Symbolic AI

Andre Freitas

Photo by Vasilyev Alexandr

Acknowledgements

- Based on the great slides of:
  - Yoav Artzi, Nicholas FitzGerald and Luke Zettlemoyer, Semantic Parsing with Combinatory Categorial Grammars
  - Combinatory Categorial Grammar: Constraining surface realisation in OpenCCG

This Lecture

- The connection between language, sets and logic
- Semantic Parsing
- Combinatory Categorial Grammars (CCGs)
- How to query KBs using NL

Language to Meaning

at the chair, move forward three steps past the sofa

$$\lambda a.pre(a, \iota x.chair(x)) \land move(a) \land len(a, 3) \land$$
$$dir(a, forward) \land past(a, \iota y.sofa(y))$$

Learn

$$f : \text{sentence} \rightarrow \text{logical form}$$

Lambda Calculus

- Formal system to express computation
- Allows high-order functions

$$\lambda a.move(a) \wedge dir(a, LEFT) \wedge to(a, \iota y.chair(y)) \wedge$$
$$pass(a, \mathcal{A}y.sofa(y) \wedge intersect(\mathcal{A}z.intersection(z), y))$$

[Church 1932]

Lambda Calculus
Base Cases

- Logical constant
- Variable
- Literal
- Lambda term

Lambda Calculus
Logical Constants

- Represent objects in the world

$$NYC, CA, RAINIER, LEFT, \ldots$$
$$located\_in, depart\_date, \ldots$$

Lambda Calculus

Variables

- Abstract over objects in the world
- Exact value not pre-determined

$$x, y, z, \ldots$$

Lambda Calculus
Literals

- Represent function application

$$city(AUSTIN)$$
$$located\_in(AUSTIN, TEXAS)$$

Lambda Calculus

Lambda Terms

- Bind/scope a variable
- Repeat to bind multiple variables

$$\lambda x.city(x)$$

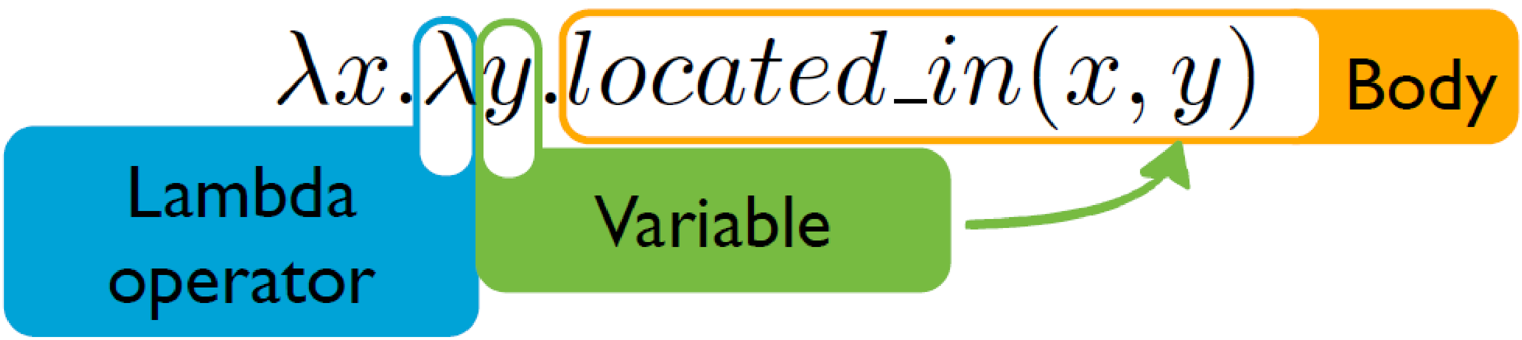
$$\lambda x.\lambda y.located\_in(x, y)$$

Lambda Calculus

Lambda Terms

- Bind/scope a variable
- Repeat to bind multiple variables

$$\lambda x.city(x)$$



Capturing Meaning with Lambda Calculus

State

Abbr.	Capital	Pop.
AL	Montgomery	3.9
AK	Juneau	0.4
AZ	Phoenix	2.7

Border

State1	State2
WA	OR
WA	ID
CA	OR
CA	NV
CA	AZ

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA
Wrangel	AK
Si	

Show me mountains in states bordering Texas

[Zettlemoyer and Collins 2005]

Capturing Meaning with Lambda Calculus

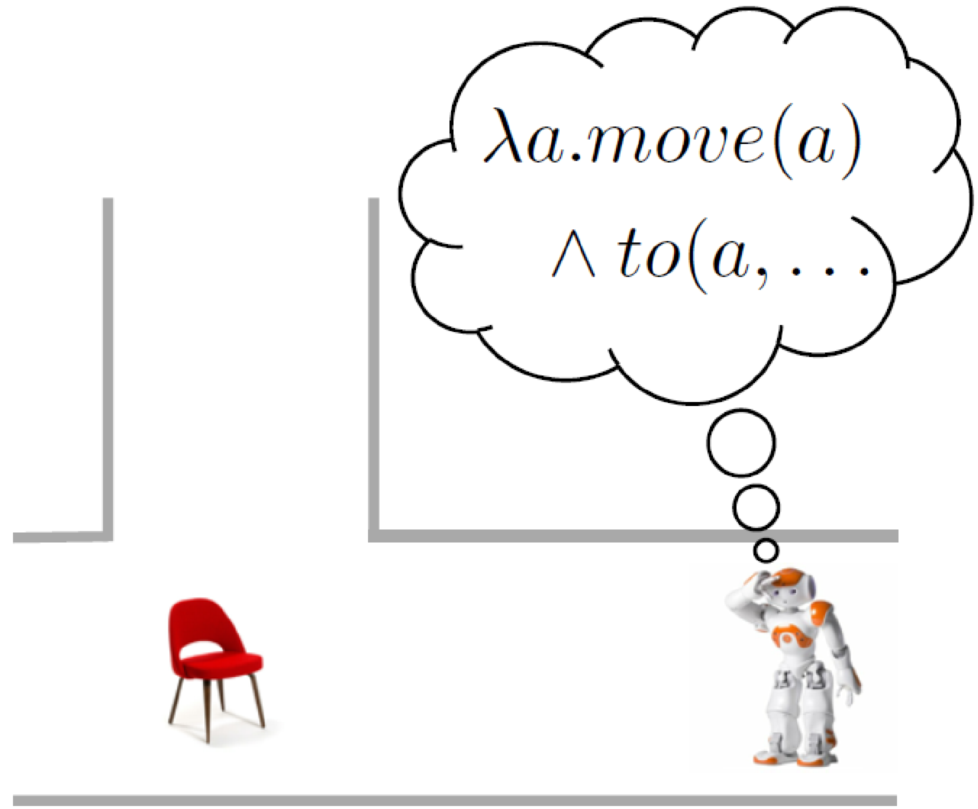
SYSTEM	how can I help you ?
USER	i ' d like to fly to new york
SYSTEM	flying to new york . leaving what city ?
USER	from boston on june seven with american airlines
SYSTEM	flying to new york . what date would you like to depart boston ?
USER	june seventh
SYSTEM	do you have a preferred airline ?
USER	american airlines
SYSTEM	o . k . leaving boston to new york on june seventh flying with american airlines . where would you like to go to next ?
USER	back to boston on june tenth

[CONVERSATION CONTINUES]

[Artzi and Zettlemoyer 2011]

Capturing Meaning with Lambda Calculus

go to the chair
and turn right



[Artzi and Zettlemoyer 2013b]

Capturing Meaning with Lambda Calculus

- Flexible representation.

- Can capture full complexity of natural language.

Constructing Lambda Calculus Expressions

at the chair, move forward three steps past the sofa

Semantic Parsing ?

$$\lambda a.pre(a, \iota x.chair(x)) \wedge move(a) \wedge len(a, 3) \wedge dir(a, forward) \wedge past(a, \iota y.sofa(y))$$

Combinatory Categorial Grammars

- Categorial formalism.
- Transparent interface between syntax and semantics.
- Designed with computation in mind.

Combinatory Categorial Grammars

CCG	is	fun
NP	$S\backslash NP/ADJ$	ADJ
CCG	$\lambda f.\lambda x.f(x)$	$\lambda x.fun(x)$

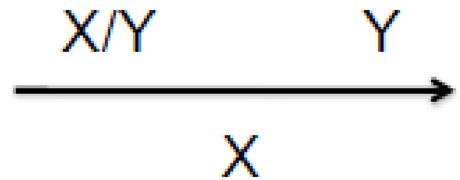
$$\frac{\lambda f.\lambda x.f(x) \quad \lambda x.fun(x)}{S\backslash NP \quad \lambda x.fun(x)} >$$

$$\frac{CCG \quad \lambda x.fun(x)}{S \quad fun(CCG)} <$$

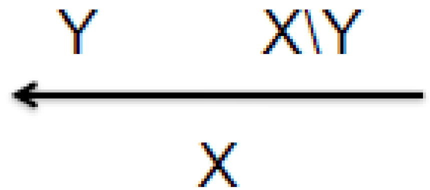
[Steedman 1996, 2000]

Formalism

- X/Y: The kind of word or phrase that **combines** with a **following** Y to form an X.

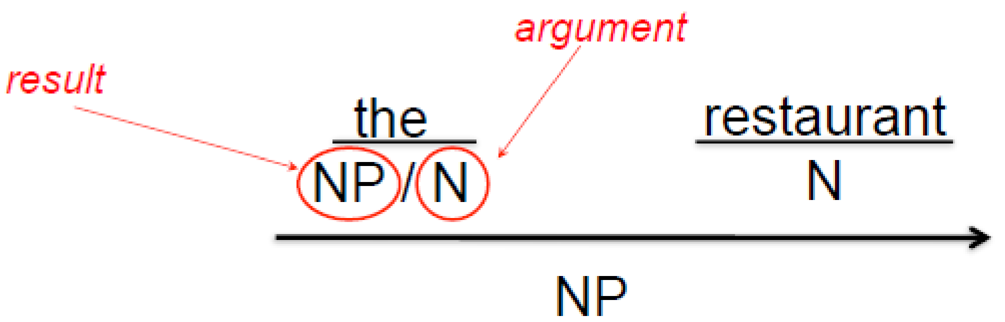


- X\Y: kind of word or phrase that combines with a **preceding** Y to form an X.



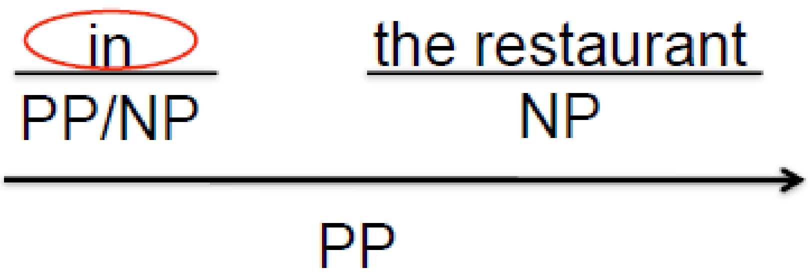
Determiners

- **Determiner:** word that combines with a following N to give an NP, i.e., an NP/N.

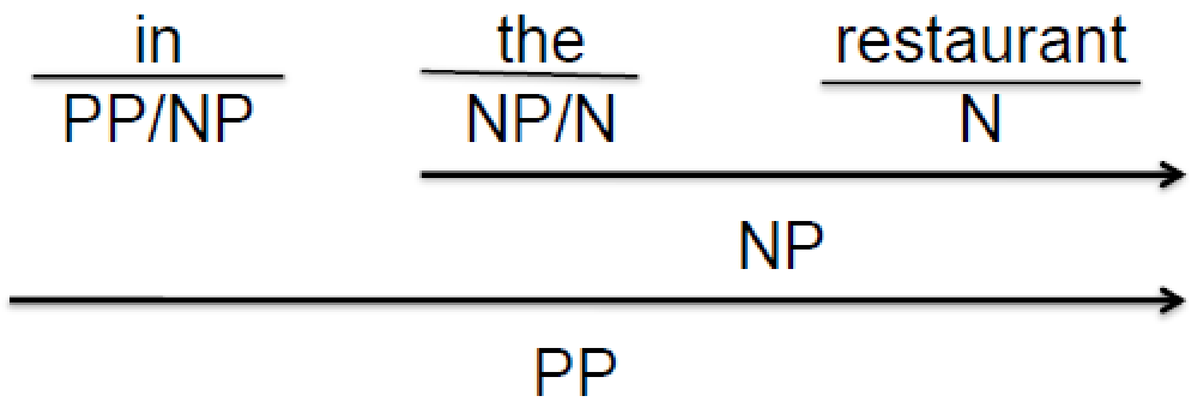


Prepositions

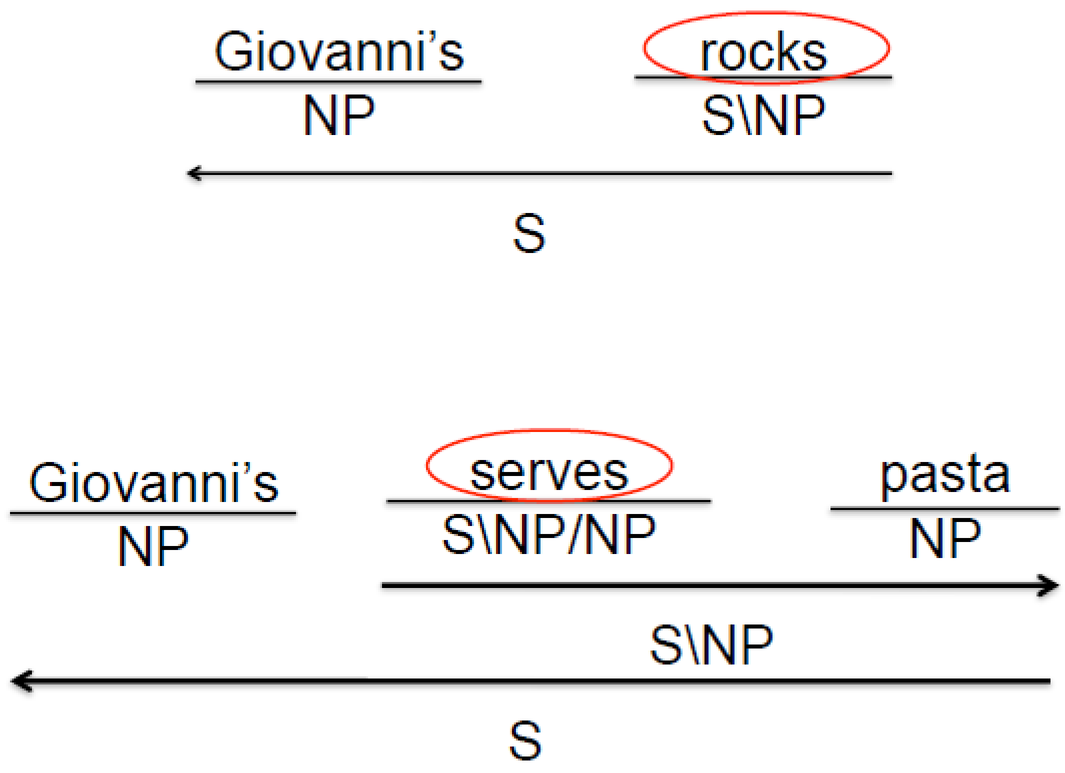
- **Preposition:** word that combines with a following NP to give a PP, i.e., a PP/NP.



Derivation



Verbs


Giovanni's
rocks
NP
S\NP
S
Giovanni's
serves
pasta
NP
S\NP/NP
NP
S\NP
S

CCG Categories

$$ADJ : \lambda x.fun(x)$$

- Basic building block.
- Capture syntactic and semantic information jointly.

CCG Categories

Syntax $ADJ : \lambda x.fun(x)$ Semantics

- Basic building block.
- Capture syntactic and semantic information jointly.

CCG Categories

Syntax

$$ADJ : \lambda x.fun(x)$$

$$(S\backslash NP)/ADJ : \lambda f.\lambda x.f(x)$$

$$NP : CCG$$

- Primitive symbols: N, S, NP, ADJ and PP.
- Syntactic combination operator (/,\).
- Slashes specify argument order and direction.

CCG Categories

$$ADJ : \lambda x.fun(x)$$

Semantics

$$(S\backslash NP)/ADJ : \lambda f.\lambda x.f(x)$$

$$NP : CCG$$

- λ-calculus expression.
- Syntactic type maps to semantic type.

CCG Lexical Entries

$$\text{fun} \ \vdash ADJ : \lambda x.fun(x)$$

CCG Lexical Entries

$$\text{fun} \vdash ADJ : \lambda x.fun(x)$$

Natural Language

CCG Category

CCG Lexicons

$$\text{fun} \vdash ADJ : \lambda x.fun(x)$$

$$\text{is} \vdash (S\backslash NP)/ADJ : \lambda f.\lambda x.f(x)$$

$$\text{CCG} \vdash NP : CCG$$

Parsing with CCGs

$$\frac{\text{CCG}}{\begin{array}{c}NP\\ CCG\end{array}} \qquad \frac{\text{is}}{\begin{array}{c}S\backslash NP/ADJ\\ \lambda f.\lambda x.f(x)\end{array}} \qquad \frac{\text{fun}}{\begin{array}{c}ADJ\\ \lambda x.fun(x)\end{array}}$$

CCG Operations
Application

Argument | Function | Result

$$B : g \quad A \backslash B : f \Rightarrow A : f(g) \qquad (<)$$

$$A / B : f \quad B : g \Rightarrow A : f(g) \qquad (>)$$

- Equivalent to function application
- Two directions: forward and backward
  - Determined by slash direction

Parsing with CCGs

$$
\begin{array}{ccc}
\dfrac{\text{CCG}}{\begin{array}{c} NP \\ CCG \end{array}} &
\dfrac{\text{is}}{\begin{array}{c} S\backslash NP/ADJ \\ \lambda f.\lambda x.f(x) \end{array}} &
\dfrac{\text{fun}}{\begin{array}{c} ADJ \\ \lambda x.fun(x) \end{array}}
\end{array}
$$

Parsing with CCGs

CCG	is	fun
NP	$S\backslash NP/ADJ$	ADJ
CCG	$\lambda f.\lambda x.f(x)$	$\lambda x.fun(x)$

$$\frac{S\backslash NP/ADJ \quad ADJ}{S\backslash NP} >$$

$$\lambda x.fun(x)$$

Combine categories using operators

$$A/B : f \quad B : g \Rightarrow A : f(g) \quad (>)$$

Parsing with CCGs

CCG	is	fun
NP	$S\backslash NP/ADJ$	ADJ
CCG	$\lambda f.\lambda x.f(x)$	$\lambda x.fun(x)$
	$>$	
	$S\backslash NP$	
	$\lambda x.fun(x)$	
$<$		
S		
$fun(CCG)$		

Combine categories using operators

$$B : g \quad A\backslash B : f \Rightarrow A : f(g) \quad (<)$$

CCG Operations
Composition

- Equivalent to function composition
- Two directions: forward and backward

$$\underbrace{A/B : f}_{f} \quad \underbrace{B/C : g}_{g} \Rightarrow \underbrace{A/C : \lambda x.f(g(x))}_{f \circ g} \quad (> B)$$

$$B\backslash C : g \quad A\backslash B : f \Rightarrow A\backslash C : \lambda x.f(g(x)) \quad (< B)$$

Querying Databases

State

Abbr.	Capital	Pop.
AL	Montgomery	3.9
AK	Juneau	0.4
AZ	Phoenix	2.7
WA	Olympia	4.1
NY	Albany	17.5
IL	Springfield	11.4

Border

State1	State2
WA	OR
WA	ID
CA	OR
CA	NV
CA	AZ

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA
Wrangel	AK
Sill	CA
Bor	[illegible]
Elbe	

[Zettlemoyer and Collins 2005]

Querying Databases

State

Abbr.	Capital	Pop.
AL	Montgomery	3.9
AK	Juneau	0.4
AZ	Phoenix	2.7

Border

State1	State2
WA	OR
WA	ID
CA	OR
CA	NV

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

What is the capital of Arizona?

How many states border California?

What is the largest state?

Querying Databases

State

Abbr.	Capital	Pop.
AL	Montgomery	3.9
AK	Juneau	0.4
AZ	Phoenix	2.7

Border

State1	State2
WA	OR
WA	ID
CA	OR
CA	NV

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

What is the capital of Arizona?

How many states border California?

What is the largest state?

Noun Phrases

Querying Databases

State

Abbr.	Capital	Pop.
AL	Montgomery	3.9
AK	Juneau	0.4
AZ	Phoenix	2.7

Border

State1	State2
WA	OR
WA	ID
CA	OR
CA	NV

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

What is the capital of Arizona?

How many states border California?

What is the largest state?

Verbs

Querying Databases

State

Abbr.	Capital	Pop.
AL	Montgomery	3.9
AK	Juneau	0.4
AZ	Phoenix	2.7

Border

State1	State2
WA	OR
WA	ID
CA	OR
CA	NV

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

What is the capital of Arizona?

How many states border California?

What is the largest state?

Nouns

Querying Databases

State

Abbr.	Capital	Pop.
AL	Montgomery	3.9
AK	Juneau	0.4
AZ	Phoenix	2.7

Border

State1	State2
WA	OR
WA	ID
CA	OR
CA	NV

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

What is the capital of Arizona?

How many states border California?

What is the largest state?

Prepositions

Querying Databases

State

Abbr.	Capital	Pop.
AL	Montgomery	3.9
AK	Juneau	0.4
AZ	Phoenix	2.7

Border

State1	State2
WA	OR
WA	ID
CA	OR
CA	NV

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

What is the capital of Arizona?

How many states border California?

What is the largest state?

Superlatives

Querying Databases

State

Abbr.	Capital	Pop.
AL	Montgomery	3.9
AK	Juneau	0.4
AZ	Phoenix	2.7

Border

State1	State2
WA	OR
WA	ID
CA	OR
CA	NV

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

What is ==the== capital of Arizona?

How many states border California?

What is ==the== largest state?

Determiners

Querying Databases

State

Abbr.	Capital	Pop.
AL	Montgomery	3.9
AK	Juneau	0.4
AZ	Phoenix	2.7

Border

State1	State2
WA	OR
WA	ID
CA	OR
CA	NV

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

What is the capital of Arizona?

How many states border California?

What is the largest state?

Questions

Referring to DB Entities

Noun phrases	Select single DB entities
Prepositions Verbs	Relations between entities
Nouns	Typing (i.e., column headers)
Superlatives	Ordering queries

Noun Phrases

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

In this context

Noun phrases name specific entities

Washington

WA

Florida

The Sunshine State

FL

Noun Phrases

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

Noun phrases name specific entities

$$\frac{\text{Washington}}{\begin{matrix} NP \\ WA \end{matrix}}$$

$$\frac{\text{The Sunshine State}}{\begin{matrix} NP \\ FL \end{matrix}}$$

Verb Relations

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

Border

State1	State2
WA	OR
WA	ID
CA	OR
CA	NV

Verbs express relations between entities

Nevada **borders** California

$border(NV, CA)$

Verb Relations

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

$$\dfrac{\text{Nevada}}{\begin{array}{c}NP\\ NV\end{array}} \quad \dfrac{\text{borders}}{\begin{array}{c}S\backslash NP/NP\\ \lambda x.\lambda y.border(y,x)\end{array}} \quad \dfrac{\text{California}}{\begin{array}{c}NP\\ CA\end{array}}$$

$$\xrightarrow{>}\quad \begin{array}{c}S\backslash NP\\ \lambda y.border(y,CA)\end{array}$$

$$\xrightarrow{<}\quad \begin{array}{c}S\\ border(NV,CA)\end{array}$$

Nouns

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

Nouns are functions that define entity type

state

$\lambda x.state(x)$

mountain

$\lambda x.mountain(x)$

Nouns

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

Nouns are functions that define entity type

state

$\lambda x.state(x)$

$\{$ WA , AL , AK $, \ldots \}$

$e \rightarrow t$

functions define sets

mountain

$\lambda x.mountain(x)$

$\{$ BIANCA , ANTERO $, \ldots \}$

Nouns

State	
Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

Mountains	
Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

Nouns are functions that define entity type

$$\frac{\textbf{state}}{N : \lambda x.state(x)}$$

$$\frac{\textbf{mountain}}{N : \lambda x.mountain(x)}$$

Prepositions

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

Prepositional phrases are conjunctive modifiers

mountain in Colorado

Prepositions

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

Prepositional phrases are conjunctive modifiers

mountain in Colorado

$$\lambda x.mountain(x) \land in(x, CO)$$

$$\{ \text{BIANCA}, \text{ANTERO} \}$$

Prepositions

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

mountain	in	Colorado
N	PP/NP	NP
$\lambda x.mountain(x)$	$\lambda y.\lambda x.in(x,y)$	CO

$$\text{in} + \text{Colorado} \xrightarrow{>} PP : \lambda x.in(x, CO)$$

$$N \backslash N : \lambda f.\lambda x.f(x) \wedge in(x, CO)$$

$$\text{mountain} + N \backslash N \xrightarrow{<} N : \lambda x.mountain(x) \wedge in(x, CO)$$

Function Words

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

Border

State1	State2
WA	OR
WA	ID
CA	OR
CA	NV

Certain words are used to modify syntactic roles

state **that** borders California

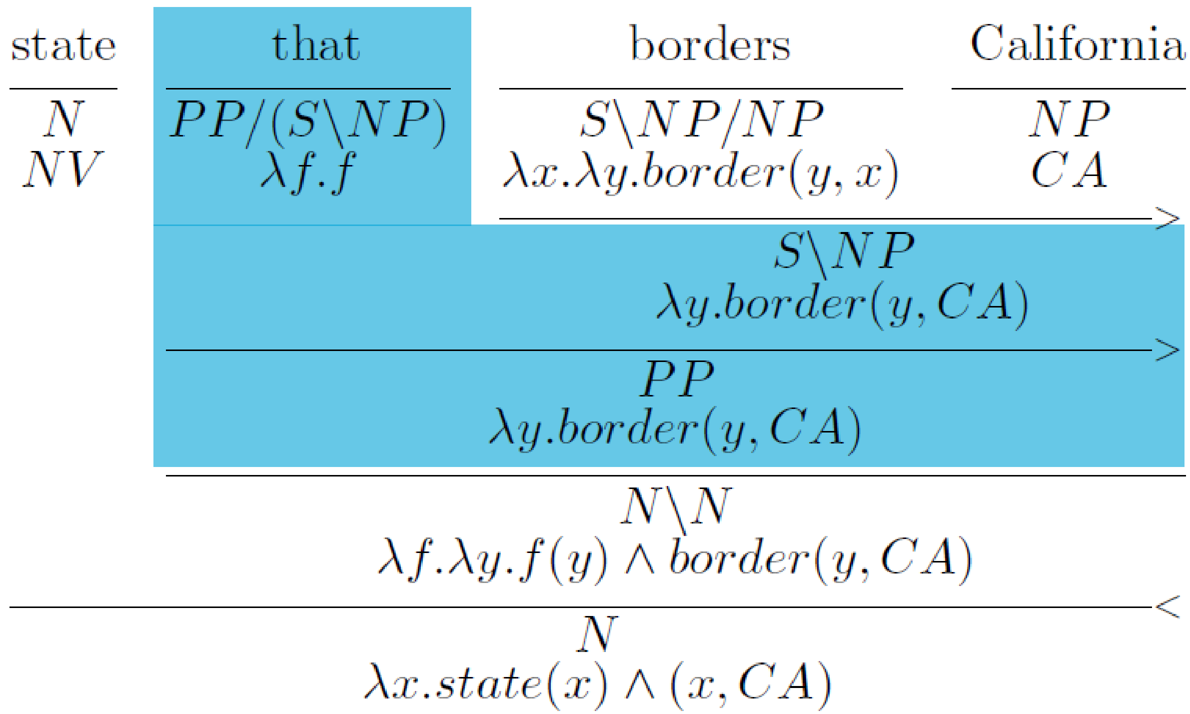
$\lambda x.state(x) \wedge border(x, CA)$

$\{$ OR, NV, AZ $\}$

Function Words

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield



Definite Determiners

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

Definite determiner selects the single members of a set when such exists

$$\iota : (e \rightarrow t) \rightarrow e$$

the mountain in Washington

Definite Determiners

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

Definite determiner selects the single members of a set when such exists

$$\iota : (e \rightarrow t) \rightarrow e$$

mountain in Washington

$$\lambda x.mountain(x) \wedge in(x, WA)$$

$\{$ RAINIER $\}$

Definite Determiners

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

Mountains

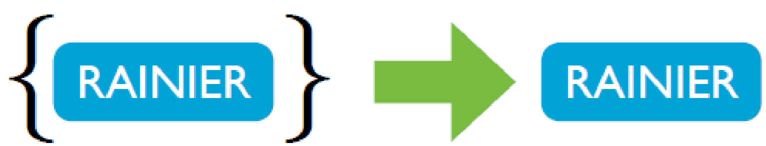
Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

Definite determiner selects the single members of a set when such exists

$$\iota : (e \to t) \to e$$

the mountain in Washington

$$\iota x.mountain(x) \wedge in(x, WA)$$



Definite Determiners

State	
Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

Mountains	
Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

Definite determiner selects the single members of a set when such exists

$$\iota : (e \rightarrow t) \rightarrow e$$

the mountain in Colorado

$$\iota x.mountain(x) \wedge in(x, CO)$$

{ BIANCA , ANTERO } → ✗

No information to disambiguate

Definite Determiners

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

the — $\frac{\text{the}}{NP/N \quad \lambda f.\iota x.f(x)}$

mountain in Colorado

$\vdots$

$$N \quad \lambda x.mountain(x) \wedge in(x, CO)$$

$$\xrightarrow{>} \quad NP \quad \iota x.mountain(x) \wedge in(x, CO)$$

Indefinite Determiners

State

Abbr.	Capital
AL	Montgomery
AK	Juneau
AZ	Phoenix
WA	Olympia
NY	Albany
IL	Springfield

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA
Shasta	CA

Indefinite determiners are select any entity from a set without a preference

$$\mathcal{A} : (e \rightarrow t) \rightarrow e$$

state with a mountain

$$\lambda x.state(x) \wedge in(\mathcal{A}y.mountain(y), x)$$

[Steedman 2011; Artzi and Zettlemoyer 2013b]

Superlatives

State

Abbr.	Capital	Pop.
AL	Montgomery	3.9
AK	Juneau	0.4
AZ	Phoenix	2.7
WA	Olympia	4.1
NY	Albany	17.5
IL	Springfield	11.4

Superlatives select optimal entities according to a measure

the largest state

$$argmax(\lambda x.state(x), \lambda y.pop(y))$$

Min or max ... over this set ... according to this measure

$\{$ WA, AL, AK, $\ldots\}$

AL	3.9
AK	0.4
Seattle	2.7
San Francisco	4.1
NY	17.5
IL	11.4

Superlatives

State

Abbr.	Capital	Pop.
AL	Montgomery	3.9
AK	Juneau	0.4
AZ	Phoenix	2.7
WA	Olympia	4.1
NY	Albany	17.5
IL	Springfield	11.4

Superlatives select optimal entities according to a measure

the largest state

$$argmax(\lambda x.state(x), \lambda y.pop(y))$$

Min or max ... over this set ... according to this measure

CA

AL	3.9
AK	0.4
Seattle	2.7
San Francisco	4.1
NY	17.5
IL	11.4

Superlatives

$$\dfrac{\text{the largest}}{\begin{array}{c} NP/N \\ \lambda f.argmax(\lambda x.f(x), \lambda y.pop(y)) \end{array}} \quad \dfrac{\text{state}}{\begin{array}{c} N \\ \lambda x.state(x) \end{array}}$$

$$\xrightarrow{\hspace{6cm}} >$$

$$\begin{array}{c} NP \\ argmax(\lambda x.state(x), \lambda y.pop(y)) \end{array}$$

Superlatives

State

Abbr.	Capi
AL	Montgo
AK	June
AZ	Phoe
WA	Olym
NY	Alba
IL	Spring

$$
\begin{array}{ccc}
\text{the most} & \text{populated} & \text{state} \\
\hline
NP/N/N & N & N \\
\lambda g.\lambda f.argmax(\lambda x.f(x), \lambda y.g(y)) & \lambda x.pop(x) & \lambda x.state(x) \\
\hline
\multicolumn{2}{c}{NP/N \quad >} & \\
\multicolumn{2}{c}{\lambda f.argmax(\lambda x.f(x), \lambda y.pop(y))} & \\
\hline
\multicolumn{3}{c}{NP \quad >} \\
\multicolumn{3}{c}{argmax(\lambda x.state(x), \lambda y.pop(y))}
\end{array}
$$

Representing Questions

State

Abbr.	Capital	Pop.
AL	Montgomery	3.9
AK	Juneau	0.4

Border

State1	State2
WA	OR
WA	ID
CA	OR

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA

Which mountains are in Arizona?

Represent questions as the queries that generate their answers

Representing Questions

State

Abbr.	Capital	Pop.
AL	Montgomery	3.9
AK	Juneau	0.4

Border

State1	State2
WA	OR
WA	ID
CA	OR

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA

Which mountains are in Arizona?

$$\lambda x.mountain(x) \wedge in(x, AZ)$$

Represent questions as the queries that generate their answers

Representing Questions

State

Abbr.	Capital	Pop.
AL	Montgomery	3.9
AK	Juneau	0.4

Border

State1	State2
WA	OR
WA	ID
CA	OR

Mountains

Name	State
Bianca	CO
Antero	CO
Rainier	WA

How many states border California?

$$count(\lambda x.state(x) \wedge border(x, CA))$$

Represent questions as the queries that generate their answers

Spatial and Instructional Language

Name objects

Noun phrases	Specific entities
Nouns	Sets of entities
Prepositional phrases Adjectives	Constrain sets

Instructions to execute

Verbs	Davidsonian events
Imperatives	Sets of events

Neo-Davidsonian Event Semantics

- Vincent shot Marvin in the car accidentally

$$\exists a.shot(a) \land agent(a, VINCENT) \land$$
$$patient(a, MARVIN) \land in(a, \iota x.car(x)) \land \neg intentional(a)$$

[Parsons 1990]

Summary

- The connection between language, sets and logic
- Semantic Parsing
- Combinatory Categorial Grammars (CCGs)
- How to query KBs using NL

Recommended Reading

A Very Short Introduction to CCG*

Mark Steedman

Draft, November 1, 1996

http://cs.brown.edu/courses/csci2952d/readings/lecture5-steedman.pdf

Recommended Reading

Open-Domain Semantic Parsing with Boxer

Johan Bos
Center for Language and Cognition
University of Groningen
johan.bos@rug.nl

http://cs.brown.edu/courses/csci2952d/readings/lecture8-bos.pdf