

Logical Forms

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CS 295: STATISTICAL NLP

WINTER 2017

February 16, 2017

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



Ad The Copper Chef Kitchen & Bar
★★★★☆ 19 reviews
\$\$ · American (New), Salad

Wyndham Hotel
Irvine, CA 92614
(949) 476-3200

Love this place, my menu favs are the short rib tacos, lobster Mac 'n cheese. They have a great Happy Hour in the bar area too. Service is friendly and efficient, atmosphere open,... [read more](#)




Ad TLT Food
★★★★☆ 120 reviews
\$\$ · American (New)

1332 Bison Ave
Newport Beach, CA 92660
(949) 873-5332

This restaurant accepts pickup orders [Start Order](#)


We stopped at this restaurant on a complete whim, we love trying new places! Opened for about 4 months we were told, have no idea how we didn't see it before. Bright, cheery and... [read more](#)



1. Burnt Crumbs
★★★★☆ 100 reviews
\$\$ · American (New), Sandwiches
✓ Good for Dinner

8549 Irvine Ctr Dr
Irvine, CA 92618
(949) 502-5998


suggested Burnt Crumbs for diner recently, I thought our dining experiences had hit a new low! Seriously, my love?! Charred bits of carb from the bottom of the toaster for **dinner**?... [read more](#)



2. CAVA
★★★★☆ 108 reviews
\$ · Mediterranean
🔥 Opened 3 months ago

3972 Barranca Pkwy
Irvine, CA 92606
(949) 200-7998

how a few bad choices could lead you to a very confused bowl of **dinner**, but overall, pick carefully, ask for samples, and I think you will be fine. The ambiance was nice and quiet [read more](#)



3. North Italia
★★★★☆ 913 reviews
\$\$ · Pizza, Italian
✓ Good for Dinner

2957 Michelson Dr
Irvine, CA 92612
(949) 629-7060

patio is a fantastic option for those looking to take advantage of our warm, California winters and unbeatable summer weather. 2. Brunch or **dinner**? Having dined here for both meals,... [read more](#)

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?
Does Cha Tea serve beverages?
What does Amir like?

er in Noisy?
(ct,be) in Serves?
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: $R(a_1, \dots, a_n)$

Formula

- n-ary relation, R , and n terms (t_1, \dots, t_n) , then $R(t_1, \dots, t_n)$ 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 $\neg \text{Loud}(gg)$
- Some humans like American $\exists x \text{ Human}(x) \wedge \text{Likes}(x, am)$
- If a person likes Eureka, they aren't friends with Brook
 $\forall x \text{ Person}(x) \wedge \text{Likes}(x, er) \Rightarrow \neg \text{Friends}(x, Brook)$
- Every restaurant has a long wait or is disliked by Amir
 $\forall x \text{ Rest}(x) \Rightarrow \text{wait}(x) \vee \neg \text{Likes}(a, x)$
- Everybody has something they don't like $\forall x \exists y \neg \text{Likes}(x, y)$
- There exists something that nobody likes $\exists y \forall x \neg \text{Likes}(x, y)$

Logical Semantics

Everybody has something they don't like.

$$\forall x \exists y \neg \text{Likes}(x, y)$$

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

$\varphi \equiv \text{Likes}(\text{Amir}, v)$

$\lambda v. \varphi$

$v \rightarrow \{T, F\}$

$\text{def anon}(v) \{ \varphi \}$

Application

$\lambda v. \varphi + \psi$

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

$\text{anon}(\psi)$

$[\text{def anon}(v) \{ \varphi \}](\psi)$

Example of λ -applications

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

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

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

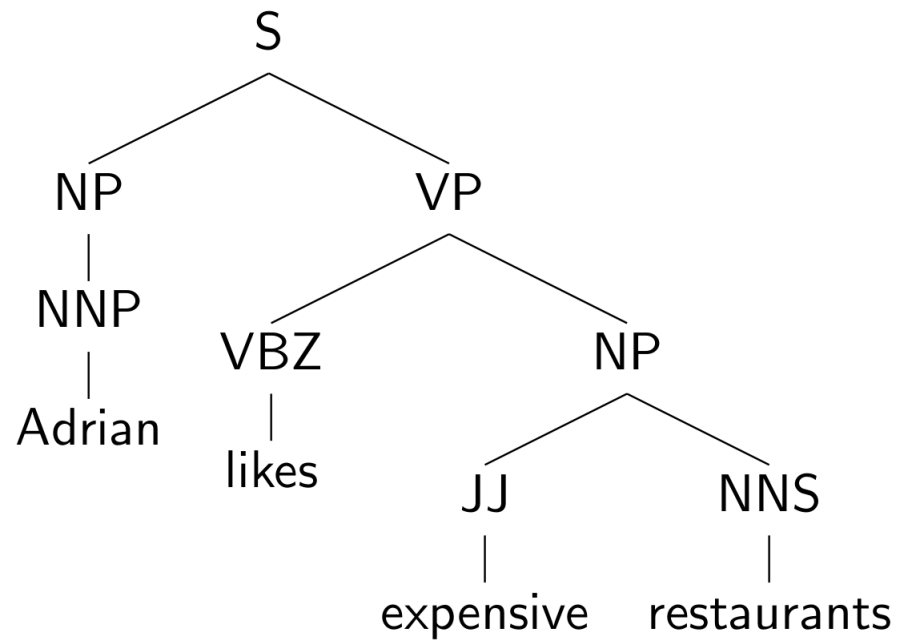
$$[\lambda x \lambda y \text{Likes}(a, x) \wedge \text{Serves}(x, y)](gg)$$

$$[\lambda y \text{Likes}(a, gg) \wedge \text{Serves}(gg, y)](k_0) \\ \text{Likes}(a, gg) \wedge \text{Serves}(gg, k_0)$$

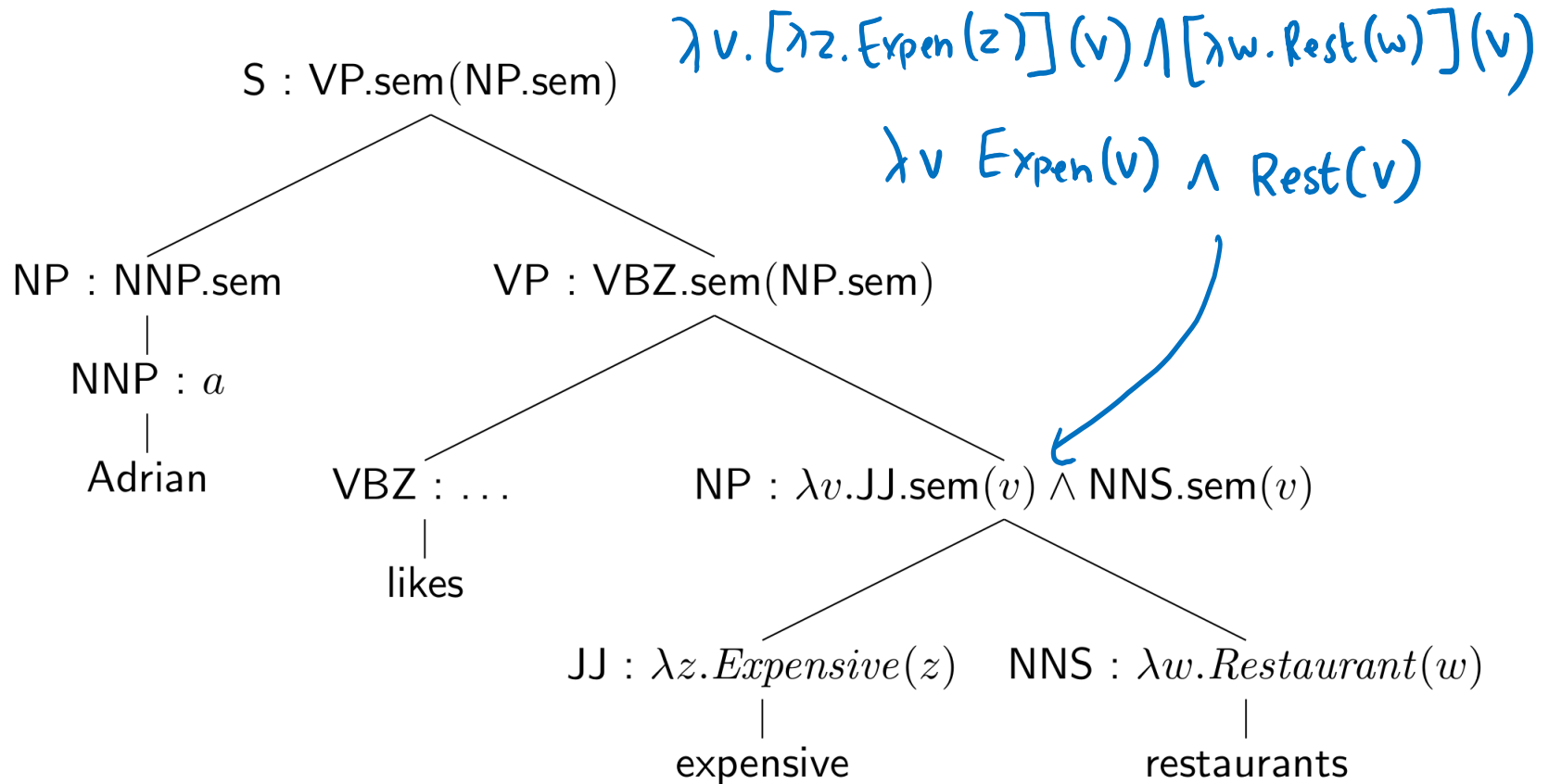
Semantic Attachments to CFG

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

CFG to λ -Calculus



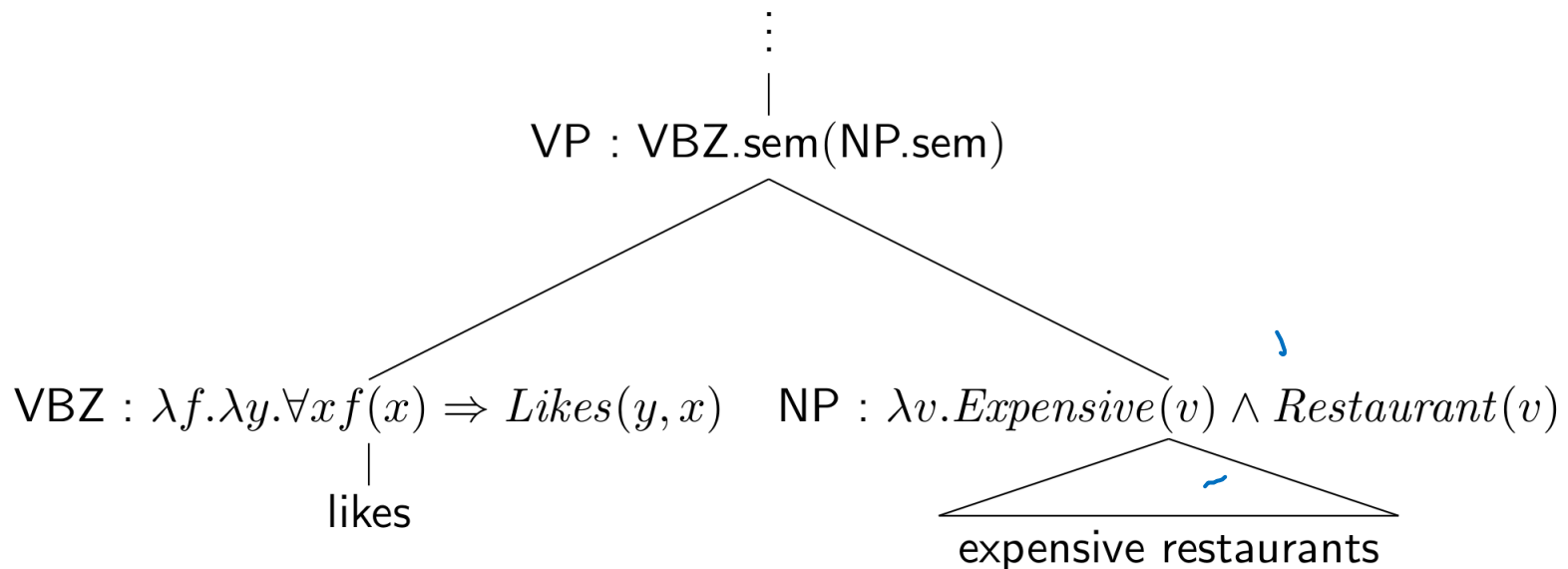
CFG to λ -Calculus



CFG to λ -Calculus

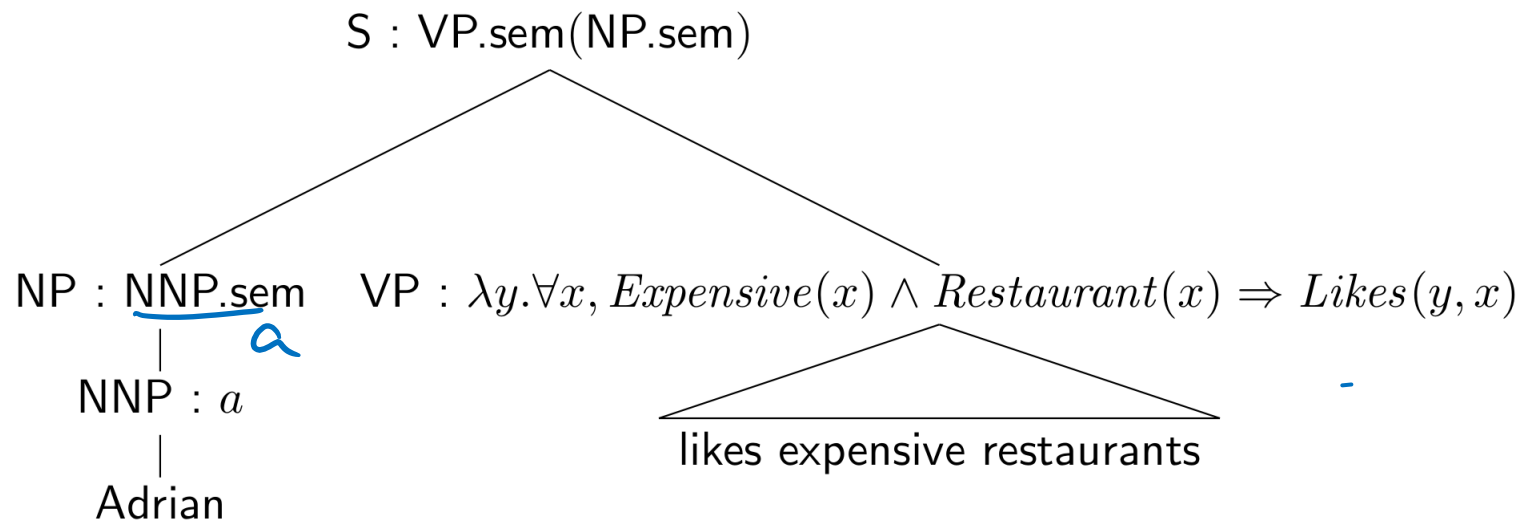
$[\lambda f. \lambda y \forall x f(x) \Rightarrow \text{Likes}(y, x)] (\lambda v. \text{Expensive}(v) \wedge \text{Restaurant}(v))$

$\lambda y \forall x \text{Expensive}(x) \wedge \text{Restaurant}(x) \Rightarrow \text{Likes}(y, x)$



CFG to λ -Calculus

$$\forall x \text{ Expensive}(x) \wedge \text{Restaurant}(x) \Rightarrow \text{Likes}(a, x)$$



Tricky Cases: Transitive Verbs

I eat food. $\lambda y \lambda x \text{ eat}(y, x)$

I eat. $\lambda y \text{ eat}(y)$

✓

Tricky Cases: Indefinites

Bob ate a waffle.

Amy ate a waffle.

$\text{ate}(\text{bob}, \text{waffle})$

$\text{ate}(\text{alice}, \text{waffle})$

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

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

Tricky Cases: Tenses and Events

Alice danced.

$\text{danced}(\text{alice})$

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

Alice had been dancing when Bob sneezed.

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

Tricky Cases: Adverbs

Bob sings terribly.

terribly (sings (bob))

$\forall e \text{ present}(e) \wedge \text{type}(e, \text{sing})$

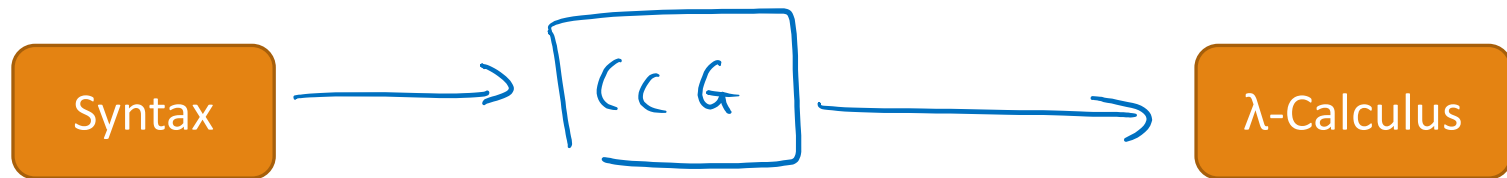
$\text{agent}(e, \text{bob}) \rightarrow \text{manner}(e, \text{terribly})$

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Combinatory Categorical Grammar



CCG Types

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

Primitive

S, NP, VP, \dots

Complex

S / NP



$S \setminus NP$

$_$ love food.

I love $_$.
Would be an S
if there was
an NP to the
right

CCG Combinators

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

CFG: $x \rightarrow y z$

CCG: $\underbrace{y \quad z}_{\text{class of types}} \rightarrow x$

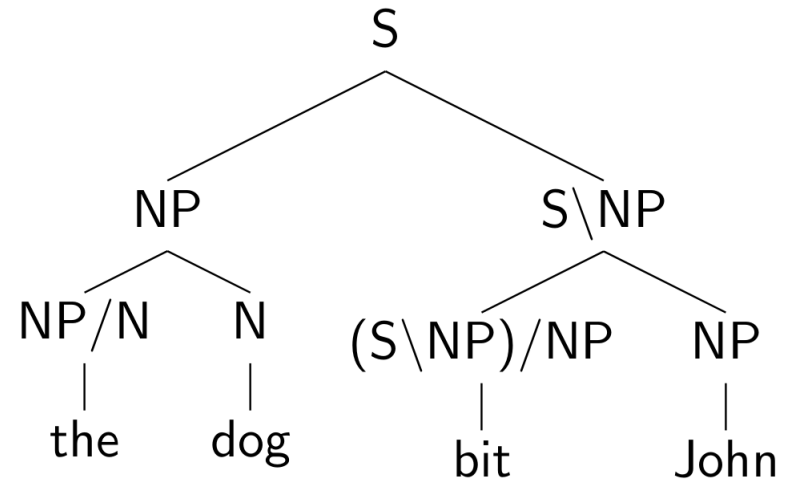
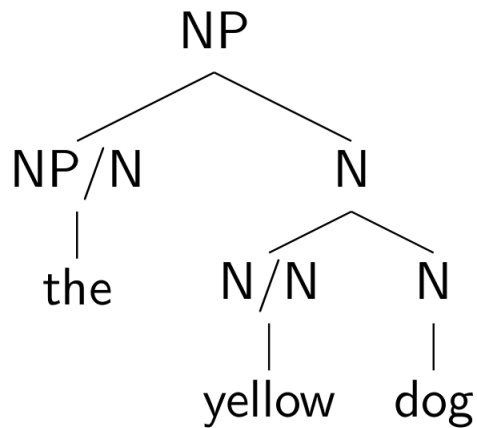
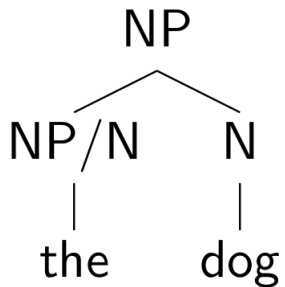
Application Combinator

Forward

$$X / Y \quad Y \Rightarrow X$$

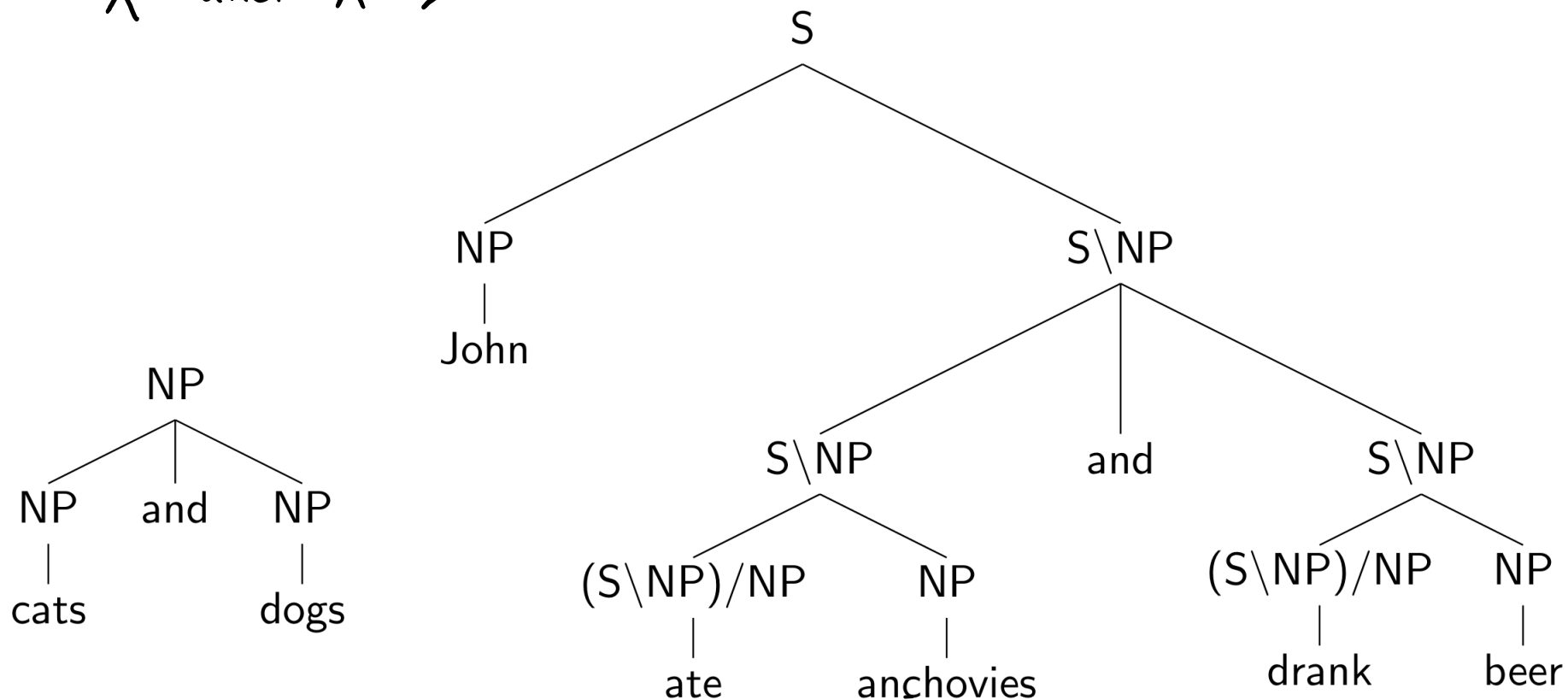
Backward

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

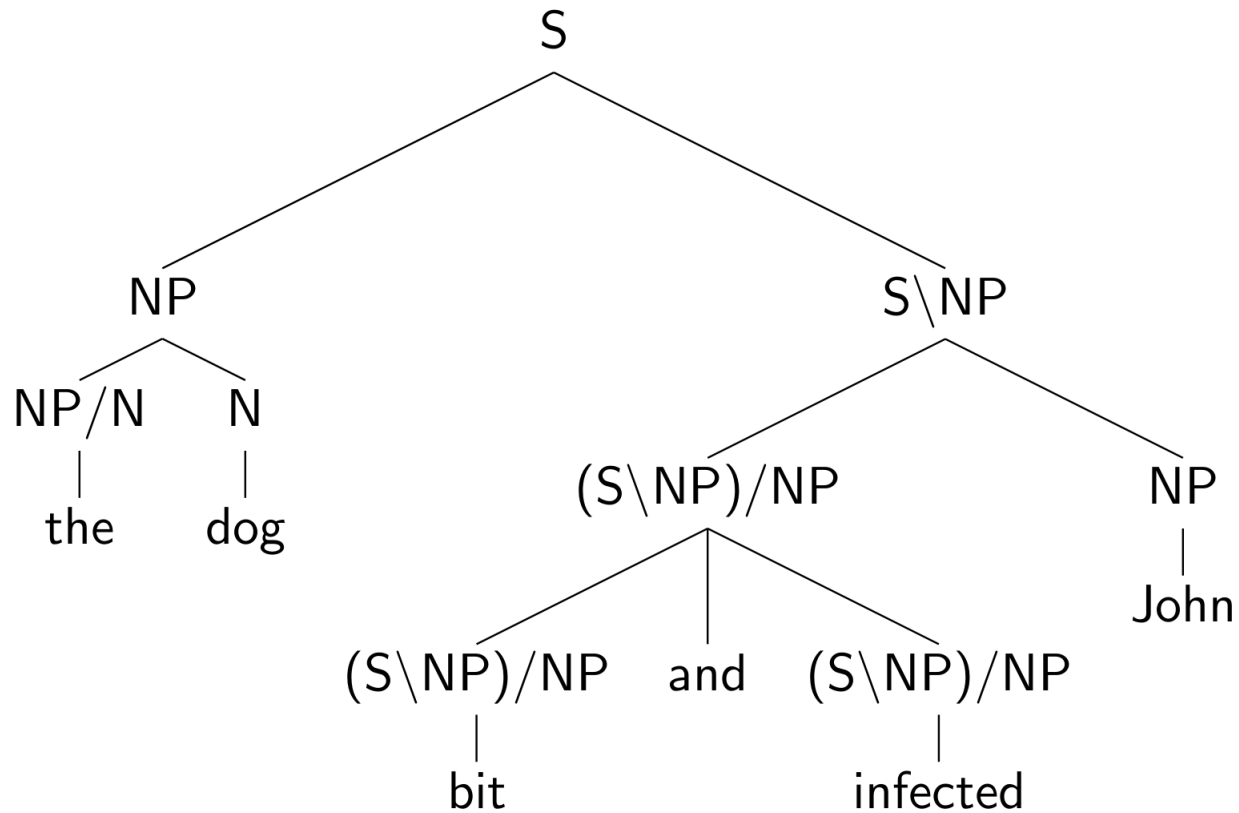


Conjunction Combinator

$X \text{ and } X \Rightarrow X$



Conjunction Combinator

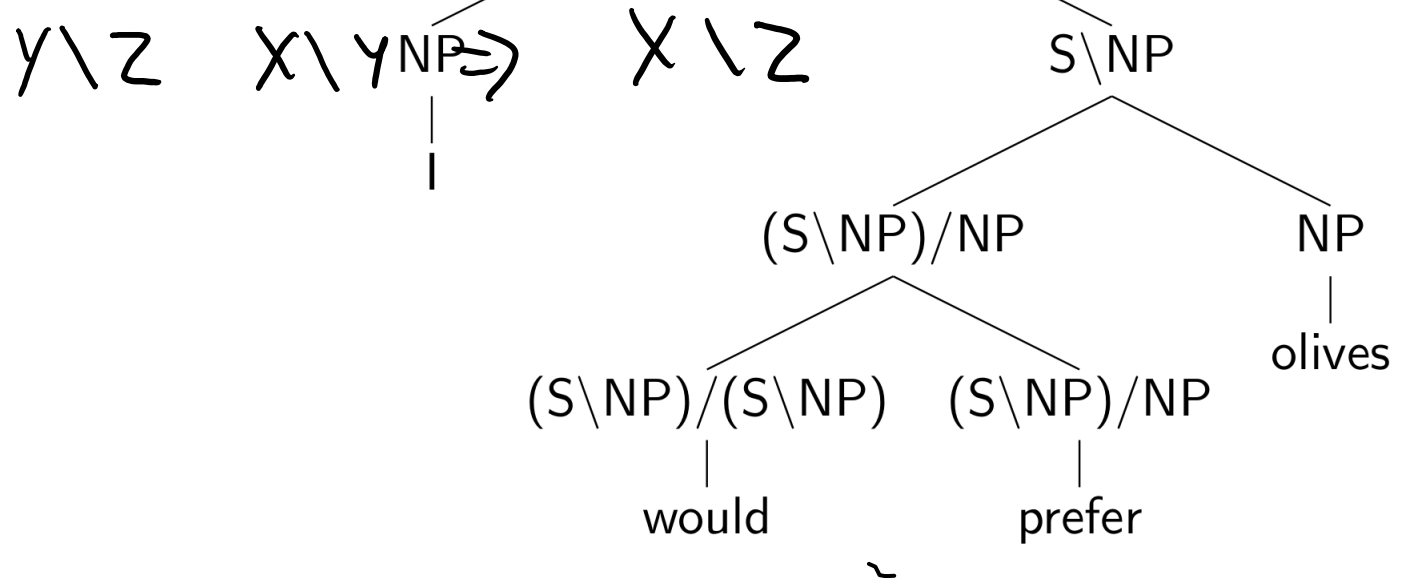


Composition Combinator

Forward

$$X/Y \quad Y/Z \Rightarrow X/Z$$

Backward



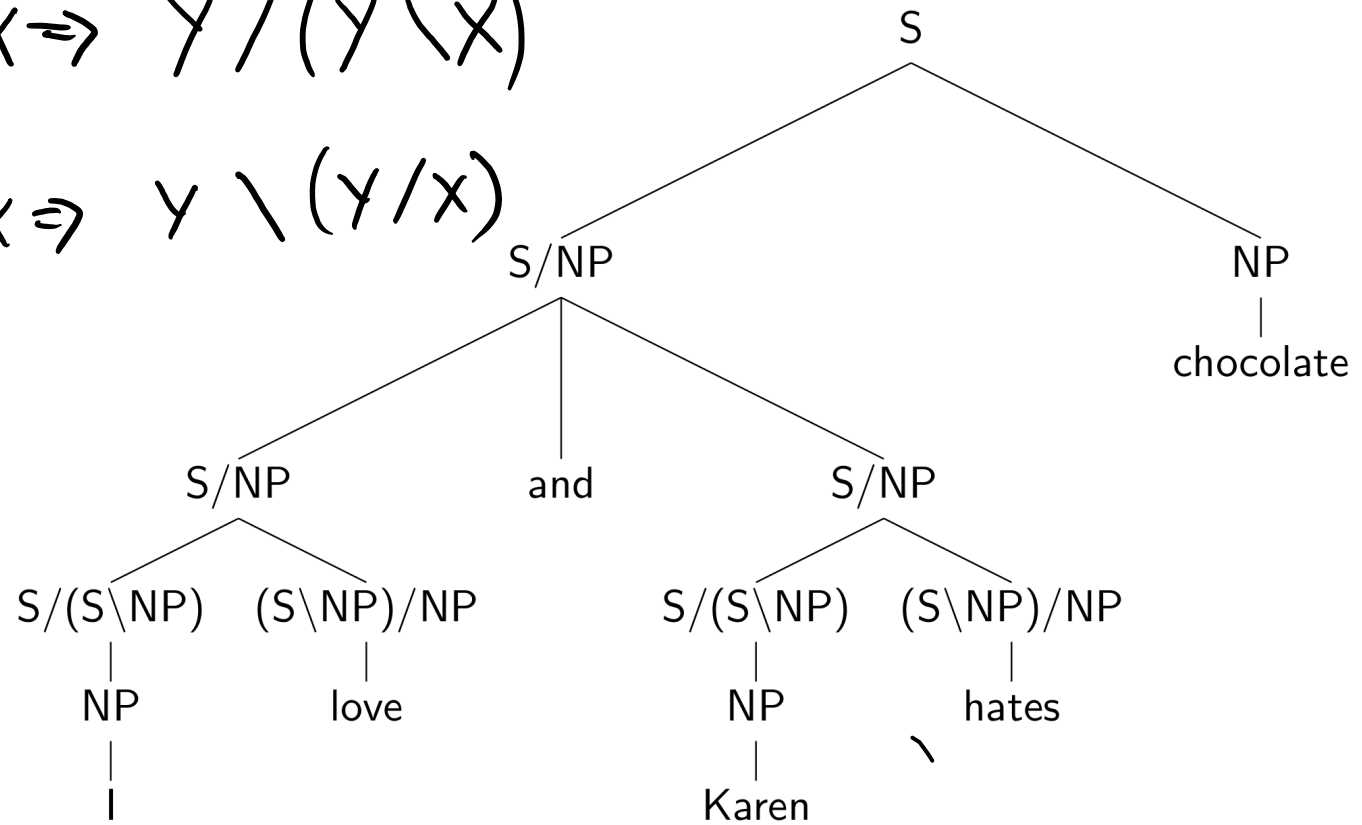
Type-Raising Combinator

Forward

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

Backward

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



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