ESSLLI 2015 Workshop
Empirical Advances in Categorial Grammar

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Outline

- Brief history of CG
- Introducing papers

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  - In particular, the λ-strand arose from Oehrle's effort to handle the syntax/semantics interface of quantification and quantifier scope ambiguity in a more principled way than in PTQ.
- We want to advance the position that, as has been argued in the case of mathematics, the most enduring and deepest theoretical discoveries are those rooted in the effort to understand and motivate what we observe in the world.

The Lambek development of AB

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We introduce a calculus of types, which is related to the well-known calculus of residuals [ftn: See Garrett Birkhoff, `Lattice Theory`*, New York, 1948]*

—all on the first page of [Lambek, 1958]!

The linguistic turn

> *The aim of this paper is to obtain an effective rule (or algorithm) for distinguishing sentences from nonsentences, which works not only for the formal languages of interest to the mathematical logician , but also for natural languages such as English, or at least for fragments of such languages.*

(p.154)

- So from the outset, TLCG has been consciously designed for NL empirical investigation,
- and the empirical—hence provisional —nature of the analysis is stressed throughout (e.g., ftn. ‡‡ on 155 alluding to Chomsky's insistence on the need for transformational operations in generating sentences).

Lambek's system in action

In general, an expression of type x/y when followed by an expression of type y produces an expression of type x, and so does an expression of type $y\backslash x$ when preceded by an expression of type y. We write symbolically

(1) $(x/y)\ y \rightarrow x, \quad y\ (y\backslash x) \rightarrow x$

$$\dfrac{\dfrac{\texttt{likes};\ (n\backslash s)/n \quad \texttt{Jane};\ n}{\texttt{likes Jane};\ n\backslash s} \quad \texttt{John};\ n}{\texttt{John likes Jane};\ s}$$

- But Lambek also suggests that we can "group" this sentence as

(John	likes)	Jane
n	$(s\backslash n)/n$	n

- There is actually a linguistic argument given for this grouping, though Lambek does not present it immediately.
- But on this basis, Lambek posits a limited form of rebracketability for his (at this point nascent) calculus:

(2) $(x\backslash y)/z \leftrightarrows x\backslash(y/z)$

- Natural language combinatorics contrasts with those for formal systems due to
  - syntactic ambiguity
  - type polymorphism
- The type *n* in particular presents special complexity, since
  - the class of names (*n*) distributes somewhat differently from pronouns (*Poor John works/*Poor he works/*Poor him works*), and
  - nominative and accusative case-marked pronouns themselves have nonoverlapping distributions:

(3) a. He/*Him works

b. He/*Him likes Jane

(4) a. That's him.

b. Jane likes him.

- Lambek proposes as a solution for (3)–(4) the type assignments

(5) a. he: $s/(n\backslash s)$

b. him: $(s/n)\backslash s$

c. John: n, $s/(n\backslash s)$, $(s/n)\backslash s$

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- But this leads to a misprediction:

he	likes	him
$s/(n\backslash s)$	$(\mathrm{n}\backslash \mathrm{s})/\mathrm{n}$	$(s/n)\backslash s$

and $(s/(\mathrm{n}\backslash \mathrm{s}))$ $((\mathrm{n}\backslash \mathrm{s})/n)$ $((s/n)\backslash s)$ "cannot be simplified any further by [(1) and/or (2)]".

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- The solution: a separate rule-pair

(6) $(x/y)\ (y/z) \rightarrow x/z, \quad (x\backslash y)\ (y\backslash z) \rightarrow x\backslash z$

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- . . . and the proof of (6), function composition, and from it the Geach rule, would have been far from obvious to the mathematically largely untrained members of the linguistics field.
- It is likely therefore that the second part of Lambek's paper, which presents his calculus explicitly and explores its proof-theoretic aspects, particularly its relation to the Gentzen sequent calculus for propositional logic, contributed to the disconnection between type-logical ideas and formal linguistics for the next two generations.

The Lambek calculus

(7)

(a) $x \vdash x$

(b) $(xy)z \vdash x(yz)$ (b') $x(yz) \vdash (xy)z$

(c) $\dfrac{xy \vdash z}{x \vdash z/y}$ (c') $\dfrac{xy \vdash z}{y \vdash x\backslash z}$

(d) $\dfrac{x \vdash z/y}{xy \vdash z}$ (d') $\dfrac{y \vdash x\backslash z}{xy \vdash z}$

(e) $\dfrac{x \vdash y \quad y \vdash z}{x \vdash z}$

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- a direct proof of function composition, which Lambek explicitly uses as the basis for the Geach rule, turns out to be rather complex!...
- ...to the extent that Lambek himself does not actually provide it, on grounds that it is excessively "lengthy".
- It turns out that late 1950s linguists who wants to understand why the type $s\backslash s$ entails the type $(np\backslash s)\backslash(np\backslash s)$ have to be able to carry out the following proof for themselves...

Function composition as a Lambek theorem

$$
\dfrac{
  \dfrac{
    \dfrac{
      \dfrac{x\backslash y \vdash x\backslash y\ \text{(a.)} \quad x \vdash x\ \text{(a.)}}{x(x\backslash y) \vdash y}\,\text{(d')}
      \qquad
      \dfrac{
        \dfrac{y\backslash z \vdash y\backslash z\ \text{(a.)} \quad y \vdash y\ \text{(a.)}}{y(y\backslash z) \vdash z}\,\text{(d')}
      }{y \vdash z/(y\backslash z)}\,\text{(c)}
    }{x(x\backslash y) \vdash z/(y\backslash z)}\,\text{(e)}
    \qquad
    y\backslash z \vdash y\backslash z\ \text{(a.)}
  }{
    \dfrac{(x(x\backslash y))(y\backslash z) \vdash z}{x((x\backslash y)(y\backslash z)) \vdash z}\,\text{(b)}
  }\,\text{(d)}
}{x\backslash y\ y\backslash z \vdash x\backslash z}\,\text{(c')}
$$

- and from function composition, $x\backslash y\ y\backslash z \vdash x\backslash z$, we get the Geach rule, $y\backslash z \vdash (x\backslash y)\backslash(x\backslash z)$, via (c'), in one step. . .
- . . . a *lot* of work for ordinary linguists, with the followup discussion (Lambek vs. . Gentzen calculi homologies, Cut theorem uses, etc.) even worse!. . .
- . . . almost certainly contributing to the long obscurity of Lambek's contribution..

Enter CCG: Ades & Steedman 1982 and after

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- This work and later papers by Steedman were widely cited early on, and still are.
- What was the difference between the Lambek Calculus and Steedman's Combinatory Categorial Grammar that accounts for the different response of the field in the two cases?

	Lambek calculus	**CCG**
First appearance	*American Mathematical Monthly*	*Linguistics & Philosophy*
Critical technology	hypothetical reasoning	prepackaged 'combinatory' rules
Linguistic coverage	simple phrasal and clausal data; no semantics	island effects; difficult data with no simple treatment in PS systems(e.g., RNR); compositional semantics

More on critical technology

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  - $X/Y; f \;\; Y; y \Rightarrow X; \; f(y)$
  - $Y: y \; X\backslash Y \,; f \Rightarrow X; \; f(y)$
- Functional Composition:
  - $X/Y \;\; f \;\; Y/Z: g \Rightarrow X/Z: f \circ g$
  - $X\backslash Y: \; f \; \mathrm{Y}\backslash\mathrm{Z}: \; g \Rightarrow X\backslash Z: \; f \circ g$

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  - $X\backslash Y$: f $Y\backslash Z$: $g \Rightarrow X\backslash Z$: $f \circ g$
- Type raising:
  - X; $x \Rightarrow W/(W\backslash X)$: $\lambda f.f(x)$ with $W\backslash X$: f
  - X; $x \Rightarrow W\backslash(W/X)$: $\lambda f.f(x)$ with W/X: f

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- the entailments which in Lambek's system correspond to hypothetical reasoning are now built into 'prepacked' operations such as Functional Composition and Type Raising.
  - The deductive flexibility of the system is corresponding reduced, and hence simplified for the user.
  - But there are costs as well as benefits...

Dependent Cluster Coordination in CCG

CCG rules

Functional Application (FA) $\dfrac{A/B \quad B}{A}$ $\qquad \dfrac{B \quad B\backslash A}{A}$

Functional Composition (FC) $\dfrac{A/B \quad B/C}{A/C}$ $\qquad \dfrac{C\backslash B \quad B\backslash A}{C\backslash A}$

Type Raising ($\Uparrow$) $\dfrac{B}{(A/B)\backslash A}$ $\qquad \dfrac{B}{A/(B\backslash A)}$

Sample lexicon:

John, Chicago, Detroit, Monday, Tuesday: NP
went: VP
to, on: (VP\VP)/NP
and, or: $(\alpha\backslash\alpha)/\alpha$ (with α a variable over all category types)

Derive *John went to Chicago on Monday and Detroit on Tuesday* as follows:

- Begin by type-raising *went* and *Chicago*:

DCC in CCG

$$\dfrac{\dfrac{\text{went}}{\mathrm{VP}}}{\mathrm{VP}/(\mathrm{VP}\backslash\mathrm{VP})}$$

$$\dfrac{\dfrac{\text{Chicago}}{\mathrm{NP}}}{(\mathrm{VP}/\mathrm{NP})\backslash\mathrm{VP}}$$

DCC in CCG

$$\dfrac{\dfrac{\text{went}}{\mathrm{VP}}}{\mathrm{VP}/(\mathrm{VP}\backslash\mathrm{VP})}$$

$$\dfrac{\dfrac{\text{Chicago}}{\mathrm{NP}}}{(\mathrm{VP}/\mathrm{NP})\backslash\mathrm{VP}}$$

- *Went* now takes an adverbial functor as its own argument.

$$\dfrac{\dfrac{\text{went}}{\mathrm{VP}/(\mathrm{VP}\backslash\mathrm{VP})} \quad \dfrac{\text{to}}{(\mathrm{VP}\backslash\mathrm{VP})/\mathrm{NP}}}{\mathrm{VP}/\mathrm{NP}}\,\mathrm{FC}$$

DCC in CCG, cont'd

- Next, derive *Chicago on Monday* as a constituent:

$$\dfrac{\dfrac{\text{Chicago}}{(\mathrm{VP}/\mathrm{NP})\backslash \mathrm{VP}} \qquad \dfrac{\dfrac{\text{on}}{(\mathrm{VP}\backslash \mathrm{VP})/\mathrm{NP}} \quad \dfrac{\text{Monday}}{\mathrm{NP}}}{\mathrm{VP}\backslash \mathrm{VP}}}{(\mathrm{VP}/\mathrm{NP})\backslash \mathrm{VP}}$$

DCC in CCG, cont'd

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- As a constituent, *Chicago on Monday* can be conjoined with *Detroit on Tuesday*, for which a strictly parallel derivation can be given.

$$\dfrac{\dfrac{\text{Chicago on Monday}}{(\mathrm{VP}/\mathrm{NP})\backslash \mathrm{VP}} \quad \dfrac{\dfrac{\text{and}}{(\alpha\backslash\alpha)/\alpha} \quad \dfrac{\text{Detroit on Monday}}{(\mathrm{VP}/\mathrm{NP})\backslash \mathrm{VP}}}{((\mathrm{VP}/\mathrm{NP})\backslash \mathrm{VP})\backslash((\mathrm{VP}/\mathrm{NP})\backslash \mathrm{VP}}}{(\mathrm{VP}/\mathrm{NP})\backslash \mathrm{VP}}$$

DCC in CCG, cont'd.

- This result combines with the category for type-raised *went to*:

$$\dfrac{\dfrac{\text{John}}{\mathrm{NP}} \quad \dfrac{\dfrac{\text{went to}}{\mathrm{VP/NP}} \quad \dfrac{\text{Chicago on Monday and Detroit on Tuesday}}{\mathrm{(VP/NP)\backslash VP}}}{\mathrm{VP}}}{\mathrm{S}}$$

Dependent cluster coordination via Lambek

- Compare the CCG proof with the directness of the Lambek proof:

$\mathtt{chicago}$; NP φ_2; PP/NP

$\varphi_2 \bullet \mathtt{chicago}$; PP φ_1; VP/PP

$\varphi_1 \bullet \varphi_2 \bullet \mathtt{chicago}$; VP $\mathtt{on} \bullet \mathtt{monday}$; VP\VP

$\varphi_1 \bullet \varphi_2 \bullet \mathtt{chicago} \bullet \mathtt{on} \bullet \mathtt{monday}$; VP

$\varphi_2 \bullet \mathtt{chicago} \bullet \mathtt{on} \bullet \mathtt{monday}$; (VP/PP)\VP

$\mathtt{chicago} \bullet \mathtt{on} \bullet \mathtt{monday}$; (PP/NP)\((VP/PP)\VP)

$\vdots \quad \vdots$

$\mathtt{detroit} \bullet \mathtt{on} \bullet \mathtt{tuesday}$; (PP/NP)\((VP/PP)\VP) $\mathtt{and}$; (X\X)/X

$\mathtt{and} \bullet \mathtt{detroit} \bullet \mathtt{on} \bullet \mathtt{tuesday}$; ((PP/NP)\((VP/PP)\VP))\((PP/NP)\((VP/PP)\V

$\mathtt{chicago} \bullet \mathtt{on} \bullet \mathtt{monday} \bullet \mathtt{and} \bullet \mathtt{detroit} \bullet \mathtt{on} \bullet \mathtt{tuesday}$; (PP/NP)\((VP/PP)\VP)

DCC, cont'd

$$
\dfrac{
  \dfrac{
    \dfrac{
      \begin{array}{l}
      \mathtt{chicago} \bullet \mathtt{on} \bullet \mathtt{monday} \bullet \mathtt{and} \bullet \\
      \mathtt{detroit} \bullet \mathtt{on} \bullet \mathtt{tuesday}; \\
      (PP/NP)\backslash((VP/PP)\backslash VP)
      \end{array}
      \qquad
      \begin{array}{l}
      \mathtt{to}; \\
      PP/NP
      \end{array}
    }{
      \begin{array}{l}
      \mathtt{to} \bullet \mathtt{chicago} \bullet \mathtt{on} \bullet \mathtt{monday} \bullet \mathtt{and} \bullet \\
      \mathtt{detroit} \bullet \mathtt{on} \bullet \mathtt{tuesday}; \\
      ((VP/PP)\backslash VP)
      \end{array}
    }
    \qquad \mathtt{went};\ VP/PP
  }{
    \begin{array}{l}
    \mathtt{went} \bullet \mathtt{to} \bullet \mathtt{chicago} \bullet \mathtt{on} \bullet \mathtt{monday} \bullet \mathtt{and} \bullet \\
    \mathtt{detroit} \bullet \mathtt{on} \bullet \mathtt{tuesday}; \\
    VP
    \end{array}
  }
  \qquad \mathtt{john};\ NP
}{
  \mathtt{john} \bullet \mathtt{went} \bullet \mathtt{to} \bullet \mathtt{chicago} \bullet \mathtt{on} \bullet \mathtt{monday} \bullet \mathtt{and} \bullet \mathtt{detroit} \bullet \mathtt{on} \bullet \mathtt{tuesday};\ S
}
$$

Problems for the Lambek calculus

Medial extraction and quantification

(8) a. This is the man that John talked to __ yesterday.

b. Someone introduced everyone to Peter. $(\exists > \forall / \forall > \exists)$

Beyond the Lambek calculus

Earlier attempts:

- [Moortgat, 1990]: three-place q operator
- [Morrill, 1994]: discontinuity operators $\uparrow$, $\downarrow$
- [Moortgat, 1997], [Bernardi, 2002]: structural control in Multi-Modal TLCG
  (incorporated into CCG by [Baldridge, 2002])

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- [Moortgat, 1997], [Bernardi, 2002]: structural control in Multi-Modal TLCG
  (incorporated into CCG by [Baldridge, 2002])

More recent proposals:

- Displacement calculus [Morrill et al., 2011]
- Continuation-based NL_λ [Barker and Shan, 2015]
- Hybrid TLCG [Kubota, 2015, Kubota and Levine, 2015]

Quantification with directional slashes

$\forall > \exists$ for *Someone met everyone*

(9)

$$
\dfrac{
  \dfrac{
    \dfrac{
      \begin{array}{l}\mathtt{someone};\\ \boldsymbol{\exists}_{\mathbf{person}};\\ \mathsf{S}/(\mathsf{NP}\backslash\mathsf{S})\end{array}
      \quad
      \dfrac{\begin{array}{l}\mathtt{met};\\ \mathbf{meet}; (\mathsf{NP}\backslash\mathsf{S})/\mathsf{NP}\end{array} \quad \begin{bmatrix}\varphi_1;\\ x;\mathsf{NP}\end{bmatrix}^1}{\begin{array}{l}\mathtt{met}\bullet\varphi_1;\\ \mathbf{meet}(x);\mathsf{NP}\backslash\mathsf{S}\end{array}}/\mathsf{E}
    }{\begin{array}{l}\mathtt{someone}\bullet\mathtt{met}\bullet\varphi_1;\\ \boldsymbol{\exists}_{\mathbf{person}}(\lambda y.\mathbf{meet}(x)(y));\mathsf{S}\end{array}}\backslash\mathsf{E}
  }{\begin{array}{l}\mathtt{someone}\bullet\mathtt{met};\\ \lambda x.\boldsymbol{\exists}_{\mathbf{person}}(\lambda y.\mathbf{meet}(x)(y));\mathsf{S}/\mathsf{NP}\end{array}}/\mathsf{I}^1
  \quad
  \begin{array}{l}\mathtt{everyone};\\ \boldsymbol{\forall}_{\mathbf{person}};\\ (\mathsf{S}/\mathsf{NP})\backslash\mathsf{S}\end{array}
}{\begin{array}{l}\mathtt{someone}\bullet\mathtt{met}\bullet\mathtt{everyone};\\ \boldsymbol{\forall}_{\mathbf{person}}(\lambda x.\boldsymbol{\exists}_{\mathbf{person}}(\lambda y.\mathbf{meet}(x)(y)));\mathsf{S}\end{array}}\backslash\mathsf{E}
$$

Quantification with directional slashes

$\exists > \forall$ for *Someone met everyone*

(10)

$$
\dfrac{
\begin{matrix}\mathtt{someone};\\ \boldsymbol{\exists}_{\mathbf{person}};\\ \mathsf{S/(NP\backslash S)}\end{matrix}
\qquad
\dfrac{
\dfrac{
\dfrac{
\dfrac{
\begin{bmatrix}\varphi_2;\\ y;\mathsf{NP}\end{bmatrix}^2
\quad
\dfrac{
\begin{matrix}\mathtt{met};\\ \mathbf{meet};\mathsf{(NP\backslash S)/NP}\end{matrix}
\quad
\begin{bmatrix}\varphi_1;\\ x;\mathsf{NP}\end{bmatrix}^1
}{
\mathtt{met}\bullet\varphi_1;\ \mathbf{meet}(x);\ \mathsf{NP\backslash S}
}\,/\mathsf{E}
}{
\varphi_2\bullet\mathtt{met}\bullet\varphi_1;\ \mathbf{meet}(x)(y);\ \mathsf{S}
}\,\backslash\mathsf{E}
}{
\varphi_2\bullet\mathtt{met};\ \lambda x.\mathbf{meet}(x)(y);\ \mathsf{S/NP}
}\,/\mathsf{I}^1
\quad
\begin{matrix}\mathtt{everyone};\\ \boldsymbol{\forall}_{\mathbf{person}};\\ \mathsf{(S/NP)\backslash S}\end{matrix}
}{
\begin{matrix}\varphi_2\bullet\mathtt{met}\bullet\mathtt{everyone};\\ \boldsymbol{\forall}_{\mathbf{person}}(\lambda x.\mathbf{meet}(x)(y));\mathsf{S}\end{matrix}
}\,\backslash\mathsf{E}
}{
\begin{matrix}\mathtt{met}\bullet\mathtt{everyone};\\ \lambda y.\boldsymbol{\forall}_{\mathbf{person}}(\lambda x.\mathbf{meet}(x)(y));\mathsf{NP\backslash S}\end{matrix}
}\,\backslash\mathsf{I}^2
}{
\begin{matrix}\mathtt{someone}\bullet\mathtt{met}\bullet\mathtt{everyone};\\ \boldsymbol{\exists}_{\mathbf{person}}(\lambda y.\boldsymbol{\forall}_{\mathbf{person}}(\lambda x.\mathbf{meet}(x)(y)));\mathsf{S}\end{matrix}
}\,/\mathsf{E}
$$

Scoping out from a medial position

(11) Someone (or other) introduced everyone to Peter.

Failed derivation for the $\forall > \exists$ reading for (11):

(12)

$$
\dfrac{
\dfrac{
\begin{array}{l}\texttt{someone};\\ \mathbf{\exists}_{\mathbf{person}};\\ \mathsf{S/(NP\backslash S)}\end{array}
\quad
\dfrac{\vdots\ \vdots \quad \begin{bmatrix}\varphi;\\ x;\mathsf{NP}\end{bmatrix}^1 \quad \vdots\ \vdots}{\begin{array}{l}\texttt{introduced} \bullet \varphi_1 \bullet \texttt{to} \bullet \texttt{peter};\\ \lambda y.\mathbf{intro}(\mathbf{p})(x)(y);\mathsf{NP\backslash S}\end{array}}
}{
\begin{array}{l}\texttt{someone} \bullet \texttt{introduced} \bullet \varphi_1 \bullet \texttt{to} \bullet \texttt{peter};\\ \mathbf{\exists}_{\mathbf{person}}(\lambda y.\mathbf{intro}(\mathbf{p})(x)(y));\mathsf{S}\end{array}
}/\mathsf{E}
}{
\begin{array}{l}???;\\ \lambda x.\mathbf{\exists}_{\mathbf{person}}(\lambda y.\mathbf{intro}(\mathbf{p})(x)(y));\color{red}{\mathsf{S/NP}}\end{array}
}/\mathsf{I}^1
\qquad
\begin{array}{l}\texttt{everyone};\\ \mathbf{\forall}_{\mathbf{person}};(\color{red}{\mathsf{S/NP}})\mathsf{\backslash S}\end{array}
$$

A solution for the medial extraction/quantification problem

Linear Categorial Grammars

- [Oehrle, 1994]: 'term labelled' categorial grammar
- [de Groote, 2001]: Abstract Categorial Grammar
- [Muskens, 2003]: Lambda Grammar
- [Pollard, 2013]: Linear Categorial Grammar

Note:

- perhaps debatable to what extent these authors proposed the respective frameworks as linguistic theories,
- but all these authors take the simple treatment of quantification as the distinct advantage of their approaches

A solution for the medial extraction/quantification problem (cont.)

Basic idea:

(Due to [Dowty, 1982, Dowty, 1996])

- Separate combinatoric structure ('tectogrammar') from surface word order ('phenogrammar').
- Relegate directionality from tectogrammar to phenogrammar.

A solution for the medial extraction/quantification problem (cont.)

Basic idea:
(Due to [Dowty, 1982, Dowty, 1996])

- Separate combinatoric structure ('tectogrammar') from surface word order ('phenogrammar').
- Relegate directionality from tectogrammar to phenogrammar.

Technical implementation:
Innovation due to [Oehrle, 1994]

- Model linguistic expressions as tripartite signs:
  $\langle$ PHON ; SEM ; CAT $\rangle$
- Model both the semantics and the phonology of linguistic expressions in terms of the lambda calculus.

Sample LCG derivation

(13)

$$
\dfrac{
  \dfrac{
    \dfrac{
      \begin{array}{l}\texttt{john};\\ \mathbf{j}; \mathsf{NP}\end{array}
      \quad
      \dfrac{
        \begin{array}{l}\lambda\varphi_1\lambda\varphi_2.\varphi_2 \bullet \texttt{saw} \bullet \varphi_1;\\ \mathbf{saw}; \mathsf{S}{\upharpoonright}\mathsf{NP}{\upharpoonright}\mathsf{NP}\end{array}
        \qquad
        [\varphi; x; \mathsf{NP}]^1
      }{
        \lambda\varphi_2.\varphi_2 \bullet \texttt{saw} \bullet \varphi;\ \mathbf{saw}(x);\ \mathsf{S}{\upharpoonright}\mathsf{NP}
      }{\upharpoonright}\mathsf{E}
    }{
      \texttt{john} \bullet \texttt{saw} \bullet \varphi;\ \mathbf{saw}(x)(\mathbf{j});\ \mathsf{S}
    }{\upharpoonright}\mathsf{E}
  }{
    \lambda\varphi.\texttt{john} \bullet \texttt{saw} \bullet \varphi;\ \lambda x.\mathbf{saw}(x)(\mathbf{j});\ \mathsf{S}{\upharpoonright}\mathsf{NP}
  }{\upharpoonright}\mathsf{I}^1
  \qquad
  \begin{array}{l}\texttt{mary};\\ \mathbf{m}; \mathsf{NP}\end{array}
}{
  \texttt{john} \bullet \texttt{saw} \bullet \texttt{mary};\ \mathbf{saw}(\mathbf{m})(\mathbf{j});\ \mathsf{S}
}{\upharpoonright}\mathsf{E}
$$

Quantification in LCG

(14)

$$\dfrac{\begin{array}{l}\lambda\sigma.\sigma(\mathtt{everyone});\\ \mathbf{V_{person}};\\ \mathsf{S}{\upharpoonright}(\mathsf{S}{\upharpoonright}\mathsf{NP})\end{array} \quad \dfrac{\dfrac{\begin{array}{l}\lambda\sigma.\sigma(\mathtt{someone});\\ \mathbf{\exists_{person}};\\ \mathsf{S}{\upharpoonright}(\mathsf{S}{\upharpoonright}\mathsf{NP})\end{array} \quad \dfrac{\dfrac{\dfrac{\begin{bmatrix}\varphi_2;\\ x_2;\\ \mathsf{NP}\end{bmatrix}^2 \quad \dfrac{\begin{array}{l}\lambda\varphi_1\lambda\varphi_2.\\ \varphi_2\bullet\mathtt{met}\bullet\varphi_1;\\ \mathbf{met};\mathsf{S}{\upharpoonright}\mathsf{NP}{\upharpoonright}\mathsf{NP}\end{array} \quad \begin{bmatrix}\varphi_1;\\ x_1;\\ \mathsf{NP}\end{bmatrix}^1}{\begin{array}{l}\lambda\varphi_2.\varphi_2\bullet\mathtt{met}\bullet\varphi_1;\\ \mathbf{met}(x_1);\mathsf{S}{\upharpoonright}\mathsf{NP}\end{array}}{\upharpoonright}\mathsf{E}}{\varphi_2\bullet\mathtt{met}\bullet\varphi_1;\ \mathbf{met}(x_1)(x_2);\ \mathsf{S}}{\upharpoonright}\mathsf{E} \quad \begin{array}{l}\lambda\varphi.\varphi\bullet\\ \mathtt{today};\\ \mathbf{tdy};\mathsf{S}{\upharpoonright}\mathsf{S}\end{array}}{\dfrac{\begin{array}{l}\varphi_2\bullet\mathtt{met}\bullet\varphi_1\bullet\mathtt{today};\\ \mathbf{tdy}(\mathbf{met}(x_1)(x_2));\mathsf{S}\end{array}}{\begin{array}{l}\lambda\varphi_2.\varphi_2\bullet\mathtt{met}\bullet\varphi_1\bullet\mathtt{today};\\ \lambda x_2.\mathbf{tdy}(\mathbf{met}(x_1)(x_2));\mathsf{S}{\upharpoonright}\mathsf{NP}\end{array}}{\upharpoonright}\mathsf{I}^2}{\upharpoonright}\mathsf{E}}{\dfrac{\begin{array}{l}\mathtt{someone}\bullet\mathtt{met}\bullet\varphi_1\bullet\mathtt{today};\\ \mathbf{\exists_{person}}(\lambda x_2.\mathbf{tdy}(\mathbf{met}(x_1)(x_2)));\mathsf{S}\end{array}}{\begin{array}{l}\lambda\varphi_1.\mathtt{someone}\bullet\mathtt{met}\bullet\varphi_1\bullet\mathtt{today};\\ \lambda x_1.\mathbf{\exists_{person}}(\lambda x_2.\mathbf{tdy}(\mathbf{met}(x_1)(x_2)));\mathsf{S}{\upharpoonright}\mathsf{NP}\end{array}}{\upharpoonright}\mathsf{I}^1}{\upharpoonright}\mathsf{E}}{\begin{array}{l}\mathtt{someone}\bullet\mathtt{met}\bullet\mathtt{everyone}\bullet\mathtt{today};\\ \mathbf{V_{person}}(\lambda x_1.\mathbf{\exists_{person}}(\lambda x_2.\mathbf{tdy}(\mathbf{met}(x_1)(x_2))));\mathsf{S}\end{array}}{\upharpoonright}\mathsf{E}$$

Problems for LCGs

[Kubota, 2010, Kubota and Levine, 2015, Moot, 2014]

Coordination

(15) a. John **walks** and **talks**.

b. John **bought** and **ate** the fish.

(16) John sent [Sandy a letter] and [Jane a postcard].

(17) [John bought], and [Sandy sold], some very expensive books.

An attempt

Coordination of $\mathbf{st} \to \mathbf{st}$ functions:

(18) $\lambda\varphi.\varphi \bullet \mathtt{walks};\ \mathbf{walk};\ \mathsf{S}{\upharpoonright}\mathsf{NP}$
$\lambda\varphi.\varphi \bullet \mathtt{talks};\ \mathbf{talk};\ \mathsf{S}{\upharpoonright}\mathsf{NP}$

(19) $\lambda\sigma_1\lambda\sigma_2\lambda\varphi.\varphi \bullet \sigma_1(\varepsilon) \bullet \mathsf{and} \bullet \sigma_2(\varepsilon);\ \lambda P \lambda Q.P \sqcap Q;$
$(\mathsf{S}{\upharpoonright}\mathsf{NP}){\upharpoonright}(\mathsf{S}{\upharpoonright}\mathsf{NP}){\upharpoonright}(\mathsf{S}{\upharpoonright}\mathsf{NP})$

(20)

$$\dfrac{\dfrac{\begin{matrix}\lambda\varphi.\varphi \bullet \mathtt{walks}; \\ \mathbf{walk}; \mathsf{S}{\upharpoonright}\mathsf{NP}\end{matrix} \quad \begin{matrix}\lambda\sigma_1\lambda\sigma_2\lambda\varphi.\varphi \bullet \sigma_1(\varepsilon) \bullet \mathsf{and} \bullet \sigma_2(\varepsilon); \\ \lambda P \lambda Q.P \sqcap Q; \\ (\mathsf{S}{\upharpoonright}\mathsf{NP}){\upharpoonright}(\mathsf{S}{\upharpoonright}\mathsf{NP}){\upharpoonright}(\mathsf{S}{\upharpoonright}\mathsf{NP})\end{matrix}}{\begin{matrix}\lambda\sigma_2\lambda\varphi.\varphi \bullet \mathtt{walks} \bullet \mathsf{and} \bullet \sigma_2(\varepsilon); \\ \lambda Q.\mathbf{walk} \sqcap Q; \\ (\mathsf{S}{\upharpoonright}\mathsf{NP}){\upharpoonright}(\mathsf{S}{\upharpoonright}\mathsf{NP})\end{matrix}} \quad \begin{matrix}\lambda\varphi.\varphi \bullet \mathtt{talks}; \\ \mathbf{talk}; \mathsf{S}{\upharpoonright}\mathsf{NP}\end{matrix}}{\lambda\varphi.\varphi \bullet \mathtt{walks} \bullet \mathsf{and} \bullet \mathtt{talks};\ \mathbf{walk} \sqcap \mathbf{talk};\ \mathsf{S}{\upharpoonright}\mathsf{NP}}$$

An attempt (cont.)

(21)

$$
\cfrac{
  \cfrac{
    \begin{array}{c}\texttt{sandy};\\ \mathbf{s}; \mathsf{NP}\end{array}
    \qquad
    \cfrac{
      \begin{array}{l}\lambda\varphi_1\lambda\varphi_2.\varphi_2 \bullet \texttt{met} \bullet \varphi_1;\\ \mathbf{meet}; (\mathsf{S}{\upharpoonright}\mathsf{NP}){\upharpoonright}\mathsf{NP}\end{array}
      \quad
      \begin{bmatrix}\varphi_1;\\ x; \mathsf{NP}\end{bmatrix}^1
    }{
      \begin{array}{l}\lambda\varphi_2.\varphi_2 \bullet \texttt{met} \bullet \varphi_1;\\ \mathbf{meet}(x); \mathsf{S}{\upharpoonright}\mathsf{NP}\end{array}
    }{\upharpoonright}\mathsf{E}
  }{
    \texttt{sandy} \bullet \texttt{met} \bullet \varphi_1;\ \mathbf{meet}(x)(\mathbf{s});\ \mathsf{S}
  }{\upharpoonright}\mathsf{E}
}{
  \lambda\varphi_1.\texttt{sandy} \bullet \texttt{met} \bullet \varphi_1;\ \lambda x.\mathbf{meet}(x)(\mathbf{s});\ \mathsf{S}{\upharpoonright}\mathsf{NP}
}{\upharpoonright}\mathsf{I}^1
$$

(22) *John [[walks] and [Sandy met __]].

(23) *[[Sandy met] and [walks]] John.

(24) *John bought and ate the fish.
‘John bought the fish and the fish ate John.’

‘Hybrid’ TLGs

Contemporary variants of TLG all recognize different types of implicational connectives. Especially, to cope with the tension between medial quantification/extraction and coordination, they all posit different ‘modes of reasoning’.

- Displacement calculus [Morrill et al., 2011]
- Continuation-based NL_λ [Barker and Shan, 2015]
- Hybrid TLCG [Kubota, 2015, Kubota and Levine, 2015]

Coordination and quantification in Hybrid TLCG

(25)

$$\vdots \quad \vdots$$

$\left[\begin{array}{l}\varphi_3;\\ x;\\ \mathsf{NP}\end{array}\right]^3$ to • robin • on • thursday • and • to • leslie • on • friday; $\lambda x \lambda P \lambda z.\mathbf{onFr}(P(x)(\mathbf{l}))(z) \wedge \mathbf{onTh}(P(x)(\mathbf{r}))(z)$; $\mathsf{NP\backslash(VP/PP/NP)\backslash VP}$

——— $\backslash$E

φ_3 • to • robin • on • thursday • and • to • leslie • on • friday; $\lambda P \lambda z.\mathbf{onFr}(P(x)(\mathbf{l}))(z) \wedge \mathbf{onTh}(P(x)(\mathbf{r}))(z)$; $\mathsf{(VP/PP/NP)\backslash VP}$

gave; $\mathbf{give}$; $\mathsf{VP/NP/PP}$

——— $\backslash$E

gave • φ_3 • to • robin • on • thursday • and • to • leslie • on • friday; $\lambda z.\mathbf{onFr}(\mathbf{give}(x)(\mathbf{l}))(z) \wedge \mathbf{onTh}(\mathbf{give}(x)(\mathbf{r}))(z)$; VP

terry; $\mathbf{t}$; NP

——— $\backslash$E

terry • gave • φ_3 • to • robin • on • thursday • and • to • leslie • on • friday; $\mathbf{onFr}(\mathbf{give}(x)(\mathbf{l}))(\mathbf{t}) \wedge \mathbf{onTh}(\mathbf{give}(x)(\mathbf{r}))(\mathbf{t})$; S

——— $\upharpoonright$I^3

$\lambda\varphi_3$.terry • gave • φ_3 • to • robin • on • thursday • and • to • leslie • on • friday; $\lambda x.\mathbf{onFr}(\mathbf{give}(x)(\mathbf{l}))(\mathbf{t}) \wedge \mathbf{onTh}(\mathbf{give}(x)(\mathbf{r}))(\mathbf{t})$; $\mathsf{S\upharpoonright NP}$

$\lambda\sigma.\sigma$(a • present); $\exists_{\mathbf{pr}}$; $\mathsf{S\upharpoonright(S\upharpoonright NP)}$

——— $\upharpoonright$E

terry • gave • a • present • to • robin • on • thursday • and • to • leslie • on • friday; $\exists_{\mathbf{pr}}(\lambda x.\mathbf{onFr}(\mathbf{give}(x)(\mathbf{l}))(\mathbf{t}) \wedge \mathbf{onTh}(\mathbf{give}(x)(\mathbf{r}))(\mathbf{t}))$; S

Developments in compositional dynamic semantics

Earlier work

Attempts at making dynamic semantics compositional:
[Groenendijk and Stokhof, 1990, Groenendijk and Stokhof, 1991],
[Muskens, 1996]

Developments in compositional dynamic semantics

Earlier work

Attempts at making dynamic semantics compositional: [Groenendijk and Stokhof, 1990, Groenendijk and Stokhof, 1991], [Muskens, 1996]

More recent proposals

- Dynamic Categorial Grammar [Martin, 2013, Martin, 2015, Martin and Pollard, 2014]
- Dependent Type Semantics [Bekki, 2014, Tanaka et al., 2014] (cf. also [Bekki and Satoh, 2015] and [Tanaka et al., 2015] from the workshop 'Lexical semantics and type theory' last week)
- Monad-based approach ([Charlow, 2014]; cf. also Chris Barker and Dylan Bumford's course 'Monads and natural language' from last week)

Developments in compositional dynamic semantics (cont.)

DyCG and DTS both employ Dependent Type Theory for making explicit the interface between sentence-internal compositional semantics and the dynamic, context-update effect of dynamic semantics.

Some ongoing results:

- A possibly more explanatory and simpler account of the semantics of (certain) CIs [Martin, 2015]
- A possibly more explanatory account of the accessibility relation for anaphora resolution in donkey anaphora, modal subordination, etc. [Bekki, 2014, Tanaka et al., 2014]

Papers

CCG and word order:

- Daisuke Bekki: Two types of Japanese scrambling in combinatory categorial grammar
- Alexander Warstadt: Right-Node Wrapping: A combinatory account

Coordination in LCG:

- Carl Pollard and Chris Worth: Coordination in Linear Categorial Grammar with Phenogrammatical Subtyping
- Makoto Kanazawa: Syntactic Features for Regular Constraints and an Approximation of Directional Slashes in Abstract Categorial Grammars

Compositional (dynamic) semantics:

- Scott Martin: A Unidimensional Syntax-Semantics Interface for Supplements
- Manjuan Duan: A Categorial Analysis of Chinese Alternative Questions
- Oleg Kiselyov: Compositional semantics of *same*, *different*, *total*

Type-Logical Grammar and grammar comparison:

- Glyn Morrill and Oriol Valentín: Computational Empirical Coverage of TLG including Non-Linear Categorial Grammar
- Richard Moot: Comparing and evaluating extended Lambek calculus

CCG and word order (Tuesday, 8/11)

Word order in CCG: [Ades and Steedman, 1982] on long-distance dependencies, [Steedman, 1985] on cross-serial dependencies, etc.

Daisuke Bekki: *Two types of Japanese scrambling in CCG*

- Argues that two types of scrambling constructions in Japanese are adequately modelled by two types of combinators in CCG, one standard (**Bx**) and one novel (**CB**).

Alexander Warstadt: *Right-Node Wrapping: A combinatory account*

- Proposes an account of a type of right-node raising construction called 'Right-Node Wrapping' [Whitman, 2009] within an extended variant of CCG that recognizes a limited amount of discontinuity via 'wrapping' rules.

(26) John should <u>fetch</u> and <u>give</u> **the book** *to Mary*.

Question: Should 'combinatory' rules be viewed as axioms (as in CCG) or theorems (as in TLG)?

Coordination in LCG (Thursday, 8/12)

These papers are direct responses to the point made above that (simple) LCGs do not offer an adequate analysis of coordination.

Carl Pollard and Chris Worth: *Coordination in Linear Categorial Grammar with Phenogrammatical Subtyping*

- Proposes to deal with the coordination problem by subtyping the linear implication in the prosodic domain

Makoto Kanazawa: *Syntactic Features for Regular Constraints and an Approximation of Directional Slashes in Abstract Categorial Grammars*

- Proposes to simulate the directional slashes in the Lambek calculus in ACG via regular constraints implemented as syntactic features

Question: Should the left/right distinction encoded in Lambek's directional slashes be treated as a fundamental primitive distinction in the (combinatoric component of) grammar?

Compositional (dynamic) semantics (Wed, 8/13; Fri, 8/14)

Scott Martin: *A Unidimensional Syntax-Semantics Interface for Supplements*

- Argues for an analysis of supplements (such as appositives in the sense of [Potts, 2005]) in a unidimensional architecture of semantics.

Manjuan Duan: *A Categorial Analysis of Chinese Alternative Questions*

- Proposes an analysis of alternative questions (*Do you like coffee* ↑ *or tea* ↓*?*) in LCG.

Oleg Kiselyov: *Compositional semantics of* same, different, total

- Argues for an analysis of symmetrical predicates and related expressions as existential quantifiers over choice functions that scope *wider than* (rather than parasitically to; cf. [Barker, 2007]) universal quantifiers.

Question: What is the right architecture of the syntax-semantics interface?

TLG and grammar comparison (Mon, 8/10; Fri, 8/14)

Glyn Morrill and Oriol Valentín: *Computational Empirical Coverage of TLG including Non-Linear Categorial Grammar*

- Describes an implementation of TLG (a version of the Displacement Calculus [Morrill et al., 2011]) which covers a range of empirical phenomena pertaining to discontinuous constituency.

Richard Moot: *Comparing and evaluating extended Lambek calculus*

- Proposes two general methods for comparing related approaches in TLG: proof nets and first-order linear logic.

Question:

- What's the form of the 'ultimate' grammar?
- Do we converge or not?

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