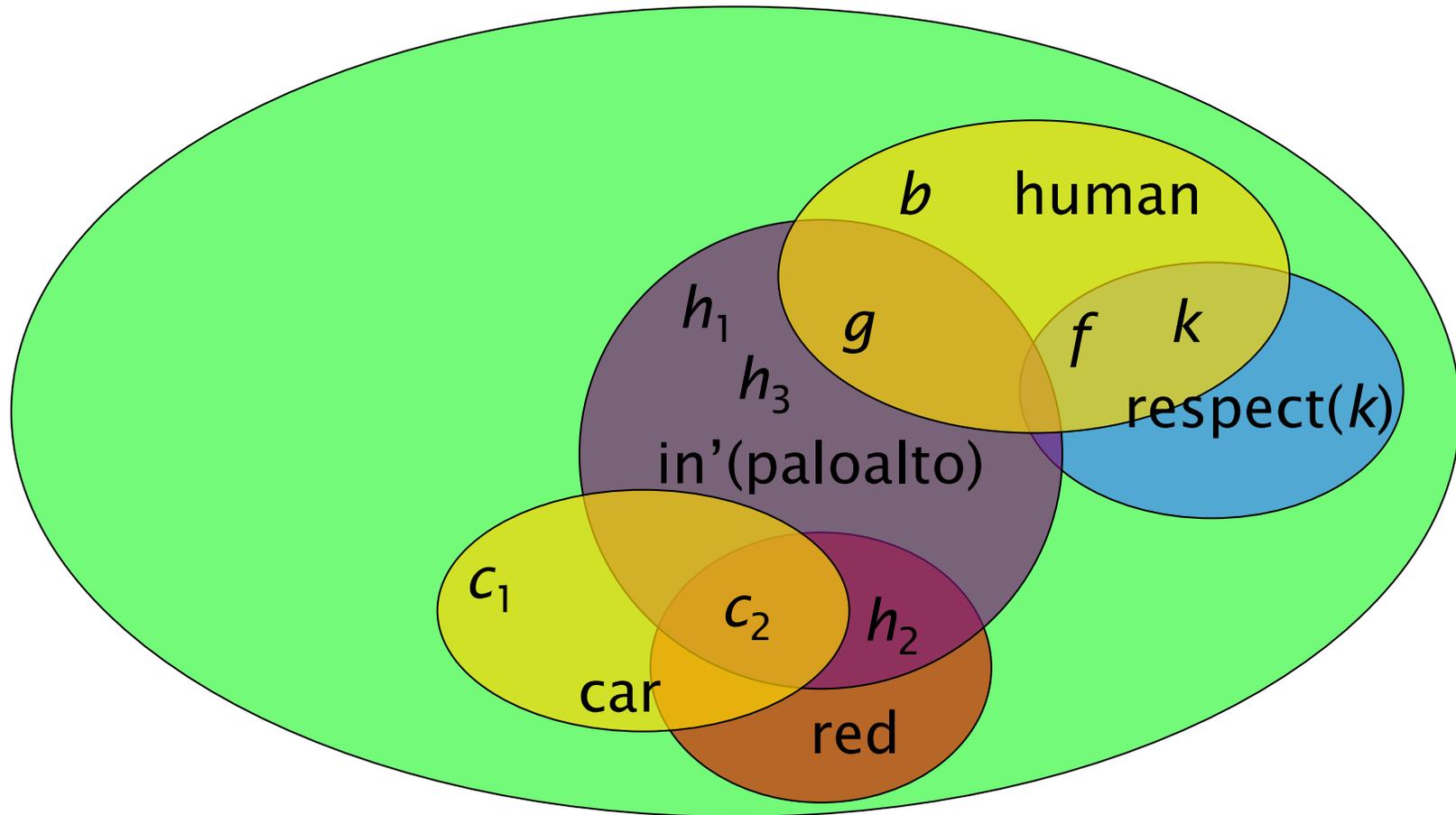


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43 slides was enough (in 2009)



# Model theory – A formalization of a “database”



Properties



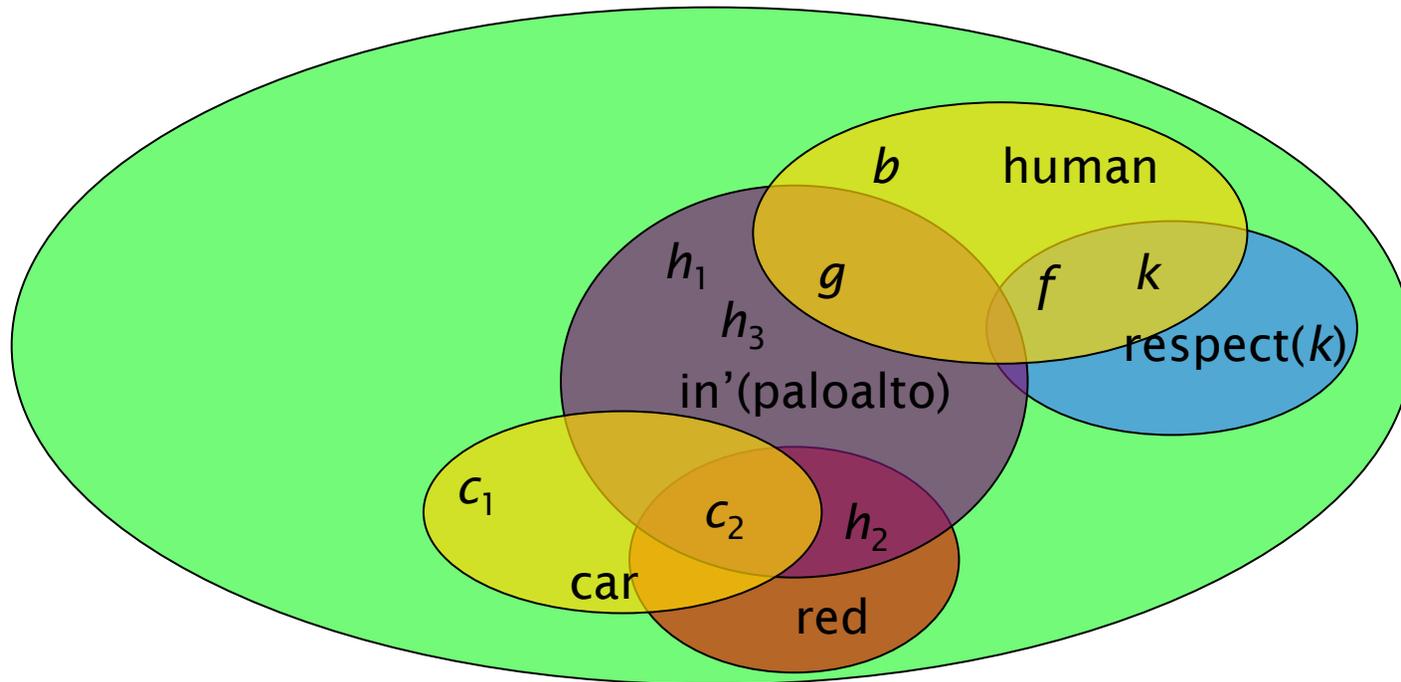
# Curried multi-argument functions

$$\llbracket \mathbf{respect} \rrbracket = \llbracket \lambda y. \lambda x. \mathbf{respect}(x, y) \rrbracket = \left[ \begin{array}{l} f \mapsto \left[ \begin{array}{l} f \mapsto \mathbf{0} \\ k \mapsto \mathbf{1} \\ b \mapsto \mathbf{0} \end{array} \right] \\ k \mapsto \left[ \begin{array}{l} f \mapsto \mathbf{1} \\ k \mapsto \mathbf{1} \\ b \mapsto \mathbf{0} \end{array} \right] \\ b \mapsto \left[ \begin{array}{l} f \mapsto \mathbf{1} \\ k \mapsto \mathbf{0} \\ b \mapsto \mathbf{0} \end{array} \right] \end{array} \right.$$

$$\llbracket \lambda x. \lambda y. \mathbf{respect}(y)(x)(b)(f) \rrbracket = \mathbf{1}$$



# Quiz question



- Which individuals are the red things in Palo Alto?
- Who respects kathy ( $k$ )?



# Adding more complex NPs

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NP: A man  $\sim > \exists x.\text{man}(x)$

S: A man loves Mary

$\sim > *$   $\text{love}(\exists x.\text{man}(x), \text{mary})$

- How to fix this?



# A disappointment

Our first idea for NPs with determiner didn't work out:

“A man”  $\sim \rightarrow \exists z.\text{man}(z)$

“A man loves Mary”  $\sim \rightarrow * \text{love}(\exists z.\text{man}(z), \text{mary})$

But what was the idea after all?

Nothing!

$\exists z.\text{man}(z)$  just isn't the meaning of “a man”.

If anything, it translates the complete sentence

“There is a man”

Let's try again, systematically...



# A solution for quantifiers

What we want is:

“A man loves Mary”  $\sim > \exists z(\text{man}(z) \wedge \text{love}(z, \text{mary}))$

What we have is:

“man”  $\sim > \lambda y. \text{man}(y)$

“loves Mary”  $\sim > \lambda x. \text{love}(x, \text{mary})$

How about:  $\exists z(\lambda y. \text{man}(y)(z) \wedge \lambda x. \text{love}(x, \text{mary})(z))$

Remember: We can use variables for any kind of term.

So next:

$\lambda P(\lambda Q. \exists z(P(z) \wedge Q(z))) \quad < \sim \text{“A”}$