COMPUTATIONAL SEMANTICS: DAY 4

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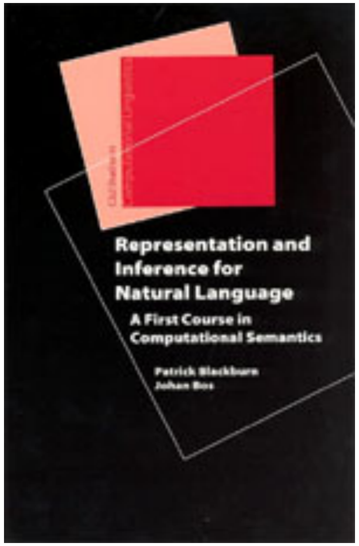
Computational Semantics

- Day 1: Exploring Models
- Day 2: Meaning Representations
- Day 3: Computing Meanings with DCG
- **Day 4: Computing Meanings with CCG**
- Day 5: Drawing Inferences and Meaning Banking



Exercise 2 (homework)

- Look at the natural language statements associated with the images in GRIM
- Pick a frequently occurring verb that is not in the lexicon already
- Specify the lexical semantics of this verb in

  a) no events (pre-Davidsonian)
  b) Davidsonian
  c) neo-Davidsonian
  d) the spatial relations only

Questions after yesterday’s lecture

- Some of the “white cats” were black… Why?

- Subsume lambdas from left to right?
  E.g., what do you get after beta-converting

$$\lambda x \lambda y HEY(y,x)@z$$


YOU GET A PARSER FOR FREE WITH PROLOG!
NOT SURE IT IS A PARSER I WANT TO USE

Combinatory Categorial Grammar

- CCG is a lexicalised theory of grammar
  - Many different lexical categories
  - Few grammar rules (based on combinatory logic)
  - Covers complex cases of coordination and long-distance dependencies

- Not just theory, also used in practice
  - OpenCCG (Baldridge, White)
  - CCGbank (Hockenmaier)
  - C&C supertagger and parser (Clark, Curran)
  - Groningen Meaning Bank

Basic Categories

S	sentence
NP	noun phrase
N	noun
PP	prepositional phrase

Note: The category S comes with a feature to distinguish between various sentence mood and verb phrase forms.

Examples: S_{dcl} (declarative sentence)
$S_{ng}\backslash NP$ (present participle)

Functor Categories

The direction of the slash determines where the argument appears:
forward slash (/): on its right; backward slash (\): on its left

NP/N	determiner
N/N	adjective
$S_{dcl}\backslash NP$	verb phrase (declarative mood)
$(S_{pt}\backslash NP)/NP$	transitive verb (present participle)
$(S_X\backslash NP)\backslash(S_X\backslash NP)$	adverb
$(N\backslash N)/NP$	preposition (modifying noun)

Example Lexicon

Word		Category
boy	:	N
everything	:	NP
the	:	NP/N
eats	:	$S_{dcl}\backslash NP$
eats	:	$(S_{dcl}\backslash NP)/NP$
quickly	:	$(S_X\backslash NP)\backslash(S_X\backslash NP)$

Application

- Forward **>**
- Backward **<**

Composition

- (Generalised) Forward **>B**
- (Generalised) Backward **<B**

Crossed Composition

- (Generalised) Forward **>Bx**
- (Generalised) Backward **<Bx**

Type Raising

- Forward **>T**
- Backward **<T**

Substitution

- Forward **>S**
- Backward **<S**

Crossed Substitution

- Forward **>Sx**
- Backward **<Sx**

Combinatory Rules of CCG

the	**manager**
$NP / \boxed{N}$	$\boxed{N}$

$$\frac{NP / \boxed{N} \qquad \boxed{N}}{NP}\;>$$

Forward Application (>)

$$\begin{array}{lll} \textbf{the manager} & \textbf{left} & \\ \boxed{NP} & S_{dcl}\backslash\boxed{NP} & \\ \hline S_{dcl} & & < \end{array}$$

Backward Application (<)

to **sell**

$$\dfrac{(S_{to}\backslash NP)/\boxed{(S_b\backslash NP)} \qquad \boxed{(S_b\backslash NP)}\,/NP}{(S_{to}\backslash NP)/NP}\ {>}B$$

Forward Composition (>B)

$$
\dfrac{\dfrac{\textbf{to}}{(S_{to}\backslash NP)/(S_b\backslash NP)} \qquad \dfrac{\textbf{sell}}{(S_b\backslash NP)/NP}}{(S_{to}\backslash NP)/NP}\;{>}B
$$

Forward Composition (>B)

… John asked **curiously**

$$\frac{\boxed{S_{dcl}}\backslash S_{ynq} \qquad\qquad S_{dcl}\backslash \boxed{S_{dcl}}}{S_{dcl}\backslash S_{ynq}}\;{<}B$$

Backward Composition (<B)

…	**John asked**	**curiously**
	$S_{dcl} \backslash S_{ynq}$	$S_{dcl} \backslash S_{dcl}$

$$\overline{\hspace{20em}}{<}B$$

$S_{dcl} \backslash S_{ynq}$

Backward Composition (<B)

did **not**

$$\dfrac{\boxed{(S_{dcl}\backslash NP)}/(S_b\backslash NP) \qquad (S_{dcl}\backslash NP)\backslash\boxed{(S_{dcl}\backslash NP)}}{(S_{dcl}\backslash NP)/(S_b\backslash NP)} \ {<}Bx$$

Backward Crossed Composition (<Bx)

$$
\begin{array}{ll}
\textbf{did} & \textbf{not} \\
(S_{dcl}\backslash NP)/(S_b\backslash NP) & (S_{dcl}\backslash NP)\backslash(S_{dcl}\backslash NP) \\
\hline
\multicolumn{2}{l}{(S_{dcl}\backslash NP)/(S_b\backslash NP)} \quad <\!Bx
\end{array}
$$

Backward Crossed Composition (<Bx)

$$\frac{X/Y \qquad Y}{X} >$$

$$\frac{Y \qquad X\backslash Y}{X} <$$

$$\frac{X/Y \qquad Y/Z}{X/Z} >B$$

$$\frac{Y\backslash Z \qquad X\backslash Y}{X\backslash Z} <B$$

$$\frac{X/Y \qquad Y\backslash Z}{X\backslash Z} >Bx$$

$$\frac{Y/Z \qquad X\backslash Y}{X/Z} <Bx$$

CCG rule schemata (1)

Zed	hates	but	Tim	adores	Prince
NP	(S\NP)/NP	CONJ	NP	(S\NP)/NP	NP
———— >T			———— >T		
S/(S\NP)			S/(S\NP)		
———————— >B			———————— >B		
S/NP			S/NP		
———————————————————— <>					
S/NP					
—————————————————————————— >					
S					

Type Raising (>T) and Coordination (<>)

Substitution (S), “parasitic gap”

book	**that**	**I**	**burnt**	**without**	**reading**
N	(N\N)/(S/NP)	NP	VP/NP	(VP\VP)/VP	VP/NP

I: NP ——— >T ⇒ S/VP

without reading: (VP\VP)/VP VP/NP ——— >B ⇒ (VP\VP)/NP

burnt without reading: VP/NP (VP\VP)/NP ——— <Sx ⇒ VP/NP

I burnt without reading: S/VP VP/NP ——— >B ⇒ S/NP

that I burnt without reading: (N\N)/(S/NP) S/NP ——— > ⇒ N\N

book that I burnt without reading: N N\N ——— < ⇒ N

Which paper did the professor read ... without understanding ... ?

$$\frac{X}{Y/(Y\backslash X)}\ >T$$

$$\frac{X}{X\backslash(Y/X)}\ <T$$

$$\frac{X \quad CONJ \quad X}{X}\ <>$$

$$\frac{(X/Y)/Z \quad Y/Z}{X/Z}\ >S$$

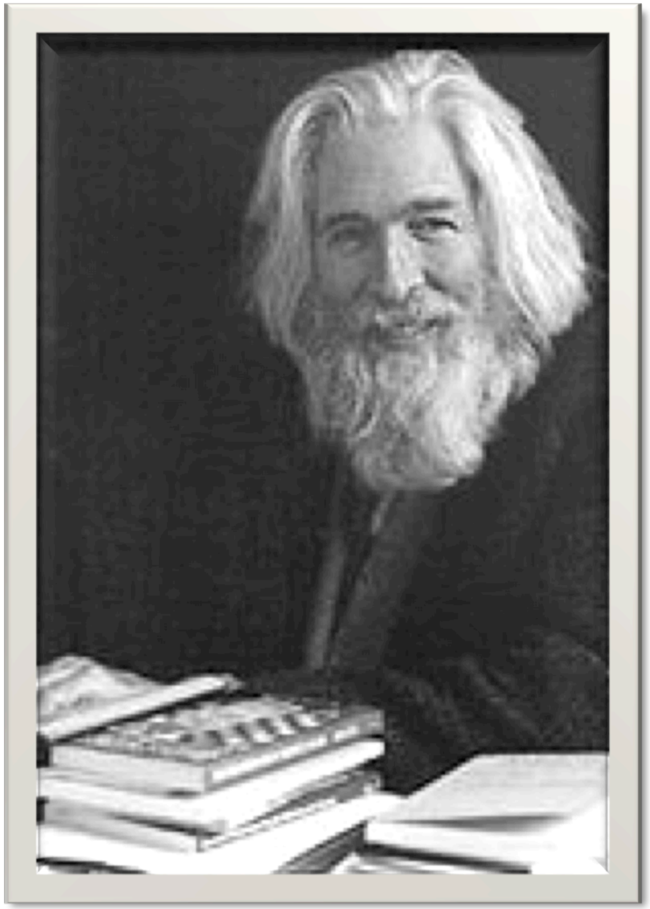
$$\frac{Y/Z \quad (X\backslash Y)/Z}{X/Z}\ <Sx$$

CCG rule schemata (2)

Bluebird

Starling

Thrush



Raymond Smullyan

to mock a mocking bird

CCG parsing

- top-down vs bottom-up
- CYK parsing
  (John Cocke, Daniel Younger, Tadao Kasami)
- worst case running time: cubic on length of input string
  (DCG are exponential)

A	white	rabbit	eats	carrots
0 - 1	0 - 2	0 - 3	0 - 4	0 - 5
	1 - 2	1 - 3	1 - 4	1 - 5
		2 - 3	2 - 4	2 - 5
			3 - 4	3 - 5
				4 - 5

CYK parsing

CYK parsing (S=1)

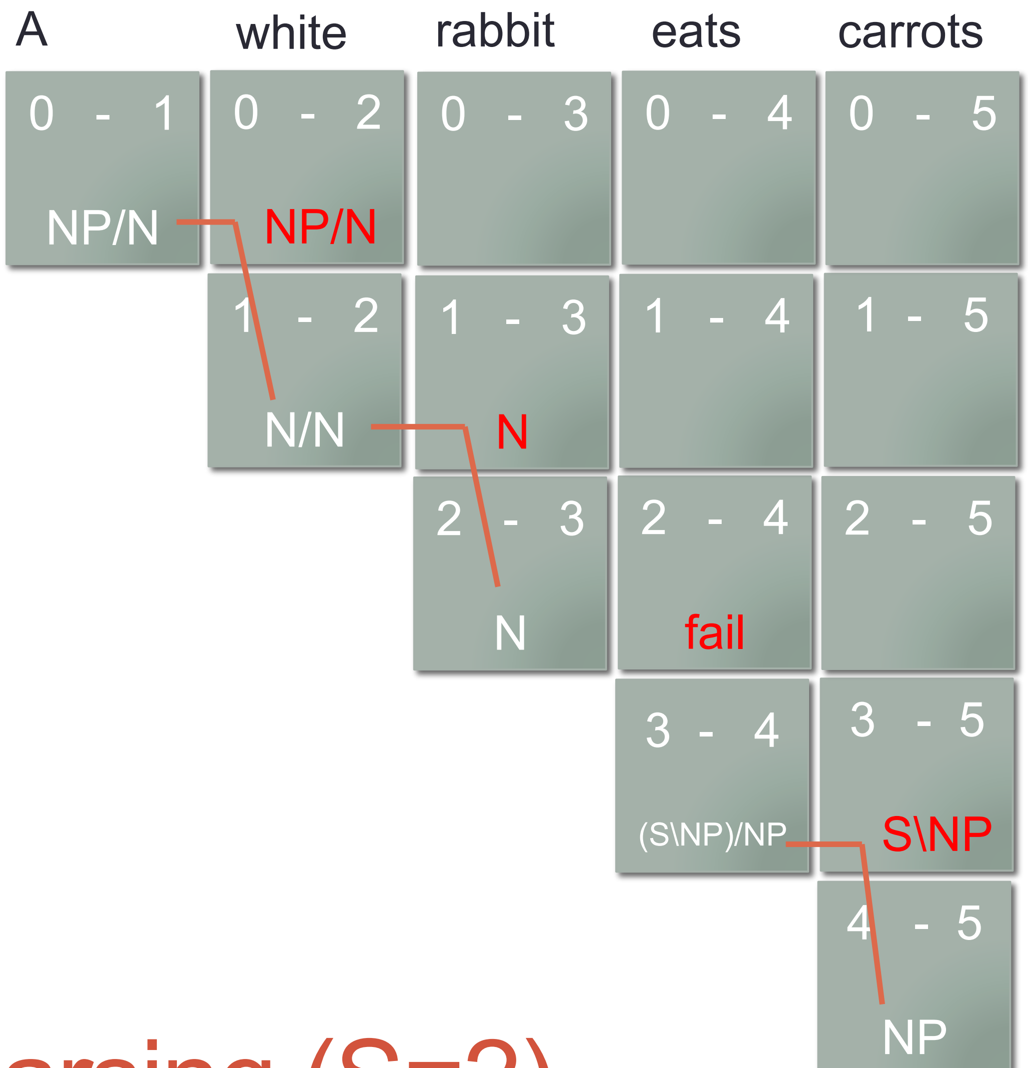
A	white	rabbit	eats	carrots
0 - 1	0 - 2	0 - 3	0 - 4	0 - 5
	1 - 2	1 - 3	1 - 4	1 - 5
		2 - 3	2 - 4	2 - 5
			3 - 4	3 - 5
				4 - 5

A	white	rabbit	eats	carrots
0 - 1 NP/N	0 - 2	0 - 3	0 - 4	0 - 5
	1 - 2 N/N	1 - 3	1 - 4	1 - 5
		2 - 3 N	2 - 4	2 - 5
			3 - 4 (S\NP)/NP	3 - 5
				4 - 5 NP

CYK parsing (S=1)

A	white	rabbit	eats	carrots
0 - 1 NP/N	0 - 2	0 - 3	0 - 4	0 - 5
	1 - 2 N/N	1 - 3	1 - 4	1 - 5
		2 - 3 N	2 - 4	2 - 5
			3 - 4 (S\NP)/NP	3 - 5
				4 - 5 NP

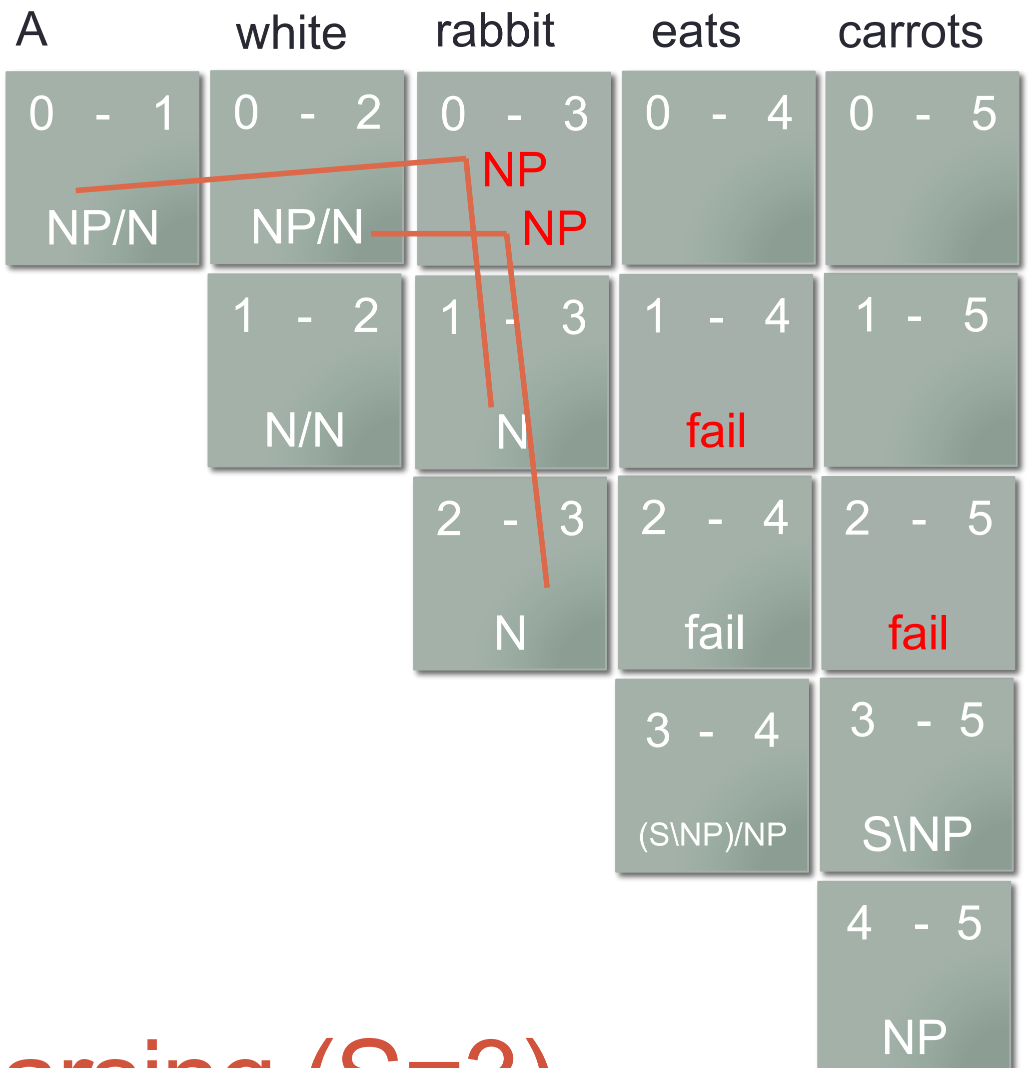
CYK parsing (S=2)



CYK parsing (S=2)

A	white	rabbit	eats	carrots
0 - 1 NP/N	0 - 2 NP/N	0 - 3	0 - 4	0 - 5
	1 - 2 N/N	1 - 3 N	1 - 4	1 - 5
		2 - 3 N	2 - 4 fail	2 - 5
			3 - 4 (S\NP)/NP	3 - 5 S\NP
				4 - 5 NP

CYK parsing (S=3)



CYK parsing (S=3)

A	white	rabbit	eats	carrots
0 - 1 NP/N	0 - 2 NP/N	0 - 3 NP NP	0 - 4	0 - 5
	1 - 2 N/N	1 - 3 N	1 - 4 fail	1 - 5
		2 - 3 N	2 - 4 fail	2 - 5 fail
			3 - 4 (S\NP)/NP	3 - 5 S\NP
				4 - 5 NP

CYK parsing (S=4)

CYK parsing (S=4)

A	white	rabbit	eats	carrots
0 - 1 NP/N	0 - 2 NP/N	0 - 3 NP NP	0 - 4 fail	0 - 5
	1 - 2 N/N	1 - 3 N	1 - 4 fail	1 - 5 fail
		2 - 3 N	2 - 4 fail	2 - 5 fail
			3 - 4 (S\NP)/NP	3 - 5 S\NP
				4 - 5 NP

A	white	rabbit	eats	carrots
0 - 1 NP/N	0 - 2 NP/N	0 - 3 NP NP	0 - 4 fail	0 - 5
	1 - 2 N/N	1 - 3 N	1 - 4 fail	1 - 5 fail
		2 - 3 N	2 - 4 fail	2 - 5 fail
			3 - 4 (S\NP)/NP	3 - 5 S\NP
				4 - 5 NP

CYK parsing (S=5)

A	white	rabbit	eats	carrots
0 - 1 NP/N	0 - 2 NP/N	0 - 3 NP NP	0 - 4 fail	0 - 5 S
	1 - 2 N/N	1 - 3 N	1 - 4 fail	1 - 5 fail
		2 - 3 N	2 - 4 fail	2 - 5 fail
			3 - 4 (S\NP)/NP	3 - 5 S\NP
				4 - 5 NP

CYK parsing (S=5)

Provide CCG analyses

TRUE DESCRIPTIONS

- A white rabbit is eating a carrot.
- A rabbit with a carrot.
- A rabbit is nibbling on a carrot.
- A rabbit holding a carrot in its mouth.
- A carrot is being eaten by a rabbit.

FALSE DESCRIPTIONS

- A rabbit without a carrot.
- A brown rabbit is eating an orange carrot.
- Two rabbits are sharing a carrot.
- A carrot is holding a white rabbit.
- A rabbit with orange flowers.

Category	Partial DRS	Example
N	λx DOG(x)	*dog*
NP/N	λpλq∃x[(p@x)&(q@x)]	*a*
S\NP	λp(p@λyBARK(y))	*barked*

CCG: lexical semantics

$$\frac{X/Y \qquad Y}{X} >$$

$$\frac{Y \qquad X\backslash Y}{X} <$$

Application (> and <)

$$\frac{X/Y:\ \varphi \qquad\qquad Y:\ \psi}{X:\ (\varphi@\psi)}\ >$$

$$\frac{Y:\ \psi \qquad\qquad X\backslash Y:\ \varphi}{X:\ (\varphi@\psi)}\ <$$

Application (> and <)

$$\frac{X/Y \qquad\qquad Y/Z}{X/Z} >B$$

$$\frac{Y\backslash Z \qquad\qquad X\backslash Y}{X\backslash Z} <B$$

Composition (>B and <B)

$$\dfrac{X/Y: \varphi \qquad\qquad Y/Z: \psi}{X/Z: \lambda x.(\varphi@(\psi@x))} >B$$

$$\dfrac{Y\backslash Z: \psi \qquad\qquad X\backslash Y: \varphi}{X\backslash Z: \lambda x.(\varphi@(\psi@x))} <B$$

Composition (>B and <B)

NP/N: **a**　　　　N: **dog**　　　　S\NP: **barked**

---------------------------------- >

NP: **a dog**

-- <

S: **a dog barked**

A simple CCG derivation

NP/N: **a** N: **dog** S\NP: **barked**

$\lambda p\ \lambda q\ \exists x[(p@x)\&(q@x)]$ $\lambda z\ DOG(z)$

------------------------------------ >

NP: **a dog**

-- <

S: **a dog barked**

A simple CCG derivation

NP/N: **a** N: **dog** S\NP: **barked**

$\lambda p\ \lambda q\ \exists x[(p@x)\&(q@x)]$ $\lambda z\ DOG(z)$

\-- >

NP: **a dog**

$\lambda p\ \lambda q\ \exists x[(p@x)\&(q@x)]\ @\ \lambda z\ DOG(z)$

\--- <

S: **a dog barked**

A simple CCG derivation

NP/N: **a** N: **dog** S\NP: **barked**

$\lambda p\ \lambda q\ \exists x[(p@x)\&(q@x)]$ $\lambda z\ DOG(z)$

------------------------------------ >

NP: **a dog**

$\lambda q\ \exists x[(\lambda z\ DOG(z)@x)\&(q@x)]$

--- <

S: **a dog barked**

A simple CCG derivation

NP/N: **a** N: **dog** S\NP: **barked**

$\lambda p\ \lambda q\ \exists x[(p@x)\&(q@x)]$ $\lambda z\ DOG(z)$

-- >

NP: **a dog**

$\lambda q\ \exists x[(\underline{\lambda z\ DOG(z)@x})\&(q@x)]$

-- <

S: **a dog barked**

A simple CCG derivation

NP/N: **a** N: **dog** S\NP: **barked**

λp λq ∃x[(p@x)&(q@x)] λz DOG(z)

-- >

NP: **a dog**

λq ∃x[DOG(x)&(q@x)]

-- <

S: **a dog barked**

A simple CCG derivation

NP/N: **a** N: **dog** S\NP: **barked**

$\lambda p\ \lambda q\ \exists x[(p@x)\&(q@x)]$ $\lambda z\ DOG(z)$ $\lambda y\ BARK(y)$

----------------------------------- >

NP: **a dog**

$\lambda q\ \exists x[DOG(x)\&(q@x)]$

-- <

S: **a dog barked**

A simple CCG derivation

NP/N: **a** N: **dog** S\NP: **barked**

$\lambda p\ \lambda q\ \exists x[(p@x)\&(q@x)]$ $\lambda z\ DOG(z)$ $\lambda p(p@\lambda y\ BARK(y))$

\- >

NP: **a dog**

$\lambda q\ \exists x[DOG(x)\&(q@x)]$

\- <

S: **a dog barked**

$\lambda p(p@\lambda y\ BARK(y))\ @\ \lambda q\ \exists x[DOG(x)\&(q@x)]$

A simple CCG derivation

NP/N: **a** N: **dog** S\NP: **barked**

λp λq ∃x[(p@x)&(q@x)] λz DOG(z) λp(p@λy BARK(y))

------------------------------------ >

NP: **a dog**

λq ∃x[DOG(x)&(q@x)]

-- <

S: **a dog barked**

λp(p@λy BARK(y)) @ λq ∃x[DOG(x)&(q@x)]

A simple CCG derivation

NP/N: **a** N: **dog** S\NP: **barked**

$\lambda p\ \lambda q\ \exists x[(p@x)\&(q@x)]$ $\lambda z\ DOG(z)$ $\lambda p(p@\lambda y\ BARK(y))$

------------------------------------ >

NP: **a dog**

$\lambda q\ \exists x[DOG(x)\ \&\ q@x]$

--- <

S: **a dog barked**

$(\lambda q\ \exists x[DOG(x)\&(q@x)]@\lambda y\ BARK(y))$

A simple CCG derivation

NP/N: **a** N: **dog** S\NP: **barked**

$\lambda p\ \lambda q\ \exists x[(p@x)\&(q@x)]$ $\lambda z\ DOG(z)$ $\lambda p(p@\lambda y\ BARK(y))$

------------------------------------ >

NP: **a dog**

$\lambda q\ \exists x[DOG(x)\&(q@x)]$

--- <

S: **a dog barked**

$\exists x[DOG(x)\&(\lambda y\ BARK(y)@x)]$

A simple CCG derivation

NP/N: **a** N: **dog** S\NP: **barked**

$\lambda p\ \lambda q\ \exists x[(p@x)\&(q@x)]$ $\lambda z\ DOG(z)$ $\lambda p(p@\lambda y\ BARK(y))$

------------------------------------ >

NP: **a dog**

$\lambda q\ \exists x[DOG(x)\ \&\ q@x]$

--- <

S: **a dog barked**

$\exists x[DOG(x)\&BARK(x)]$

A simple CCG derivation

Boxer demo

DirectPoll!

Computational Semantics Quiz

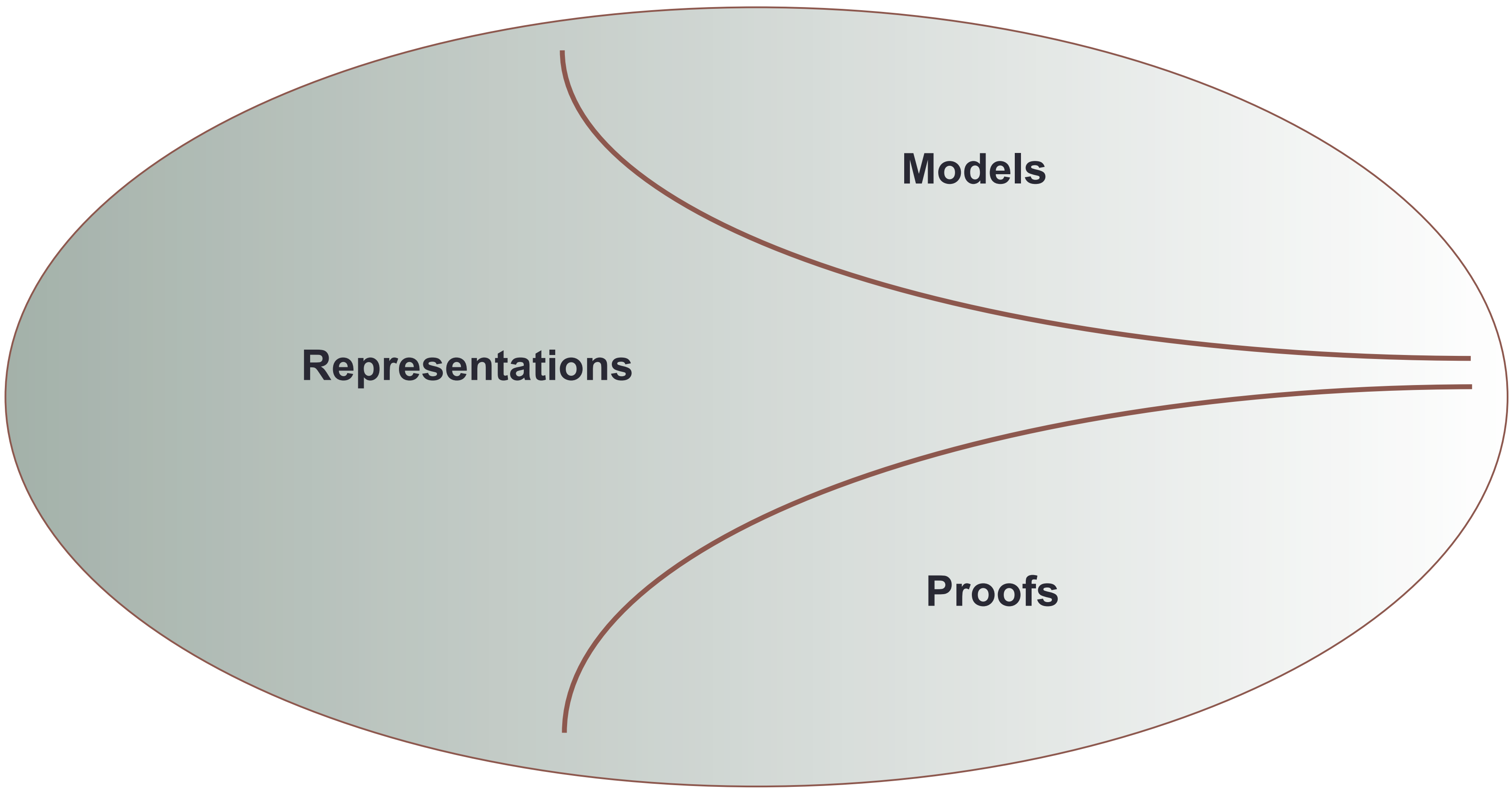
1. What event semantics representation does Boxer use?
   a) Davidsonian
   b) neo-Davidsonian
   c) Hobbsian
2. (λxWALK(x)@vincent) is
   a) a funny email address
   b) a well-formed lambda-expression
   c) a first-order formula
3. The expression (λxLOVES(x,x)@vincent)
   a) can be reduced to LOVES(vincent,vincent)
   b) can be reduced to LOVES(vincent,x)
   c) cannot be reduced

Exercise 2

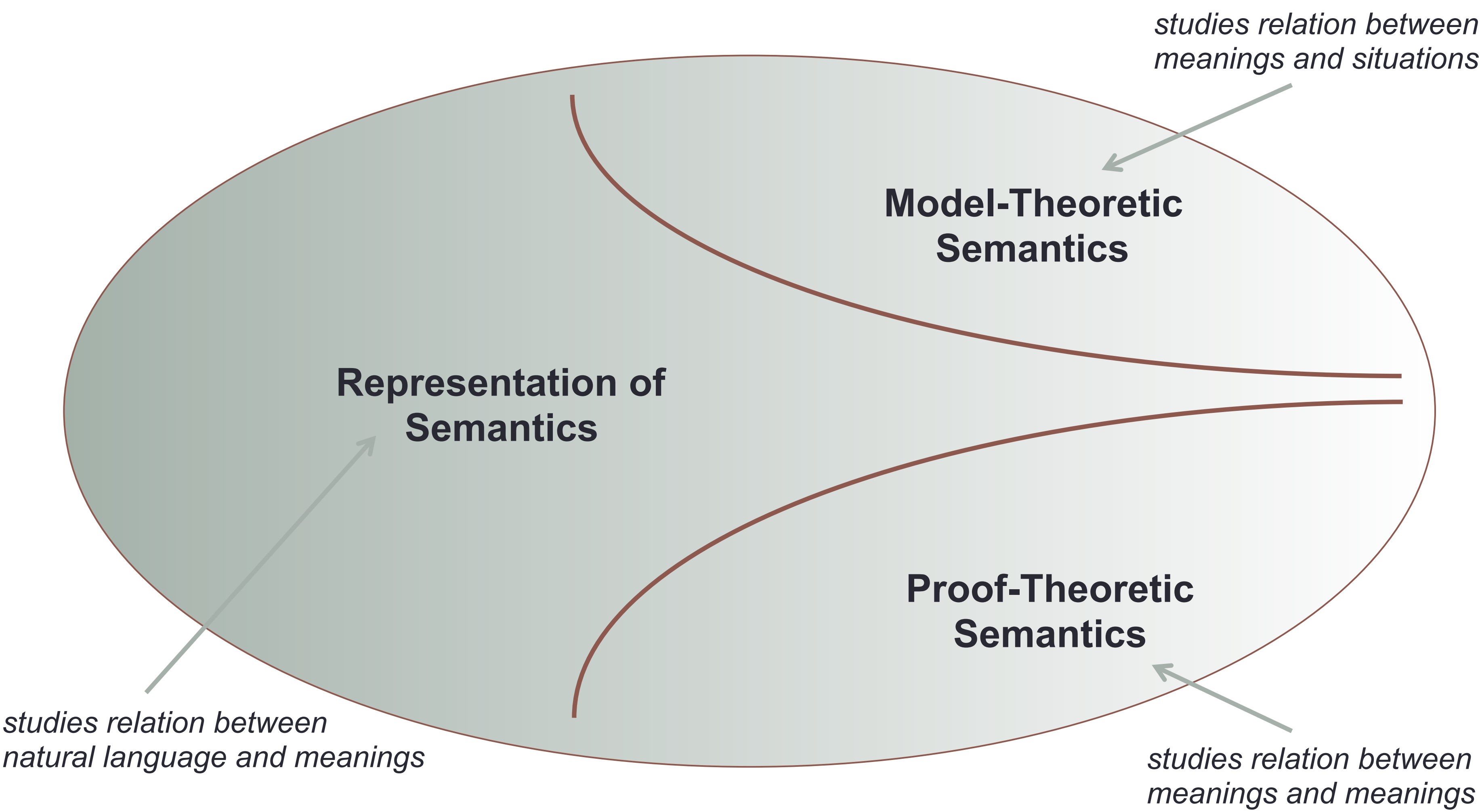
- Look at the natural language statements associated with the images in GRIM
- Pick a frequently occurring verb that is not in the lexicon already
- Specify the lexical semantics of this verb in

  a) no events (pre-Davidsonian)
  b) Davidsonian
  c) neo-Davidsonian
  d) the spatial relations only

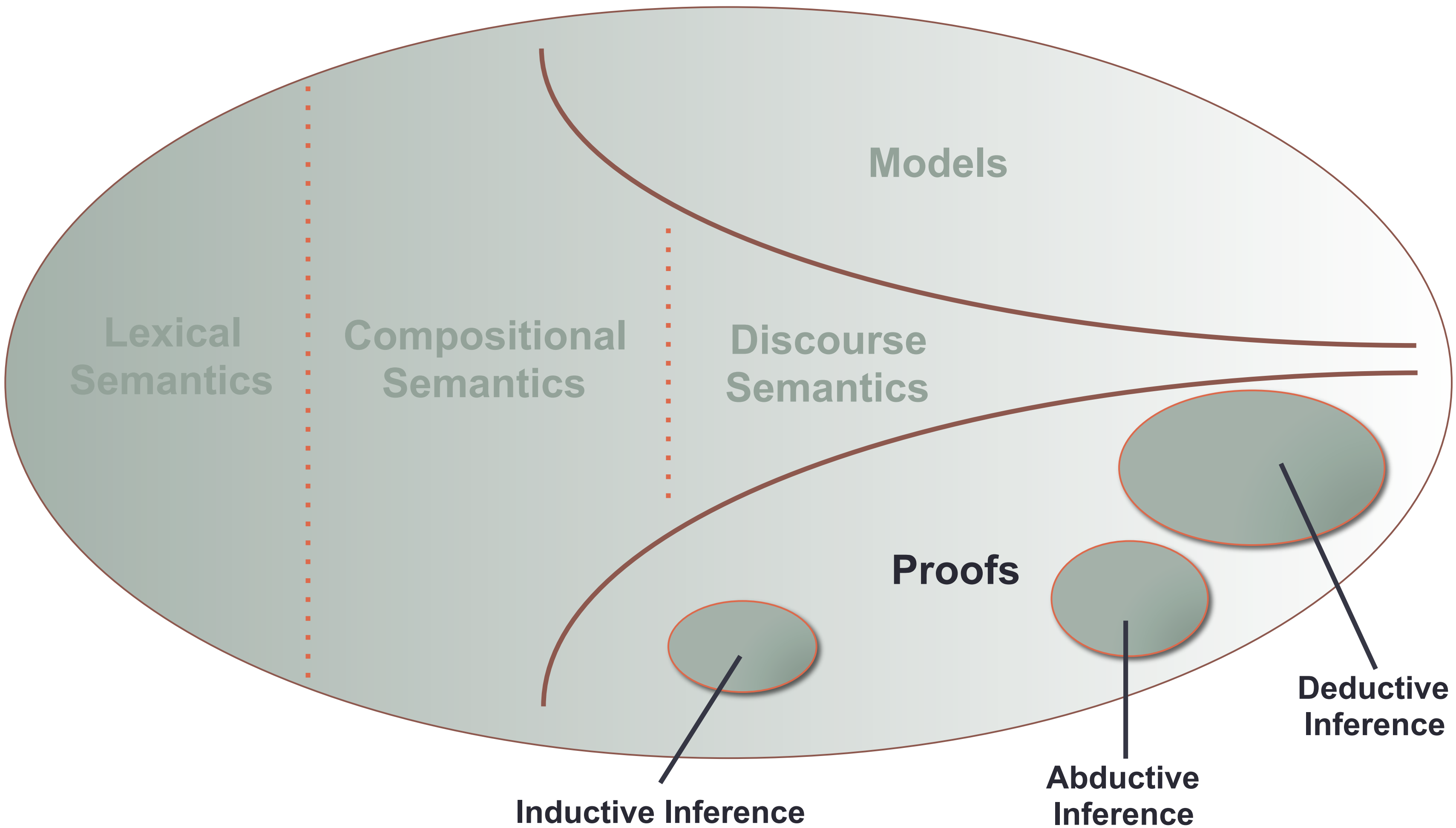
Planet Semantics



Planet Semantics



Proof-Theoretical Semantics



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