Logical Forms

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CS 295: STATISTICAL NLP

WINTER 2017

February 16, 2017

Based on slides from Noah Smith, Dan Klein, Tom Kwiatkowski, and everyone else they copied from.

Outline

Logical Semantics

Combinatory Categorical Grammar

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Logical Semantics

Combinatory Categorical Grammar

So far….

Meaning of Words

- Word Vectors
- Parts of Speech
- Named Entities
- Word senses
- ….

Meaning of Verbs

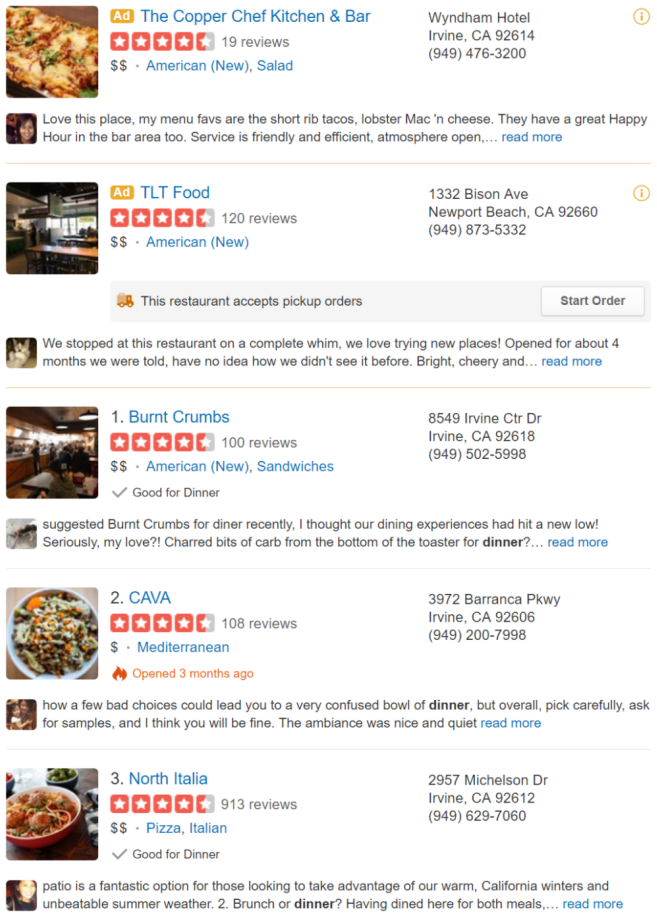
- Context-free grammars
- Thematic Roles
- Semantic Roles
- Dependency Relations
- …

Still a gap between language and actionable representations

Language "World"

What is a good Korean restaurant near UCI campus?

Meaning Representation



A (Tiny) World Model

Domain

Amir, Brook, Chen, …
Gogi Grill, Eureka, Cha Tea, UCI, …
Korean, American, Beverages, ..

a, b, c, ...
gg, er, ct, uci, ..
ko, am, be, ...

Properties

Amir, Brook, Chen, … are humans
Gogi Grill is good, Cha Tea has a long wait,
Eureka is noisy, They are restaurants..

Humans = {a, b, c, ...}
Good = {gg} Noisy={er}
Restaurant={gg,er,ct} ...

Relations

Gogi serves Korean, Eureka serves American,
Cha Tea serves Beverages, Amir likes Gogi,
Chen likes Korean, …

Serves = {(gg,ko),(er,am),
(ct,be), ...}
Likes={(a,gg),(c,ko),..} ...

Is Eureka noisy? — er in Noisy?
Does Cha Tea serve beverages? — (ct,be) in Serves?
What does Amir like? — list (a,?) in Likes

First-Order Logic

Terms

- Constant: a,b,c,gg,ct
- Variables: x,y,z

Relations

- Unary: ~~Serves(x)~~ Good(x), Noisy(x)
- Binary: Likes(x,y)
- n-ary: $R(a_1,..,a_n)$

Formula

- n-ary relation, R, and n terms $(t_1,..,t_n)$, then $R(t_1,..,t_n)$ is a formula
- If F is a formula, then so is $\neg F$
- Boolean operators: $F \vee F$, $F \wedge F$, $F \rightarrow F$
- Quantifiers: $\exists x\ F$, $\forall x\ F$

Likes(Amir,x), Noisy(er)

$\neg$ Good(er)

Likes(Amir,x) $\wedge$ Serves(x,ko)

Translating b/w FoL and NL

- Gogi is not loud $\neg Loud(gg)$
- Some humans like American $\exists x \; Human(x) \wedge Likes(x, am)$
- If a person likes Eureka, they aren't friends with Brook $\forall x \; Person(x) \wedge Likes(x, er) \Rightarrow \neg Friends(X, Brook)$
- Every restaurant has a long wait or is disliked by Amir $\forall x \; Rest(x) \Rightarrow Wait(x) \vee \neg Likes(a, x)$
- Everybody has something they don't like $\forall x \; \exists y \; \neg Likes(x, y)$
- There exists something that nobody likes $\exists y \; \forall x \; \neg Likes(x, y)$

Logical Semantics

Everybody has something they don't like.

$\forall x \exists y \neg Likes(x,y)$

The denotation of a natural language sentence is the set of conditions that must hold in the (model) world for the sentence to be true.

This is called the logical form of the sentence.

- Less ambiguous
- Can check truth value by querying a database
- If you know it's true, you can update database
- Questions become queries on the database
- Comprehending a document is same as chaining

λ-Calculus

Abstraction

If φ is a FOL formula

$\varphi \equiv$ Likes(Amir, v)

$\lambda v . \varphi$ $\quad v \rightarrow \{T, F\}$

def anon(v) { φ }

Application

$\lambda v . \varphi + \psi$

$[\lambda v . \varphi](\psi)$

anon(ψ)

[def anon(v){φ}](ψ)

Example of λ-applications

$[\lambda x.\ \text{Likes}(a,x)](b)$ $\quad$ $\text{Likes}(a,b)$

$[\lambda x\ \lambda y\ \text{Friends}(x,y)](a)$ $\quad$ $\lambda y\ \text{Friends}(a,y)$

$[\lambda y\ \text{Friends}(a,y)](c)$ $\quad$ $\text{Friends}(a,c)$

$[\lambda x \lambda y\ \text{Likes}(a,x) \wedge \text{Serves}(x,y)]$

(gg)

$[\lambda y\ \text{Likes}(a,gg) \wedge \text{Serves}(gg,y)]$

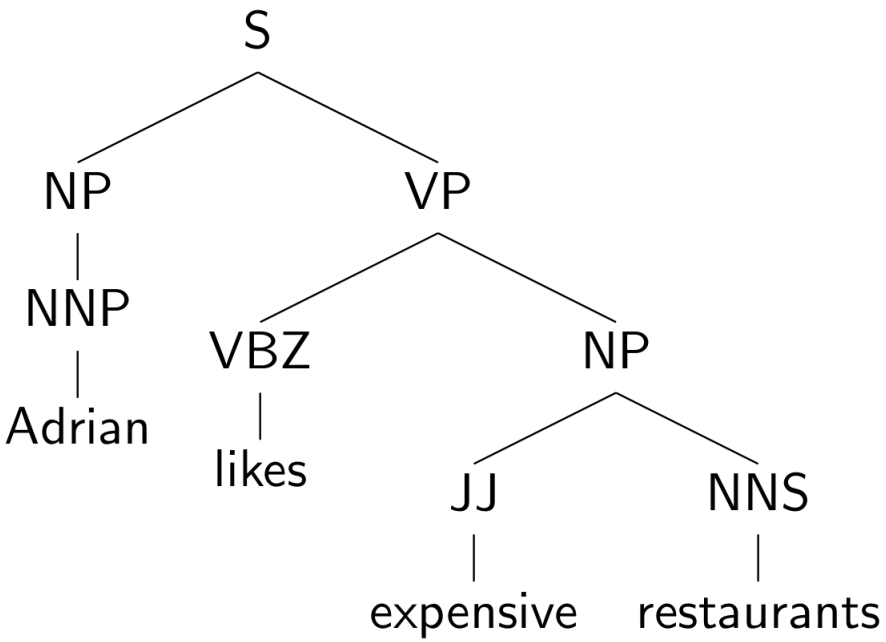
(k_o)

$\text{Likes}(a,gg) \wedge \text{Serves}(gg,k_o)$

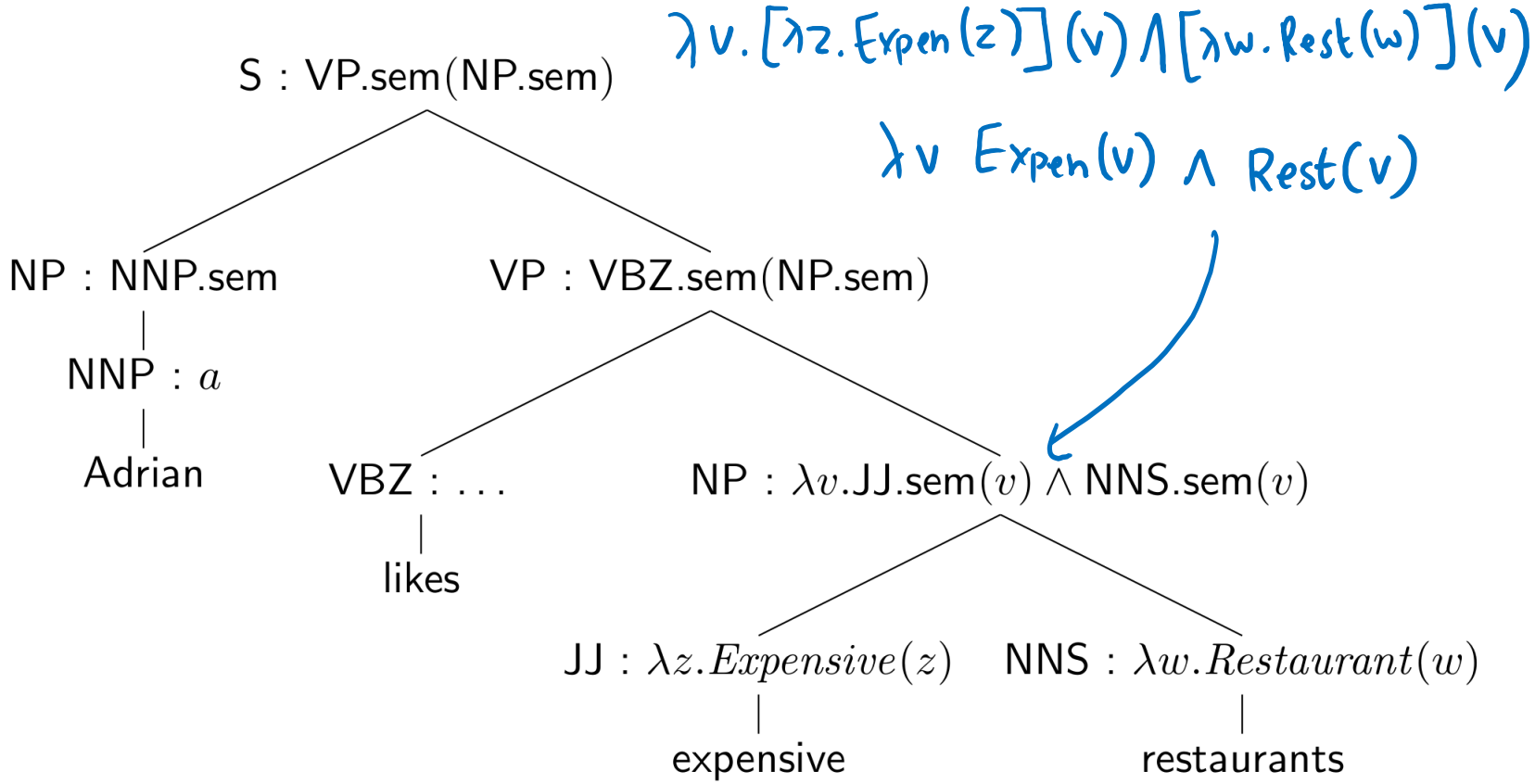
Semantic Attachments to CFG

- NNP $\rightarrow$ Adrian $\{a\}$
- VBZ $\rightarrow$ likes $\{\lambda f.\lambda y.\forall x f(x) \Rightarrow Likes(y, x)\}$
- JJ $\rightarrow$ expensive $\{\lambda x.Expensive(x)\}$
- NNS $\rightarrow$ restaurants $\{\lambda x.Restaurant(x)\}$
- NP $\rightarrow$ NNP $\{$NNP.sem$\}$
- NP $\rightarrow$ JJ NNS $\{\lambda x.$JJ.sem$(x) \wedge$ NNS.sem$(x)\}$
- VP $\rightarrow$ VBZ NP $\{$VBZ.sem(NP.sem)$\}$
- S $\rightarrow$ NP VP $\{$VP.sem(NP.sem)$\}$

CFG to λ-Calculus



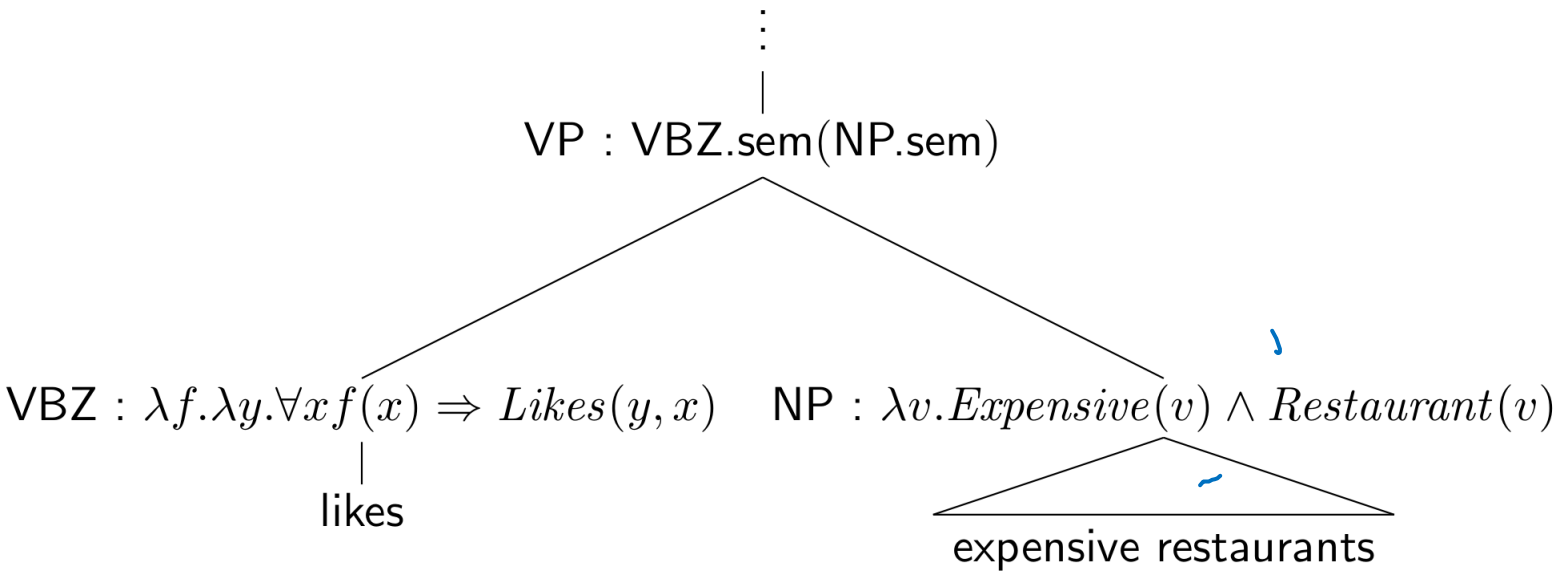
CFG to λ-Calculus



CFG to λ-Calculus

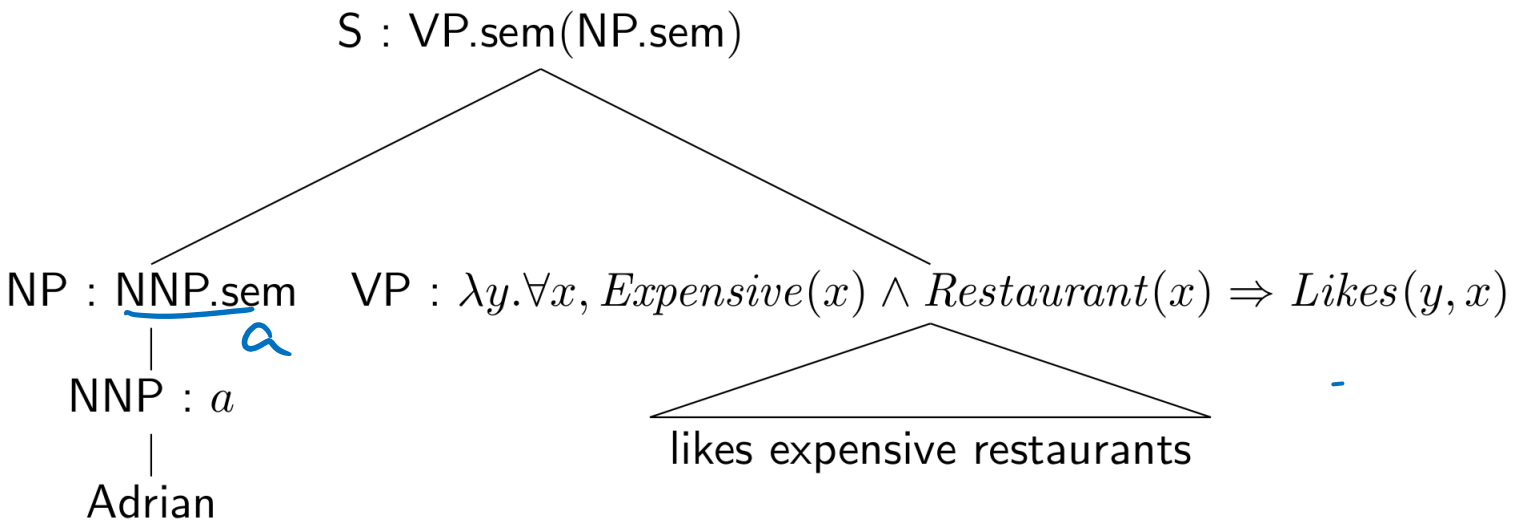
$[\lambda f.\lambda y\, \forall x\, f(x) \Rightarrow Likes(y,x)]\,(\lambda v.\, Expen(v) \wedge Rest(v))$

$\lambda y\, \forall x\quad Expen(x) \wedge Rest(x) \Rightarrow Likes(y,x)$



CFG to λ-Calculus

$\forall x \; Expen(x) \wedge Rest(x) \Rightarrow Likes(a, x)$



Tricky Cases: Transitive Verbs

I eat food. $\lambda y \lambda x \; eat(y, x)$

I eat. $\lambda y \; eat(y)$

Tricky Cases: Indefinites

Bob ate a waffle.
Amy ate a waffle.

$ate(bob, waffle)$
$ate(alice, waffle)$

$\exists x : waffle(x) \wedge ate(bob, x)$

$\exists x : waffle(x) \wedge ate(alice, x)$

Tricky Cases: Tenses and Events

Alice danced.

$danced(alice)$

$\exists e \; dance(e) \wedge agent(e, alice) \wedge start(e) < \text{"now"}$

Alice had been dancing when Bob sneezed.

$\exists e \exists e' \; dance(e) \wedge agent(e, a) \wedge sneeze(e') \wedge start(e) < start(e') \wedge agent(e', bob) \wedge end(e) = end(e') \wedge time(e') < now$

Tricky Cases: Adverbs

Bob sings terribly.

terribly (sings (bob))

$\forall e \; present(e) \wedge type(e, sing)$

$agent(e, bob) \rightarrow manner(e, terrible$

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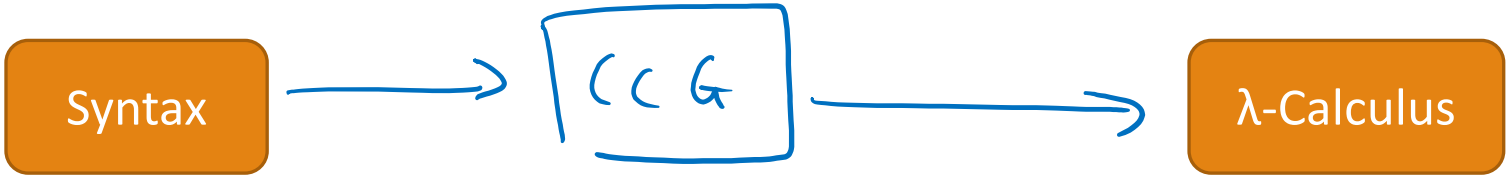
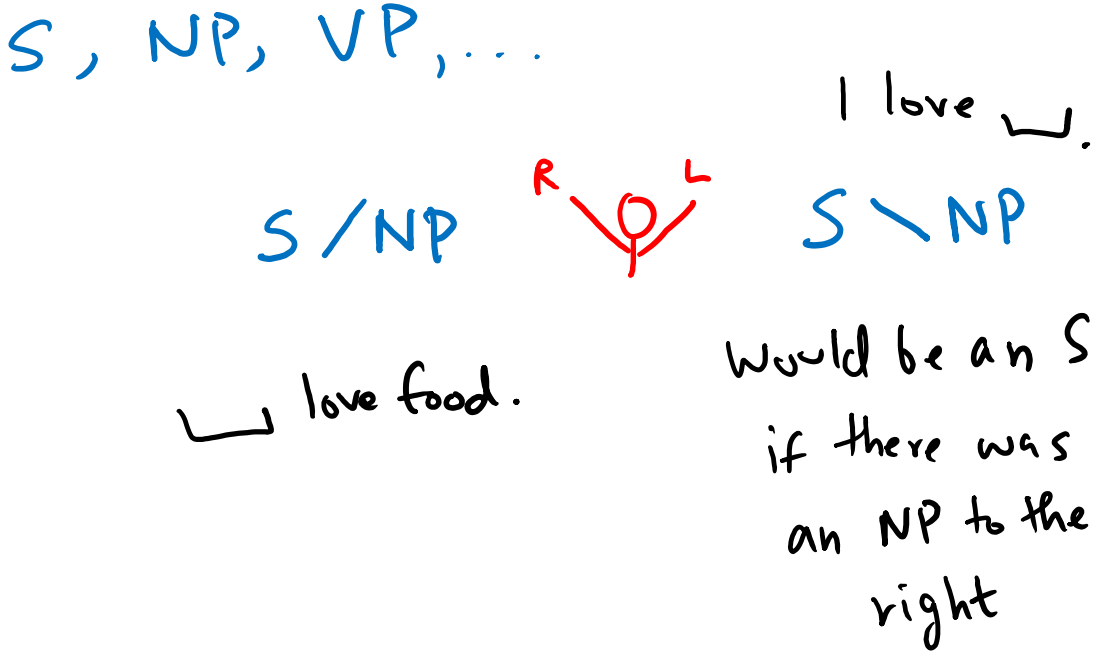


CCG Types

Instead of non-terminals, it has infinitely large set of **categories or types**

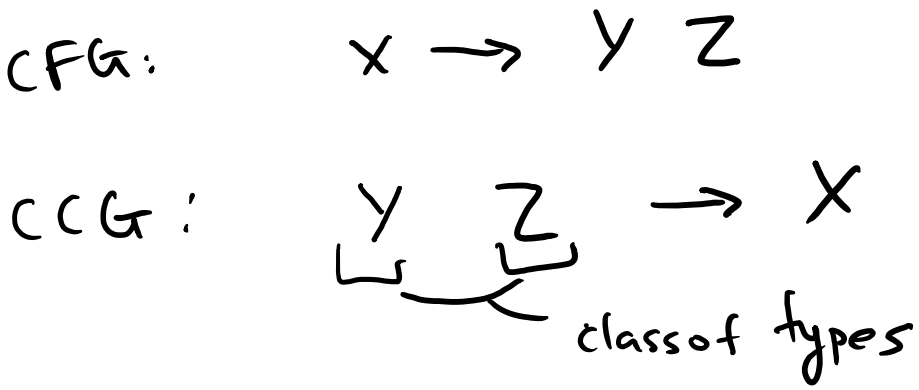
Primitive

Complex



CCG Combinators

Instead of rules, we have a small set of **generic combinators**.



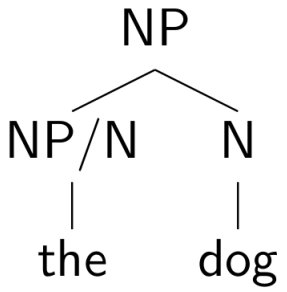
Application Combinator

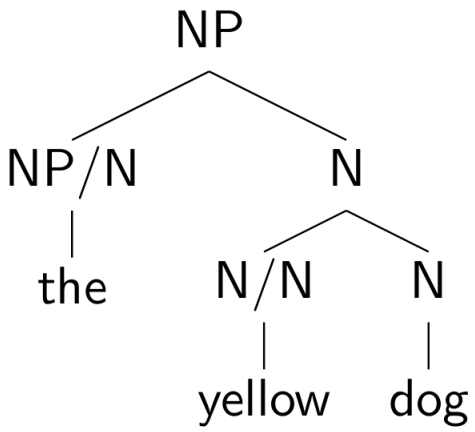
Forward

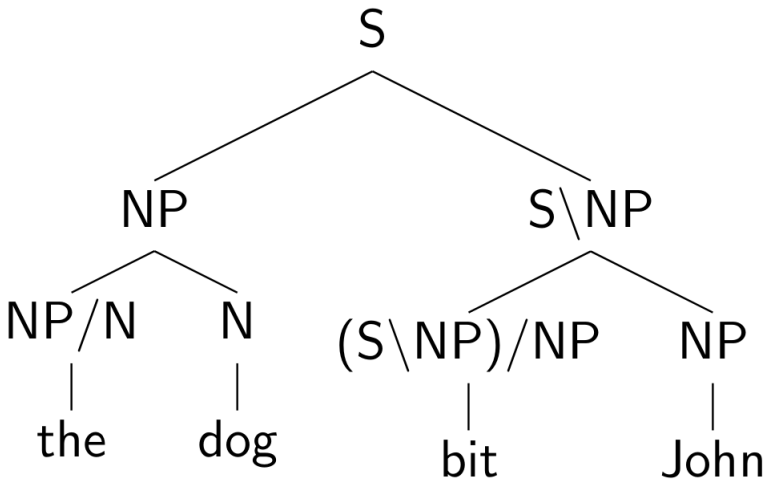
$X/Y \quad Y \Rightarrow X$

Backward

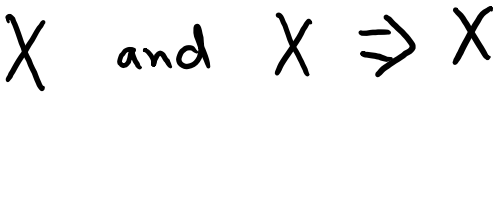
$Y \quad X\backslash Y \Rightarrow X$

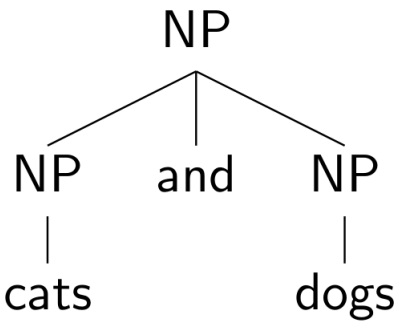


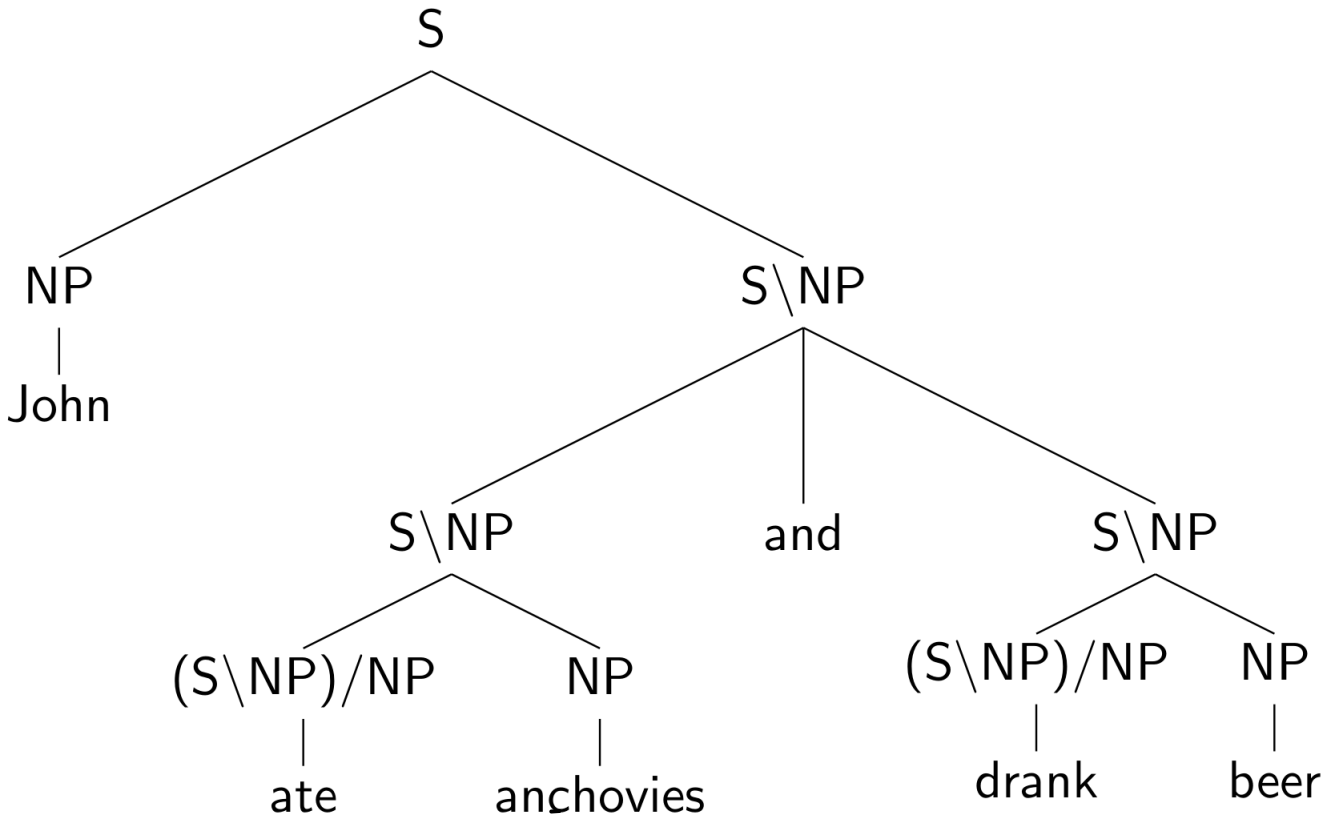




Conjunction Combinator







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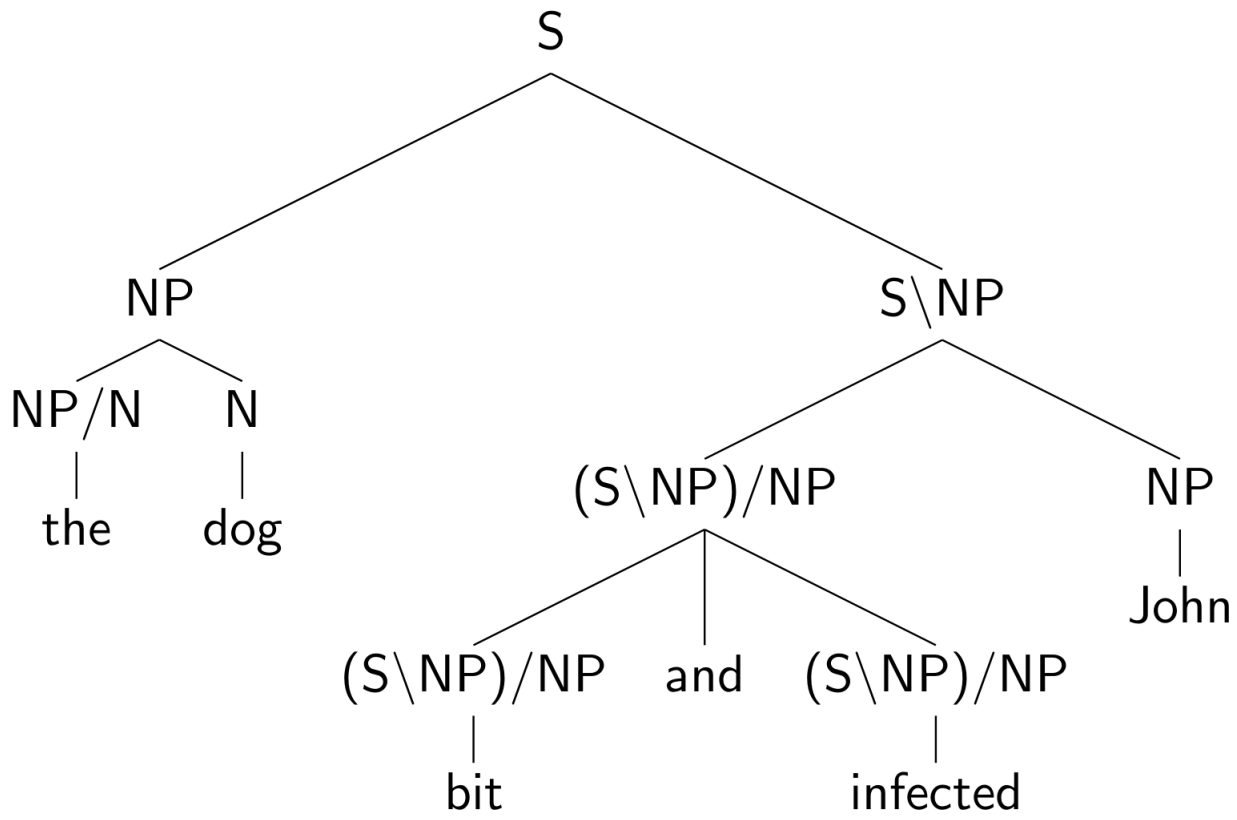
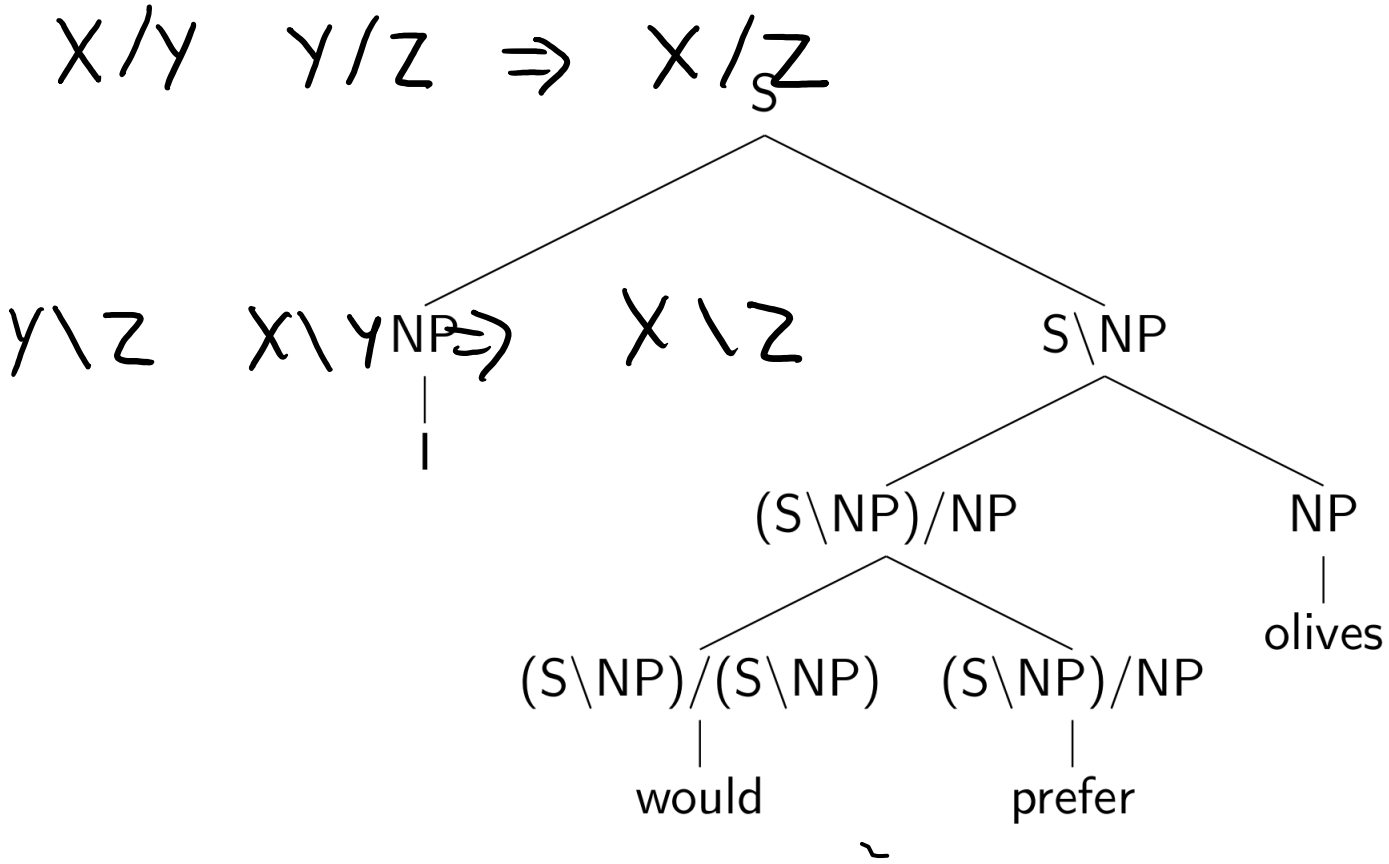


Composition Combinator

Forward

Backward



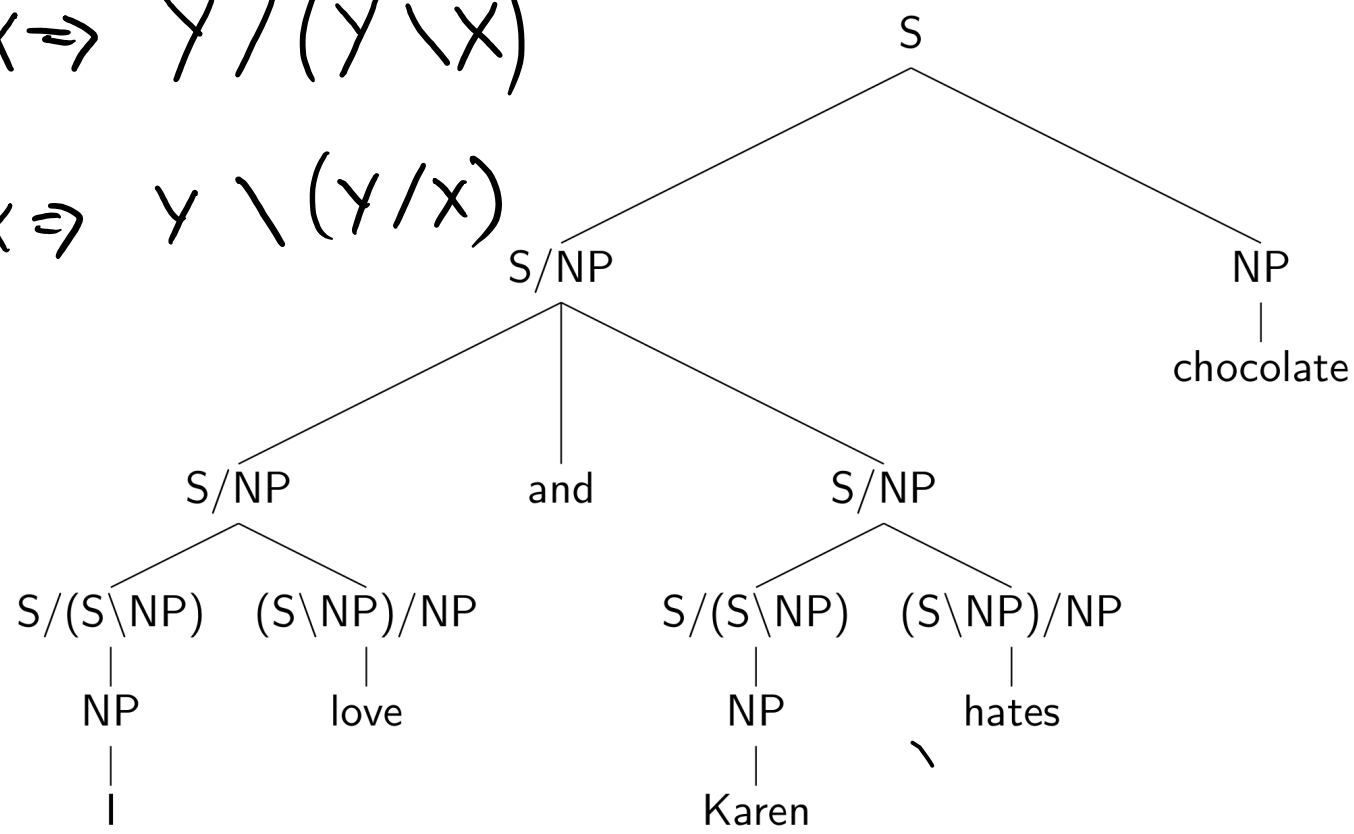
Type-Raising Combinator

Forward

$X \Rightarrow Y/(Y\backslash X)$

Backward

$X \Rightarrow Y\backslash(Y/X)$



Upcoming...

Homework

- Homework 3 is due on February 27
- Write-up and data has been released.

Project

- Status report due in 2 weeks: March 2, 2017
- Instructions coming soon
- Only 5 pages

Summaries

- Paper summaries: **February 17**, February 28, March 14
- Only 1 page each