Type-Logical Grammar and Natural Language Syntax

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Outline

Overview of **Hybrid Type-Logical Grammar**
[Kubota, 2010, Kubota and Levine, 2015]

- A version of Type-Logical Grammar jointly developed with Bob Levine (OSU)

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- Motivations
- Basic architecture
- Linguistic application – Gapping in English

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Outline of presentation

- Motivations
- Basic architecture
- Linguistic application – Gapping in English
- Larger issues, open questions
  - Comparison with some recent HPSG work
  - Formal properties of Hybrid TLG
  - Parsing

Hybrid Type-Logical Grammar [Kubota, 2010, Kubota and Levine, 2015]

Motivations:

- Logic-based version of CG
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- Wide empirical coverage

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  'Get rid of word order from syntax'

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	local combinatorics (e.g. coordination)	non-local dependencies (e.g. extraction, scope)
Lambek calculus	✓	*
λ grammars	*	✓

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- Hybrid TLG $\approx$ Lambek calculus + λ grammar

Hybrid Type-Logical Grammar [Kubota, 2010, Kubota and Levine, 2015]

Empirical results:

- **coordination**
  - nonconstituent coordination [Kubota and Levine, 2015]
  - Gapping [Kubota and Levine, 2016a]
- **scopal operators** (*same*/*different*, *respectively*) [Kubota and Levine, 2016b]
- **ellipsis**
  - pseudogapping [Kubota and Levine, 2017]
  - stripping [Puthawala, 2018]
  - comparatives [Vaikšnoraitė, 2018]

Lambek calculus

Syntactic types

- $\mathcal{A} := \{$ N, NP, S, $\ldots \}$ (atomic type)
- $\mathcal{T} := \mathcal{A} \mid \mathcal{T}\backslash\mathcal{T} \mid \mathcal{T}/\mathcal{T}$ (type)

Lambek calculus

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Syntactic rules of the Lambek calculus

Forward Slash Elimination

$$\frac{A/B \qquad B}{A}\ /\mathsf{E}$$

Backward Slash Elimination

$$\frac{B \qquad B\backslash A}{A}\ \backslash\mathsf{E}$$

Forward Slash Introduction

$$\frac{\begin{array}{c}\vdots \\ \vdots\end{array} \quad \begin{array}{c}[A]^n \\ \hline \vdots\end{array}}{\dfrac{B}{B/A}\ /\mathsf{I}^n}$$

Backward Slash Introduction

$$\frac{\begin{array}{c}[A]^n \\ \hline \vdots\end{array} \quad \begin{array}{c}\vdots \\ \vdots\end{array}}{\dfrac{B}{A\backslash B}\ \backslash\mathsf{I}^n}$$

Sample derivation

(1)

$$\dfrac{\dfrac{\mathrm{NP} \qquad \dfrac{(\mathrm{NP}\backslash\mathrm{S})/\mathrm{NP} \quad [\mathrm{NP}]^1}{\mathrm{NP}\backslash\mathrm{S}}\,{}^{/\mathrm{E}}}{\mathrm{S}}}{\dfrac{\mathrm{S}}{\mathrm{S}/\mathrm{NP}}\,{}^{/\mathrm{I}^1}} \qquad \dfrac{((\mathrm{S}/\mathrm{NP})\backslash\mathrm{S})/\mathrm{N} \quad \mathrm{N}}{(\mathrm{S}/\mathrm{NP})\backslash\mathrm{S}}$$
$$\mathrm{S}$$

NP	(NP\S)/NP	((S/NP)\S)/N	N	$\vdash$	S
John	saw	every	student		

Derivation with prosodic term labelling (cf. [Morrill, 1994])

(2)

$$
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\dfrac{
\begin{array}{ll}\texttt{john}; & \texttt{saw} \bullet \varphi; \\ \mathbf{j}; \mathsf{NP} & \mathbf{saw}(x); \mathsf{NP}\backslash\mathsf{S}
\end{array}
\quad
\dfrac{
\begin{array}{ll}\texttt{saw}; & \\ \mathbf{saw}; & \\ (\mathsf{NP}\backslash\mathsf{S})/\mathsf{NP} & \end{array}
\begin{bmatrix}\varphi; \\ x; \\ \mathsf{NP}\end{bmatrix}^1
}{
\begin{array}{l}\texttt{john} \bullet \texttt{saw} \bullet \varphi; \\ \mathbf{saw}(x)(\mathbf{j}); \mathsf{S}\end{array}
}
}{
\begin{array}{l}\texttt{john} \bullet \texttt{saw}; \\ \lambda x.\mathbf{saw}(x)(\mathbf{j}); \mathsf{S}/\mathsf{NP}\end{array}
}\,/\mathrm{I}^1
\quad
\dfrac{
\begin{array}{ll}\texttt{every}; & \texttt{student}; \\ \mathbf{\forall}; & \mathbf{student}; \\ ((\mathsf{S}/\mathsf{NP})\backslash\mathsf{S})/\mathsf{N} & \mathsf{N}\end{array}
}{
\begin{array}{l}\texttt{every} \bullet \texttt{student}; \\ \mathbf{\forall_{student}}; \\ (\mathsf{S}/\mathsf{NP})\backslash\mathsf{S}\end{array}
}
}{
\begin{array}{l}\texttt{john} \bullet \texttt{saw} \bullet \texttt{every} \bullet \texttt{student}; \\ \mathbf{\forall_{student}}(\lambda x.\mathbf{saw}(x)(\mathbf{j})); \mathsf{S}\end{array}
}
$$

Lambek calculus, with semantic and prosodic term-labelling

Forward Slash Introduction

$$\dfrac{\dfrac{\begin{array}{c}\vdots\\ \vdots\end{array}\quad \dfrac{[\varphi; x; A]^n}{\vdots} \quad \begin{array}{c}\vdots\\ \vdots\end{array}}{b \bullet \varphi;\ \mathcal{F};\ B}}{b;\ \lambda x.\mathcal{F};\ B/A}\ /\mathrm{I}^n$$

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$$\dfrac{\mathtt{a};\ \mathcal{F};\ A/B \qquad \mathtt{b};\ \mathcal{G};\ B}{\mathtt{a} \bullet \mathtt{b};\ \mathcal{F}(\mathcal{G});\ A}\ /\mathrm{E}$$

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- Labelled deduction for notating the prosody (cf. [Morrill, 1994, Oehrle, 1994]).

Note: the prosodic terms are not proof terms in this setup.

Lambek calculus

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But...

Lambek calculus

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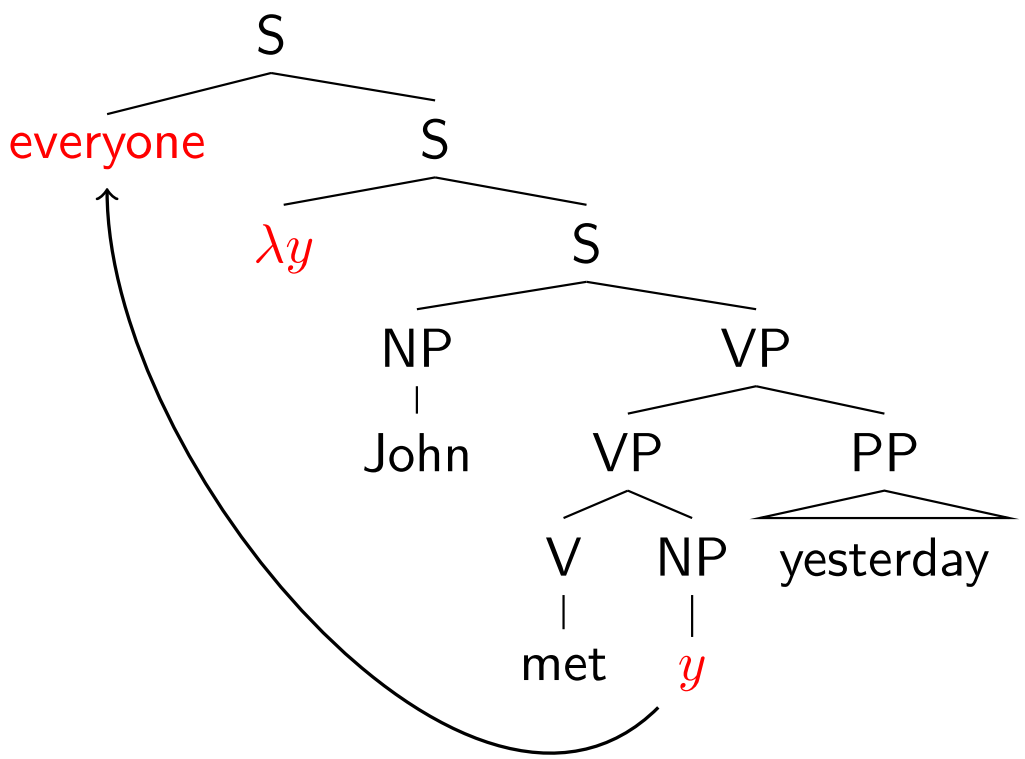
But... What about syntactic movement?

(3) a. I don't know who$_i$ [John met __$_i$ at the party].

b. John met every student yesterday.

Syntactic movement in the Lambek calculus?

(4)



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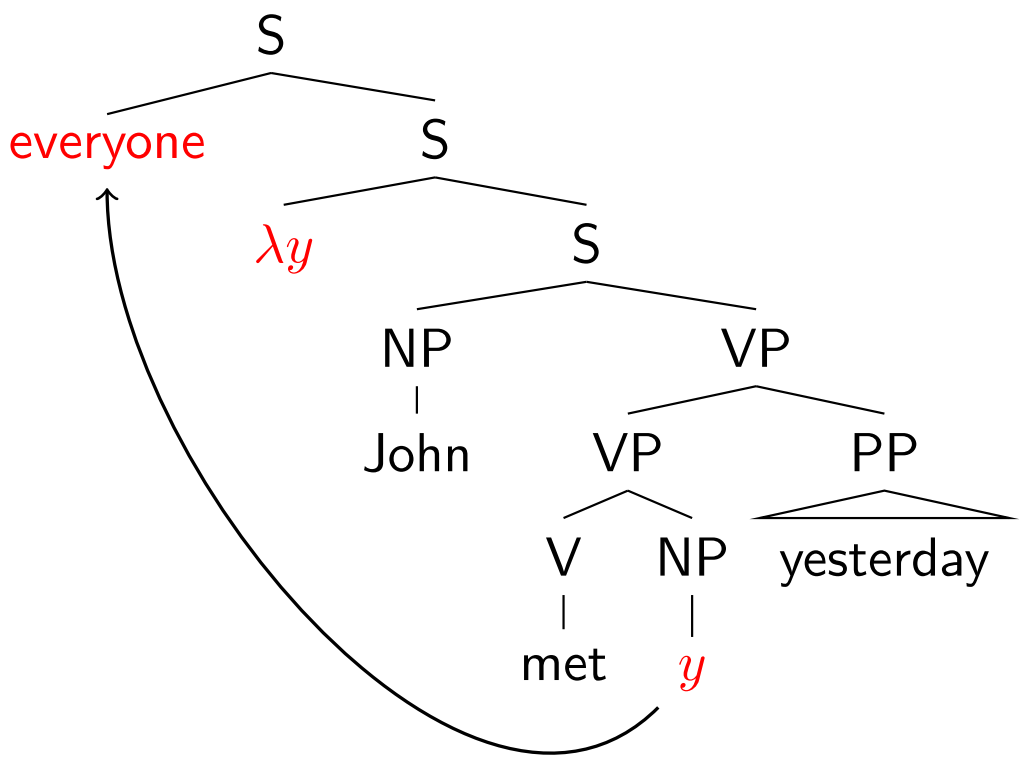

(5)

$$\dfrac{\texttt{everyone};\ \mathrm{NP} \qquad \dfrac{\texttt{john};\ \mathrm{NP} \qquad \dfrac{\dfrac{\texttt{met};\ (\mathrm{NP}\backslash\mathrm{S})/\mathrm{NP} \quad t\ ;\ \mathrm{NP}}{\texttt{met} \bullet t;\ \mathrm{NP}\backslash\mathrm{S}}\ /\mathrm{E} \qquad \begin{array}{l}\texttt{yesterday};\\ (\mathrm{NP}\backslash\mathrm{S})\backslash(\mathrm{NP}\backslash\mathrm{S})\end{array}}{\texttt{met} \bullet t \bullet \texttt{yesterday};\ \mathrm{NP}\backslash\mathrm{S}}\ \backslash\mathrm{E}}{\texttt{john} \bullet \texttt{met} \bullet t \bullet \texttt{yesterday};\ \mathrm{S}}\ \backslash\mathrm{E}}{\texttt{john} \bullet \texttt{met} \bullet \texttt{everyone} \bullet \texttt{yesterday};\ \mathrm{S}}\ ????$$

‘Vertical Slash’ for movement (cf. [Oehrle, 1994])

(6) John saw everyone yesterday.

(7)

$$\dfrac{\begin{array}{c}\texttt{john};\\ \mathbf{j};\ \mathsf{NP}\end{array} \qquad \dfrac{\dfrac{\begin{array}{c}\texttt{saw};\\ \mathbf{see};\\ (\mathsf{NP}\backslash\mathsf{S})/\mathsf{NP}\end{array} \quad \boxed{\begin{bmatrix}\varphi;\\ x;\\ \mathsf{NP}\end{bmatrix}^{1}}}{\begin{array}{c}\texttt{saw} \bullet \varphi;\\ \mathbf{see}(x);\ \mathsf{NP}\backslash\mathsf{S}\end{array}}\,/\mathsf{E} \quad \begin{array}{c}\texttt{yesterday};\\ \mathbf{yest};\\ (\mathsf{NP}\backslash\mathsf{S})\backslash(\mathsf{NP}\backslash\mathsf{S})\end{array}}{\texttt{saw} \bullet \varphi \bullet \texttt{yesterday};\ \mathbf{yest}(\mathbf{see}(x));\ \mathsf{NP}\backslash\mathsf{S}}}{\texttt{john} \bullet \texttt{saw} \bullet \varphi \bullet \texttt{yesterday};\ \mathbf{yest}(\mathbf{see}(x))(\mathbf{j});\ \mathsf{S}}\,\backslash\mathsf{E}$$

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where $\forall_{\mathbf{person}} =_{def} \lambda P[\forall x.\mathbf{person}(x) \rightarrow P(x)]$

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\begin{array}{c}
\lambda\sigma.\sigma(\texttt{everyone});\ \mathbf{\forall_{person}};\ \mathsf{S}\uparrow(\mathsf{S}\uparrow\mathsf{NP}) \qquad \dfrac{\dfrac{\dfrac{\dfrac{\texttt{saw};\ \mathbf{see};\ (\mathsf{NP}\backslash\mathsf{S})/\mathsf{NP} \qquad \begin{bmatrix}\varphi;\\ x;\\ \mathsf{NP}\end{bmatrix}^1}{\texttt{saw}\bullet\varphi;\ \mathbf{see}(x);\ \mathsf{NP}\backslash\mathsf{S}}\,{/}\mathsf{E} \qquad \begin{array}{c}\texttt{yesterday};\\ \mathbf{yest};\\ (\mathsf{NP}\backslash\mathsf{S})\backslash(\mathsf{NP}\backslash\mathsf{S})\end{array}}{\texttt{saw}\bullet\varphi\bullet\texttt{yesterday};\ \mathbf{yest}(\mathbf{see}(x));\ \mathsf{NP}\backslash\mathsf{S}}\,{\backslash}\mathsf{E} \qquad \begin{array}{c}\texttt{john};\\ \mathbf{j};\ \mathsf{NP}\end{array}}{\texttt{john}\bullet\texttt{saw}\bullet\varphi\bullet\texttt{yesterday};\ \mathbf{yest}(\mathbf{see}(x))(\mathbf{j});\ \mathsf{S}}\,{\backslash}\mathsf{E}}{\lambda\varphi.\texttt{john}\bullet\texttt{saw}\bullet\varphi\bullet\texttt{yesterday};\ \lambda x.\mathbf{yest}(\mathbf{see}(x))(\mathbf{j});\ \mathsf{S}\uparrow\mathsf{NP}}\,{\uparrow}\mathsf{I}^1 \\
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$$
\begin{array}{l}
\lambda\varphi.[\texttt{john} \bullet \texttt{saw} \bullet \varphi \bullet \texttt{yesterday}](\texttt{everyone});\\
\forall_{\mathbf{person}}(\lambda x.\mathbf{yest}(\mathbf{see}(x))(\mathbf{j}));\ \mathsf{S}
\end{array}
$$

$$
\begin{array}{l}
\texttt{john} \bullet \texttt{saw} \bullet \texttt{everyone} \bullet \texttt{yesterday};\\
\forall_{\mathbf{person}}(\lambda x.\mathbf{yest}(\mathbf{see}(x))(\mathbf{j}));\ \mathsf{S}
\end{array}
$$

where $\forall_{\mathbf{person}} =_{def} \lambda P[\forall x.\mathbf{person}(x) \rightarrow P(x)]$

- $\restriction$ (vertical slash): order-insensitive implication

Scope ambiguity

(8)

$$
\dfrac{
\begin{matrix}\lambda\sigma.\sigma(\mathtt{everyone}); \\ \forall_{\mathbf{person}}; \\ \mathsf{S}\upharpoonright(\mathsf{S}\upharpoonright\mathsf{NP})\end{matrix}
\quad
\dfrac{
\dfrac{
\begin{matrix}\lambda\sigma.\sigma(\mathtt{someone}); \\ \exists_{\mathbf{person}}; \\ \mathsf{S}\upharpoonright(\mathsf{S}\upharpoonright\mathsf{NP})\end{matrix}
\quad
\dfrac{
\dfrac{
\dfrac{
\begin{bmatrix}\varphi_2; \\ x_2; \\ \mathsf{NP}\end{bmatrix}^2
\quad
\dfrac{
\begin{matrix}\mathtt{talked}\bullet\mathtt{to}; \\ \mathbf{talked\text{-}to}; \\ (\mathsf{NP}\backslash\mathsf{S})/\mathsf{NP}\end{matrix}
\quad
\begin{bmatrix}\varphi_1; \\ x_1; \\ \mathsf{NP}\end{bmatrix}^1
}{
\begin{matrix}\mathtt{talked}\bullet\mathtt{to}\bullet\varphi_1; \\ \mathbf{talked\text{-}to}(x_1);\mathsf{NP}\backslash\mathsf{S}\end{matrix}
}/\mathsf{E}
}{
\begin{matrix}\varphi_2\bullet\mathtt{talked}\bullet\mathtt{to}\bullet\varphi_1; \\ \mathbf{talked\text{-}to}(x_1)(x_2);\mathsf{S}\end{matrix}
}\backslash\mathsf{E}
\quad
\begin{matrix}\mathtt{yesterday}; \\ \mathbf{yest};\mathsf{S}\backslash\mathsf{S}\end{matrix}
}{
\begin{matrix}\varphi_2\bullet\mathtt{talked}\bullet\mathtt{to}\bullet\varphi_1\bullet\mathtt{yesterday}; \\ \mathbf{yest}(\mathbf{talked\text{-}to}(x_1)(x_2));\mathsf{S}\end{matrix}
}\backslash\mathsf{E}
}{
\begin{matrix}\lambda\varphi_2.\varphi_2\bullet\mathtt{talked}\bullet\mathtt{to}\bullet\varphi_1\bullet\mathtt{yesterday}; \\ \lambda x_2.\mathbf{yest}(\mathbf{talked\text{-}to}(x_1)(x_2));\mathsf{S}\upharpoonright\mathsf{NP}\end{matrix}
}{\upharpoonright}\mathsf{I}^2
}{
\begin{matrix}\mathtt{someone}\bullet\mathtt{talked}\bullet\mathtt{to}\bullet\varphi_1\bullet\mathtt{yesterday}; \\ \exists_{\mathbf{person}}(\lambda x_2.\mathbf{yest}(\mathbf{talked\text{-}to}(x_1)(x_2)));\mathsf{S}\end{matrix}
}{\upharpoonright}\mathsf{E}
}{
\begin{matrix}\lambda\varphi_1.\mathtt{someone}\bullet\mathtt{talked}\bullet\mathtt{to}\bullet\varphi_1\bullet\mathtt{yesterday}; \\ \lambda x_1.\exists_{\mathbf{person}}(\lambda x_2.\mathbf{yest}(\mathbf{talked\text{-}to}(x_1)(x_2)));\mathsf{S}\upharpoonright\mathsf{NP}\end{matrix}
}{\upharpoonright}\mathsf{I}^1
}{
\begin{matrix}\mathtt{someone}\bullet\mathtt{talked}\bullet\mathtt{to}\bullet\mathtt{everyone}\bullet\mathtt{yesterday}; \\ \forall_{\mathbf{person}}(\lambda x_1.\exists_{\mathbf{person}}(\lambda x_2.\mathbf{yest}(\mathbf{talked\text{-}to}(x_1)(x_2))));\mathsf{S}\end{matrix}
}{\upharpoonright}\mathsf{E}
$$

Rules for the vertical slash

Vertical Slash Introduction

$$\dfrac{\dfrac{\begin{array}{c}\vdots\\ \vdots\end{array}\quad \dfrac{[\varphi; x; A]^n}{\begin{array}{c}\vdots\\ \vdots\end{array}}\quad \begin{array}{c}\vdots\\ \vdots\end{array}}{b;\ \mathcal{F};\ B}}{\lambda\varphi.b;\ \lambda x.\mathcal{F};\ B\restriction A}\ \restriction\mathrm{I}^n$$

Vertical Slash Elimination

$$\dfrac{\mathtt{a};\ \mathcal{F};\ A\restriction B \qquad \mathtt{b};\ \mathcal{G};\ B}{\mathtt{a}(\mathtt{b});\ \mathcal{F}(\mathcal{G});\ A}\ \restriction\mathrm{E}$$

Syntactic types in Hybrid TLG

- $\mathcal{A} := \{$ S, NP, N, ... $\}$ (atomic type)
- $\mathcal{D} := \mathcal{A} \mid \mathcal{D}\backslash\mathcal{D} \mid \mathcal{D}/\mathcal{D}$ (directional type)

Syntactic types in Hybrid TLG

- $\mathcal{A} := \{$ S, NP, N, ... $\}$ (atomic type)
- $\mathcal{D} := \mathcal{A} \mid \mathcal{D}\backslash\mathcal{D} \mid \mathcal{D}/\mathcal{D}$ (directional type)
- $\mathcal{T} := \mathcal{D} \mid \mathcal{T}\restriction\mathcal{T}$ (type)

Syntactic types in Hybrid TLG

- $\mathcal{A} := \{\ \mathsf{S}, \mathsf{NP}, \mathsf{N}, \ldots\ \}$ (atomic type)
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- $\mathcal{T} := \mathcal{D} \mid \mathcal{T}\restriction\mathcal{T}$ (type)

Some examples:

- $\mathsf{S}/\mathsf{NP} \in \mathcal{T}$
- $\mathsf{S}\restriction(\mathsf{S}\restriction\mathsf{NP}) \in \mathcal{T}$
- $\mathsf{S}\restriction(\mathsf{S}/\mathsf{NP}) \in \mathcal{T}$

Syntactic types in Hybrid TLG

- $\mathcal{A} := \{\ \mathsf{S}, \mathsf{NP}, \mathsf{N}, \ldots\ \}$ (atomic type)
- $\mathcal{D} := \mathcal{A} \mid \mathcal{D}\backslash\mathcal{D} \mid \mathcal{D}/\mathcal{D}$ (directional type)
- $\mathcal{T} := \mathcal{D} \mid \mathcal{T}\restriction\mathcal{T}$ (type)

Some examples:

- $\mathsf{S}/\mathsf{NP} \in \mathcal{T}$
- $\mathsf{S}\restriction(\mathsf{S}\restriction\mathsf{NP}) \in \mathcal{T}$
- $\mathsf{S}\restriction(\mathsf{S}/\mathsf{NP}) \in \mathcal{T}$
- $\mathsf{S}/(\mathsf{S}\restriction\mathsf{NP}) \notin \mathcal{T}$

Note: A vertical slash cannot occur under a Lambek slash.

Rules in Hybrid TLG

Connective	Introduction	Elimination
$/$	$\dfrac{\dfrac{\begin{array}{c}\vdots \\ [\varphi; x; A]^n \\ \vdots\end{array} \quad \begin{array}{c}\vdots \\ \vdots \\ \vdots\end{array}}{\mathsf{b} \bullet \varphi;\ \mathcal{F};\ B}}{\mathsf{b};\ \lambda x.\mathcal{F};\ B/A}\ /\mathrm{I}^n$	$\dfrac{\mathsf{a};\ \mathcal{F};\ A/B \quad \mathsf{b};\ \mathcal{G};\ B}{\mathsf{a} \bullet \mathsf{b};\ \mathcal{F}(\mathcal{G});\ A}\ /\mathrm{E}$
$\backslash$	$\dfrac{\dfrac{\begin{array}{c}\vdots \\ [\varphi; x; A]^n \\ \vdots\end{array} \quad \begin{array}{c}\vdots \\ \vdots \\ \vdots\end{array}}{\varphi \bullet \mathsf{b};\ \mathcal{F};\ B}}{\mathsf{b};\ \lambda x.\mathcal{F};\ A\backslash B}\ \backslash\mathrm{I}^n$	$\dfrac{\mathsf{b};\ \mathcal{G};\ B \quad \mathsf{a};\ \mathcal{F};\ B\backslash A}{\mathsf{b} \bullet \mathsf{a};\ \mathcal{F}(\mathcal{G});\ A}\ \backslash\mathrm{E}$
$\upharpoonright$	$\dfrac{\dfrac{\begin{array}{c}\vdots \\ [\varphi; x; A]^n \\ \vdots\end{array} \quad \begin{array}{c}\vdots \\ \vdots \\ \vdots\end{array}}{\mathsf{b};\ \mathcal{F};\ B}}{\lambda\varphi.\mathsf{b};\ \lambda x.\mathcal{F};\ B\upharpoonright A}\ \upharpoonright\mathrm{I}^n$	$\dfrac{\mathsf{a};\ \mathcal{F};\ A\upharpoonright B \quad \mathsf{b};\ \mathcal{G};\ B}{\mathsf{a}(\mathsf{b});\ \mathcal{F}(\mathcal{G});\ A}\ \upharpoonright\mathrm{E}$

Rules in Hybrid TLG

	Connective	Introduction	Elimination
Lambek calculus	$/$	$\dfrac{\dfrac{\begin{array}{c}\vdots\\ [\varphi; x; A]^n\\ \vdots\end{array} \quad \begin{array}{c}\vdots\\ \vdots\\ \vdots\end{array}}{\mathsf{b} \bullet \varphi;\ \mathcal{F};\ B}}{\mathsf{b};\ \lambda x.\mathcal{F};\ B/A}\ /\mathrm{I}^n$	$\dfrac{\mathsf{a};\ \mathcal{F};\ A/B \quad \mathsf{b};\ \mathcal{G};\ B}{\mathsf{a} \bullet \mathsf{b};\ \mathcal{F}(\mathcal{G});\ A}\ /\mathrm{E}$
	$\backslash$	$\dfrac{\dfrac{\begin{array}{c}\vdots\\ [\varphi; x; A]^n\\ \vdots\end{array} \quad \begin{array}{c}\vdots\\ \vdots\\ \vdots\end{array}}{\varphi \bullet \mathsf{b};\ \mathcal{F};\ B}}{\mathsf{b};\ \lambda x.\mathcal{F};\ A\backslash B}\ \backslash\mathrm{I}^n$	$\dfrac{\mathsf{b};\ \mathcal{G};\ B \quad \mathsf{a};\ \mathcal{F};\ B\backslash A}{\mathsf{b} \bullet \mathsf{a};\ \mathcal{F}(\mathcal{G});\ A}\ \backslash\mathrm{E}$

Rules in Hybrid TLG

Connective	Introduction	Elimination
λ grammar	$\upharpoonright$	

$$\dfrac{\dfrac{\begin{array}{c}\vdots \\ \vdots\end{array} \quad \dfrac{[\varphi; x; A]^n}{\vdots} \quad \begin{array}{c}\vdots \\ \vdots\end{array}}{b;\ \boldsymbol{\mathcal{F}};\ B}}{\lambda\varphi.b;\ \lambda x.\boldsymbol{\mathcal{F}};\ B\upharpoonright A}\ \upharpoonright\mathrm{I}^n$$

$$\dfrac{\mathtt{a};\ \boldsymbol{\mathcal{F}};\ A\upharpoonright B \quad \mathtt{b};\ \boldsymbol{\mathcal{G}};\ B}{\mathtt{a}(\mathtt{b});\ \boldsymbol{\mathcal{F}}(\boldsymbol{\mathcal{G}});\ A}\ \upharpoonright\mathrm{E}$$

Rules in Hybrid TLG

	Connective	Introduction	Elimination
Hybrid TLG	$/$	$\dfrac{\dfrac{\begin{array}{c}\vdots\\ [\varphi; x; A]^n\\ \vdots\end{array} \quad \begin{array}{c}\vdots\\ \vdots\\ \vdots\end{array}}{b \bullet \varphi;\ \mathcal{F};\ B}}{b;\ \lambda x.\mathcal{F};\ B/A}\ /\mathrm{I}^n$	$\dfrac{\mathsf{a};\ \mathcal{F};\ A/B \quad \mathsf{b};\ \mathcal{G};\ B}{\mathsf{a} \bullet \mathsf{b};\ \mathcal{F}(\mathcal{G});\ A}\ /\mathrm{E}$
	$\backslash$	$\dfrac{\dfrac{\begin{array}{c}\vdots\\ [\varphi; x; A]^n\\ \vdots\end{array} \quad \begin{array}{c}\vdots\\ \vdots\\ \vdots\end{array}}{\varphi \bullet b;\ \mathcal{F};\ B}}{b;\ \lambda x.\mathcal{F};\ A\backslash B}\ \backslash\mathrm{I}^n$	$\dfrac{\mathsf{b};\ \mathcal{G};\ B \quad \mathsf{a};\ \mathcal{F};\ B\backslash A}{b \bullet \mathsf{a};\ \mathcal{F}(\mathcal{G});\ A}\ \backslash\mathrm{E}$
	$\upharpoonright$	$\dfrac{\dfrac{\begin{array}{c}\vdots\\ [\varphi; x; A]^n\\ \vdots\end{array} \quad \begin{array}{c}\vdots\\ \vdots\\ \vdots\end{array}}{b;\ \mathcal{F};\ B}}{\lambda\varphi.b;\ \lambda x.\mathcal{F};\ B\upharpoonright A}\ \upharpoonright\mathrm{I}^n$	$\dfrac{\mathsf{a};\ \mathcal{F};\ A\upharpoonright B \quad \mathsf{b};\ \mathcal{G};\ B}{\mathsf{a}(b);\ \mathcal{F}(\mathcal{G});\ A}\ \upharpoonright\mathrm{E}$

Gapping

Simple Gapping examples

(9) a. Robin **speaks** French, and Leslie, ∅ German.

Gapping

Simple Gapping examples

(9) a. Robin **speaks** French, and Leslie, ∅ German.

b. Robin **wants to speak** French, and Leslie, ∅ German.

c. To Robin **Chris gave** the book, and to Leslie, ∅ the magazine.

Gapping

Simple Gapping examples

(9) a. Robin **speaks** French, and Leslie, ∅ German.

b. Robin **wants to speak** French, and Leslie, ∅ German.

c. To Robin **Chris gave** the book, and to Leslie, ∅ the magazine.

Scope anomaly in Gapping [Siegel, 1984, Oehrle, 1987]

(10) a. Mrs. J **can't live** in LA and Mr. J ∅ in Boston.

$(= \neg\Diamond[\varphi \wedge \psi])$

b. Kim **didn't** play bingo or Sandy ∅ sit at home all evening.

$(= \neg[\varphi \vee \psi])$

Gapping in Hybrid TLG

Deriving a gapped sentence via hypothetical reasoning

(11)

$$\dfrac{\dfrac{\texttt{robin};\ \mathbf{r};\ \mathsf{NP} \qquad \dfrac{\left[\begin{array}{l}\varphi_1;\\ P;\ \mathsf{VP/NP}\end{array}\right]^1 \quad \texttt{leslie};\ \mathbf{l};\ \mathsf{NP}}{\varphi_1 \bullet \texttt{leslie};\ P(\mathbf{l});\ \mathsf{VP}}\ /\mathsf{E}}{\texttt{robin} \bullet \varphi_1 \bullet \texttt{leslie};\ P(\mathbf{l})(\mathbf{r});\ \mathsf{S}}\ \backslash\mathsf{E}}{\lambda\varphi_1.\texttt{robin} \bullet \varphi_1 \bullet \texttt{leslie};\ \lambda P.P(\mathbf{l})(\mathbf{r});\ \mathsf{S}\uparrow(\mathsf{VP/NP})}\ \uparrow\mathsf{I}^1$$

Gapping as like-category coordination (cont.)

(12) $\lambda\varphi_1.\texttt{robin} \bullet \varphi_1 \bullet \texttt{leslie};\ \lambda P.P(\mathbf{l})(\mathbf{r});\ \mathsf{S}\restriction\mathsf{TV}$

(13) $\lambda\varphi_1.\texttt{sandy} \bullet \varphi_1 \bullet \texttt{kim};\ \lambda P.P(\mathbf{k})(\mathbf{s});\ \mathsf{S}\restriction\mathsf{TV}$

Conjunction entry for Gapping:

(14) $\lambda\sigma_2\lambda\sigma_1\lambda\varphi_0.\sigma_1(\varphi_0) \bullet \texttt{and} \bullet \sigma_2(\varepsilon);\ \lambda\mathcal{W}\lambda\mathcal{V}.\mathcal{V} \sqcap \mathcal{W};$
$(\mathsf{S}\restriction\mathsf{TV})\restriction(\mathsf{S}\restriction\mathsf{TV})\restriction(\mathsf{S}\restriction\mathsf{TV})$

Gapping as like-category coordination (cont.)

(15)

$$\dfrac{\dfrac{\vdots \qquad \lambda\varphi_1.\texttt{robin} \bullet \varphi_1 \bullet \texttt{leslie};\ \lambda P.P(\mathbf{l})(\mathbf{r});\ \mathsf{S}\restriction\mathsf{TV}}{\lambda\sigma_1\lambda\varphi_0.\sigma_1(\varphi_0) \bullet \texttt{and} \bullet \texttt{sandy} \bullet \varepsilon \bullet \texttt{kim};\ \lambda\mathcal{V}.\mathcal{V} \sqcap \lambda P.P(\mathbf{k})(\mathbf{s});\ (\mathsf{S}\restriction\mathsf{TV})\restriction(\mathsf{S}\restriction\mathsf{TV})} \qquad \dfrac{\dfrac{\vdots \qquad \lambda\sigma_2\lambda\sigma_1\lambda\varphi_0.\sigma_1(\varphi_0) \bullet \texttt{and} \bullet \sigma_2(\varepsilon);\ \lambda\mathcal{W}\lambda\mathcal{V}.\mathcal{V} \sqcap \mathcal{W};\ (\mathsf{S}\restriction\mathsf{TV})\restriction(\mathsf{S}\restriction\mathsf{TV})\restriction(\mathsf{S}\restriction\mathsf{TV})}{\lambda\varphi_1.\texttt{sandy} \bullet \varphi_1 \bullet \texttt{kim};\ \lambda P.P(\mathbf{k})(\mathbf{s});\ \mathsf{S}\restriction\mathsf{TV}}}{\lambda\varphi_0[\texttt{robin} \bullet \varphi_0 \bullet \texttt{leslie} \bullet \texttt{and} \bullet \texttt{sandy} \bullet \varepsilon \bullet \texttt{kim}];\ \lambda P.P(\mathbf{l})(\mathbf{r}) \sqcap \lambda P.P(\mathbf{k})(\mathbf{s});\ \mathsf{S}\restriction\mathsf{TV}}$$

Gapping as like-category coordination (cont.)

(15)

$$
\begin{array}{l}
\texttt{met}; \\
\textbf{meet}; \\
\mathsf{TV}
\end{array}
\quad
\dfrac{\dfrac{\begin{array}{l}\lambda\varphi_1.\texttt{robin} \bullet \varphi_1 \bullet \texttt{leslie}; \\ \lambda P.P(\mathbf{l})(\mathbf{r}); \\ \mathsf{S}\restriction\mathsf{TV}\end{array} \quad \dfrac{\begin{array}{l}\lambda\sigma_2\lambda\sigma_1\lambda\varphi_0. \\ \sigma_1(\varphi_0) \bullet \texttt{and} \bullet \sigma_2(\varepsilon); \\ \lambda\mathcal{W}\lambda\mathcal{V}.\mathcal{V} \sqcap \mathcal{W}; \\ (\mathsf{S}\restriction\mathsf{TV})\restriction(\mathsf{S}\restriction\mathsf{TV})\restriction(\mathsf{S}\restriction\mathsf{TV})\end{array} \quad \begin{array}{c}\vdots \\ \begin{array}{l}\lambda\varphi_1.\texttt{sandy} \bullet \varphi_1 \bullet \texttt{kim}; \\ \lambda P.P(\mathbf{k})(\mathbf{s}); \\ \mathsf{S}\restriction\mathsf{TV}\end{array}\end{array}}{\begin{array}{l}\lambda\sigma_1\lambda\varphi_0.\sigma_1(\varphi_0) \bullet \texttt{and} \bullet \texttt{sandy} \bullet \varepsilon \bullet \texttt{kim}; \\ \lambda\mathcal{V}.\mathcal{V} \sqcap \lambda P.P(\mathbf{k})(\mathbf{s}); \\ (\mathsf{S}\restriction\mathsf{TV})\restriction(\mathsf{S}\restriction\mathsf{TV})\end{array}}\ \vdots}{\begin{array}{l}\lambda\varphi_0[\texttt{robin} \bullet \varphi_0 \bullet \texttt{leslie} \bullet \texttt{and} \bullet \texttt{sandy} \bullet \varepsilon \bullet \texttt{kim}]; \\ \lambda P.P(\mathbf{l})(\mathbf{r}) \sqcap \lambda P.P(\mathbf{k})(\mathbf{s}); \mathsf{S}\restriction\mathsf{TV}\end{array}}
$$

$$
\begin{array}{l}
\texttt{robin} \bullet \texttt{met} \bullet \texttt{leslie} \bullet \texttt{and} \bullet \texttt{sandy} \bullet \varepsilon \bullet \texttt{kim}; \\
\mathbf{meet}(\mathbf{l})(\mathbf{r}) \sqcap \mathbf{meet}(\mathbf{k})(\mathbf{s}); \mathsf{S}
\end{array}
$$

Explaining scope anomaly in Gapping

(16)

$$
\begin{array}{l}
\texttt{met}; \\
\textbf{meet}; \\
\mathsf{TV}
\end{array}
\quad
\dfrac{
\begin{array}{c}
\vdots \\
\lambda\varphi_1.\texttt{robin} \bullet \varphi_1 \bullet \texttt{leslie}; \\
\lambda P.P(\mathbf{l})(\mathbf{r}); \\
\mathsf{S}\restriction\mathsf{TV}
\end{array}
\quad
\dfrac{
\begin{array}{c}
\lambda\sigma_2\lambda\sigma_1\lambda\varphi_0. \\
\sigma_1(\varphi_0) \bullet \texttt{and} \bullet \sigma_2(\varepsilon); \\
\lambda\mathcal{W}\lambda\mathcal{V}.\mathcal{V} \sqcap \mathcal{W}; \\
(\mathsf{S}\restriction\mathsf{TV})\restriction(\mathsf{S}\restriction\mathsf{TV})\restriction(\mathsf{S}\restriction\mathsf{TV})
\end{array}
\quad
\begin{array}{c}
\vdots \\
\lambda\varphi_1.\texttt{sandy} \bullet \varphi_1 \bullet \texttt{kim}; \\
\lambda P.P(\mathbf{k})(\mathbf{s}); \\
\mathsf{S}\restriction\mathsf{TV}
\end{array}
}{
\begin{array}{c}
\lambda\sigma_1\lambda\varphi_0.\sigma_1(\varphi_0) \bullet \texttt{and} \bullet \texttt{sandy} \bullet \varepsilon \bullet \texttt{kim}; \\
\lambda\mathcal{V}.\mathcal{V} \sqcap \lambda P.P(\mathbf{k})(\mathbf{s}); \\
(\mathsf{S}\restriction\mathsf{TV})\restriction(\mathsf{S}\restriction\mathsf{TV})
\end{array}
}
}{
\begin{array}{c}
\lambda\varphi_0[\texttt{robin} \bullet \varphi_0 \bullet \texttt{leslie} \bullet \texttt{and} \bullet \texttt{sandy} \bullet \varepsilon \bullet \texttt{kim}]; \\
\lambda P.P(\mathbf{l})(\mathbf{r}) \sqcap \lambda P.P(\mathbf{k})(\mathbf{s}); \mathsf{S}\restriction\mathsf{TV}
\end{array}
}
$$

$$
\dfrac{
\begin{array}{c}
\texttt{met}; \\
\textbf{meet}; \\
\mathsf{TV}
\end{array}
\quad
\begin{array}{c}
\lambda\varphi_0[\texttt{robin} \bullet \varphi_0 \bullet \texttt{leslie} \bullet \texttt{and} \bullet \texttt{sandy} \bullet \varepsilon \bullet \texttt{kim}]; \\
\lambda P.P(\mathbf{l})(\mathbf{r}) \sqcap \lambda P.P(\mathbf{k})(\mathbf{s}); \mathsf{S}\restriction\mathsf{TV}
\end{array}
}{
\begin{array}{c}
\texttt{robin} \bullet \texttt{met} \bullet \texttt{leslie} \bullet \texttt{and} \bullet \texttt{sandy} \bullet \varepsilon \bullet \texttt{kim}; \\
\mathbf{meet}(\mathbf{l})(\mathbf{r}) \sqcap \mathbf{meet}(\mathbf{k})(\mathbf{s}); \mathsf{S}
\end{array}
}
$$

(17) a. Mrs. J can't live in LA and Mr. J in Boston. $\neg\Diamond > \wedge$

b. Kim didn't play bingo or Sandy sit at home all evening. $\neg > \vee$

Explaining scope anomaly in Gapping

(16)

$$
\begin{array}{c}
\vdots \\
\lambda\varphi_1.\texttt{robin} \bullet \varphi_1 \bullet \texttt{leslie}; \\
\lambda P.P(\mathbf{l})(\mathbf{r}); \\
\mathsf{S}\restriction\mathsf{TV}
\end{array}
\qquad
\begin{array}{c}
\lambda\sigma_2\lambda\sigma_1\lambda\varphi_0. \\
\sigma_1(\varphi_0) \bullet \texttt{and} \bullet \sigma_2(\varepsilon); \\
\lambda\mathcal{W}\lambda\mathcal{V}.\mathcal{V} \sqcap \mathcal{W}; \\
(\mathsf{S}\restriction\mathsf{TV})\restriction(\mathsf{S}\restriction\mathsf{TV})\restriction(\mathsf{S}\restriction\mathsf{TV})
\end{array}
\qquad
\begin{array}{c}
\vdots \\
\lambda\varphi_1.\texttt{sandy} \bullet \varphi_1 \bullet \texttt{kim}; \\
\lambda P.P(\mathbf{k})(\mathbf{s}); \\
\mathsf{S}\restriction\mathsf{TV}
\end{array}
$$

$$
\begin{array}{c}
\lambda\sigma_1\lambda\varphi_0.\sigma_1(\varphi_0) \bullet \texttt{and} \bullet \texttt{sandy} \bullet \varepsilon \bullet \texttt{kim}; \\
\lambda\mathcal{V}.\mathcal{V} \sqcap \lambda P.P(\mathbf{k})(\mathbf{s}); \\
(\mathsf{S}\restriction\mathsf{TV})\restriction(\mathsf{S}\restriction\mathsf{TV})
\end{array}
$$

$$
\begin{array}{l}
\texttt{met}; \\
\mathbf{meet}; \\
\mathsf{TV}
\end{array}
\qquad
\begin{array}{c}
\lambda\varphi_0[\texttt{robin} \bullet \varphi_0 \bullet \texttt{leslie} \bullet \texttt{and} \bullet \texttt{sandy} \bullet \varepsilon \bullet \texttt{kim}]; \\
\lambda P.P(\mathbf{l})(\mathbf{r}) \sqcap \lambda P.P(\mathbf{k})(\mathbf{s}); \mathsf{S}\restriction\mathsf{TV}
\end{array}
$$

$$
\begin{array}{c}
\texttt{robin} \bullet \texttt{met} \bullet \texttt{leslie} \bullet \texttt{and} \bullet \texttt{sandy} \bullet \varepsilon \bullet \texttt{kim}; \\
\mathbf{meet}(\mathbf{l})(\mathbf{r}) \sqcap \mathbf{meet}(\mathbf{k})(\mathbf{s}); \mathsf{S}
\end{array}
$$

(17) a. Mrs. J can't live in LA and Mr. J in Boston. $\neg\Diamond > \wedge$

b. Kim didn't play bingo or Sandy sit at home all evening. $\neg > \vee$

Rough story:

- In examples like (17), the auxiliary is gapped.
- Thus, the auxiliary is outside the coordinate structure 'at LF'.
- Auxiliary wide scope is then immediately predicted.

Explaining scope anomaly, specifics

Auxiliary as a scope-taking expression

(18) Robin must discover a solution.

(19) $\lambda\sigma.\sigma(\texttt{must})$; $\lambda\mathscr{F}.\Box\mathscr{F}(\mathsf{id}_{et})$; $\mathsf{S}\uparrow(\mathsf{S}\uparrow(\mathsf{VP}/\mathsf{VP}))$

(where $\mathsf{id}_{et} =_{def} \lambda P_{et}.P$)

Auxiliaries in English (cont.)

(20) Someone must be present at the meeting. $(\Box > \exists)$

(21)

$$
\begin{array}{l}
\lambda\sigma.\sigma(\mathtt{must});\\
\lambda\mathscr{F}.\Box\mathscr{F}(\mathsf{id}_{et});\\
\mathsf{S}\uparrow(\mathsf{S}\uparrow(\mathsf{VP}/\mathsf{VP}))
\end{array}
\qquad
\dfrac{
\begin{array}{l}
\lambda\sigma.\sigma(\mathtt{someone});\\
\mathbf{H}_{\mathbf{person}};\\
\mathsf{S}\uparrow(\mathsf{S}\uparrow\mathsf{NP})
\end{array}
\qquad
\dfrac{
\dfrac{
\begin{bmatrix}\varphi_2;\\ x;\\ \mathsf{NP}\end{bmatrix}^2
\qquad
\dfrac{
[\varphi_1; f; \mathsf{VP}/\mathsf{VP}]^1
\qquad
\begin{array}{l}\mathtt{be}\bullet\mathtt{present};\\ \mathbf{present};\\ \mathsf{VP}\end{array}
}{
\begin{array}{l}\varphi_1\bullet\mathtt{be}\bullet\mathtt{present};\\ f(\mathbf{present});\mathsf{VP}\end{array}
}\,/\mathrm{E}
}{
\begin{array}{l}\varphi_2\bullet\varphi_1\bullet\mathtt{be}\bullet\mathtt{present};\\ f(\mathbf{present})(x);\mathsf{S}\end{array}
}\,\backslash\mathrm{E}
}{
\begin{array}{l}\lambda\varphi_2.\varphi_2\bullet\varphi_1\bullet\mathtt{be}\bullet\mathtt{present};\\ \lambda x.f(\mathbf{present})(x);\mathsf{S}\uparrow\mathsf{NP}\end{array}
}\,\uparrow\mathrm{I}^2
}{
\begin{array}{l}\mathtt{someone}\bullet\varphi_1\bullet\mathtt{be}\bullet\mathtt{present};\\ \mathbf{H}_{\mathbf{person}}(\lambda x.f(\mathbf{present})(x));\mathsf{S}\end{array}
}\,\uparrow\mathrm{E}
}{
\begin{array}{l}\lambda\varphi_1.\mathtt{someone}\bullet\varphi_1\bullet\mathtt{be}\bullet\mathtt{present};\\ \lambda f.\mathbf{H}_{\mathbf{person}}(\lambda x.f(\mathbf{present})(x));\mathsf{S}\uparrow(\mathsf{VP}/\mathsf{VP})\end{array}
}\,\uparrow\mathrm{I}^1
}{
\begin{array}{l}\mathtt{someone}\bullet\mathtt{must}\bullet\mathtt{be}\bullet\mathtt{present};\\ \Box\mathbf{H}_{\mathbf{person}}(\lambda x.\mathbf{present}(x));\mathsf{S}\end{array}
}\,\uparrow\mathrm{E}
$$

Deriving the VP/VP entry

(22) $\texttt{can't}$; $\lambda P \lambda x.\neg\Diamond P(x)$; VP/VP

Deriving the VP/VP entry

(22) $\mathtt{can't};\ \lambda P \lambda x.\neg\Diamond P(x);\ \mathsf{VP/VP}$

(23)

$$
\dfrac{\dfrac{\dfrac{\lambda\sigma_0.\sigma_0(\mathtt{can't});\ \lambda\mathscr{F}.\neg\Diamond\mathscr{F}(\mathsf{id}_{et});\ \mathsf{S}\restriction(\mathsf{S}\restriction\mathsf{VP/VP}) \qquad \dfrac{\dfrac{[\varphi_1; x; \mathsf{NP}]^1 \qquad \dfrac{[\varphi_2; g; \mathsf{VP/VP}]^2 \quad [\varphi_3; P; \mathsf{VP}]^3}{\varphi_2 \bullet \varphi_3;\ g(P);\ \mathsf{VP}}\,/\mathsf{E}}{\varphi_1 \bullet \varphi_2 \bullet \varphi_3;\ g(P)(x);\ \mathsf{S}}\,\backslash\mathsf{E}}{\lambda\varphi_2.\varphi_1 \bullet \varphi_2 \bullet \varphi_3;\ \lambda g.g(P)(x); \mathsf{S}\restriction(\mathsf{VP/VP})}\,\restriction\mathsf{I}^2}{\varphi_1 \bullet \mathtt{can't} \bullet \varphi_3;\ \neg\Diamond P(x);\ \mathsf{S}}\,\restriction\mathsf{E}}{\mathtt{can't} \bullet \varphi_3;\ \lambda x.\neg\Diamond P(x);\ \mathsf{VP}}\,\backslash\mathsf{I}^1}{\mathtt{can't};\ \lambda P \lambda x.\neg\Diamond P(x);\ \mathsf{VP/VP}}\,/\mathsf{I}^3
$$

Auxiliary Gapping, auxiliary wide-scope

(24)

$$
\begin{array}{c}
\begin{array}{c}
\mathtt{john};\\ \mathbf{j};\mathsf{NP}
\end{array}
\quad
\begin{array}{c}
\left[\begin{array}{l}\varphi_1;\\ f;\mathsf{VP}/\mathsf{VP}\end{array}\right]^1
\quad
\begin{array}{l}\mathtt{eat}\bullet\mathtt{steak};\\ \mathbf{eat}(\mathbf{s});\\ \mathsf{VP}\end{array}
\\
\hline
\begin{array}{l}\varphi_1\bullet\mathtt{eat}\bullet\mathtt{steak};\\ f(\mathbf{eat}(\mathbf{s}));\\ \mathsf{VP}\end{array}
\end{array}
\\
\hline
\begin{array}{l}\mathtt{john}\bullet\varphi_1\bullet\mathtt{eat}\bullet\mathtt{steak};\\ f(\mathbf{eat}(\mathbf{s}))(\mathbf{j});\\ \mathsf{S}\end{array}
\\
\hline
\begin{array}{l}\lambda\varphi_1.\mathtt{john}\bullet\varphi_1\bullet\mathtt{eat}\bullet\mathtt{steak};\\ \lambda f.f(\mathbf{eat}(\mathbf{s}))(\mathbf{j});\\ \mathsf{S}\restriction(\mathsf{VP}/\mathsf{VP})\end{array}
\restriction\mathsf{I}^1
\end{array}
\quad
\begin{array}{c}
\vdots
\\
\begin{array}{l}\lambda\sigma_2\lambda\sigma_1\lambda\varphi_0.\\ \sigma_1(\varphi_0)\bullet\mathtt{and}\bullet\sigma_2(\varepsilon);\\ \lambda\mathscr{F}_2\lambda\mathscr{F}_1.\mathscr{F}_1\sqcap\mathscr{F}_2;\\ (\mathsf{S}\restriction\mathsf{X})\restriction(\mathsf{S}\restriction\mathsf{X})\restriction(\mathsf{S}\restriction\mathsf{X})\end{array}
\quad
\begin{array}{l}\lambda\varphi_2.\mathtt{mary}\bullet\varphi_2\bullet\\ \mathtt{eat}\bullet\mathtt{pizza};\\ \lambda g.g(\mathbf{eat}(\mathbf{p}))(\mathbf{m});\\ \mathsf{S}\restriction(\mathsf{VP}/\mathsf{VP})\end{array}
\\
\hline
\begin{array}{l}\lambda\sigma_1\lambda\varphi_0.\sigma_1(\varphi_0)\bullet\mathtt{and}\bullet\mathtt{mary}\bullet\varepsilon\bullet\mathtt{eat}\bullet\mathtt{pizza};\\ \lambda\mathscr{F}_1.\mathscr{F}_1\sqcap\lambda g.g(\mathbf{eat}(\mathbf{p}))(\mathbf{m});\\ (\mathsf{S}\restriction(\mathsf{VP}/\mathsf{VP}))\restriction(\mathsf{S}\restriction(\mathsf{VP}/\mathsf{VP}))\end{array}
\end{array}
$$

$$
\begin{array}{l}\lambda\varphi_0.\mathtt{john}\bullet\varphi_0\bullet\mathtt{eat}\bullet\mathtt{steak}\bullet\mathtt{and}\bullet\mathtt{mary}\bullet\varepsilon\bullet\mathtt{eat}\bullet\mathtt{pizza};\\ \lambda f.f(\mathbf{eat}(\mathbf{s}))(\mathbf{j})\sqcap\lambda g.g(\mathbf{eat}(\mathbf{p}))(\mathbf{m});\\ \mathsf{S}\restriction(\mathsf{VP}/\mathsf{VP})\end{array}
$$

Auxiliary Gapping, auxiliary wide-scope (cont.)

(25)

$$\dfrac{\begin{array}{l}\lambda\sigma.\sigma(\mathtt{can't});\\ \lambda\mathscr{F}.\neg\Diamond\mathscr{F}(\mathsf{id}_{et});\\ \mathsf{S}\restriction(\mathsf{S}\restriction(\mathsf{VP}/\mathsf{VP}))\end{array} \qquad \begin{array}{c}\vdots \qquad \vdots\\ \lambda\varphi_0.\mathtt{john}\bullet\varphi_0\bullet\mathtt{eat}\bullet\mathtt{steak}\bullet\\ \mathtt{and}\bullet\mathtt{mary}\bullet\varepsilon\bullet\mathtt{eat}\bullet\mathtt{pizza};\\ \lambda f.f(\mathbf{eat}(\mathbf{s}))(\mathbf{j})\sqcap\lambda g.G(\mathbf{eat}(\mathbf{p}))(\mathbf{m});\\ \mathsf{S}\restriction(\mathsf{VP}/\mathsf{VP})\end{array}}{\begin{array}{l}\mathtt{john}\bullet\mathtt{can't}\bullet\mathtt{eat}\bullet\mathtt{steak}\bullet\mathtt{and}\bullet\mathtt{mary}\bullet\varepsilon\bullet\mathtt{eat}\bullet\mathtt{pizza};\\ \neg\Diamond[\mathbf{eat}(\mathbf{s})(\mathbf{j})\wedge\mathbf{eat}(\mathbf{p})(\mathbf{m})];\mathsf{S}\end{array}}$$

Summary

Hybrid TLG

- $\approx$ Lambek calculus + λ grammar
- enables simple analyses of complex linguistic phenomena, capturing potentially interesting empirical generalizations
- can, at a certain level of abstraction, be thought of as a formalization of the 'movement-based' syntax-semantics interface

Summary

Hybrid TLG

- $\approx$ Lambek calculus + λ grammar
- enables simple analyses of complex linguistic phenomena, capturing potentially interesting empirical generalizations
- can, at a certain level of abstraction, be thought of as a formalization of the 'movement-based' syntax-semantics interface

Caveat: Many (supposedly) central properties of mainstream syntax are not part of Hybrid TLG.

- E.g.: island constraints
- But note that the exact status of island constraints is unclear in the minimalist program also (cf. [Boeckx, 2012]).

Open questions

- Comparison with some recent HPSG work
  - complex combinatoric component (Hybrid TLG) vs. underspecification (HPSG)
- Formal properties of Hybrid TLG
  - decidability
  - relations to other variants of TLG
- Parsing

Comparison with HPSG using underspecification

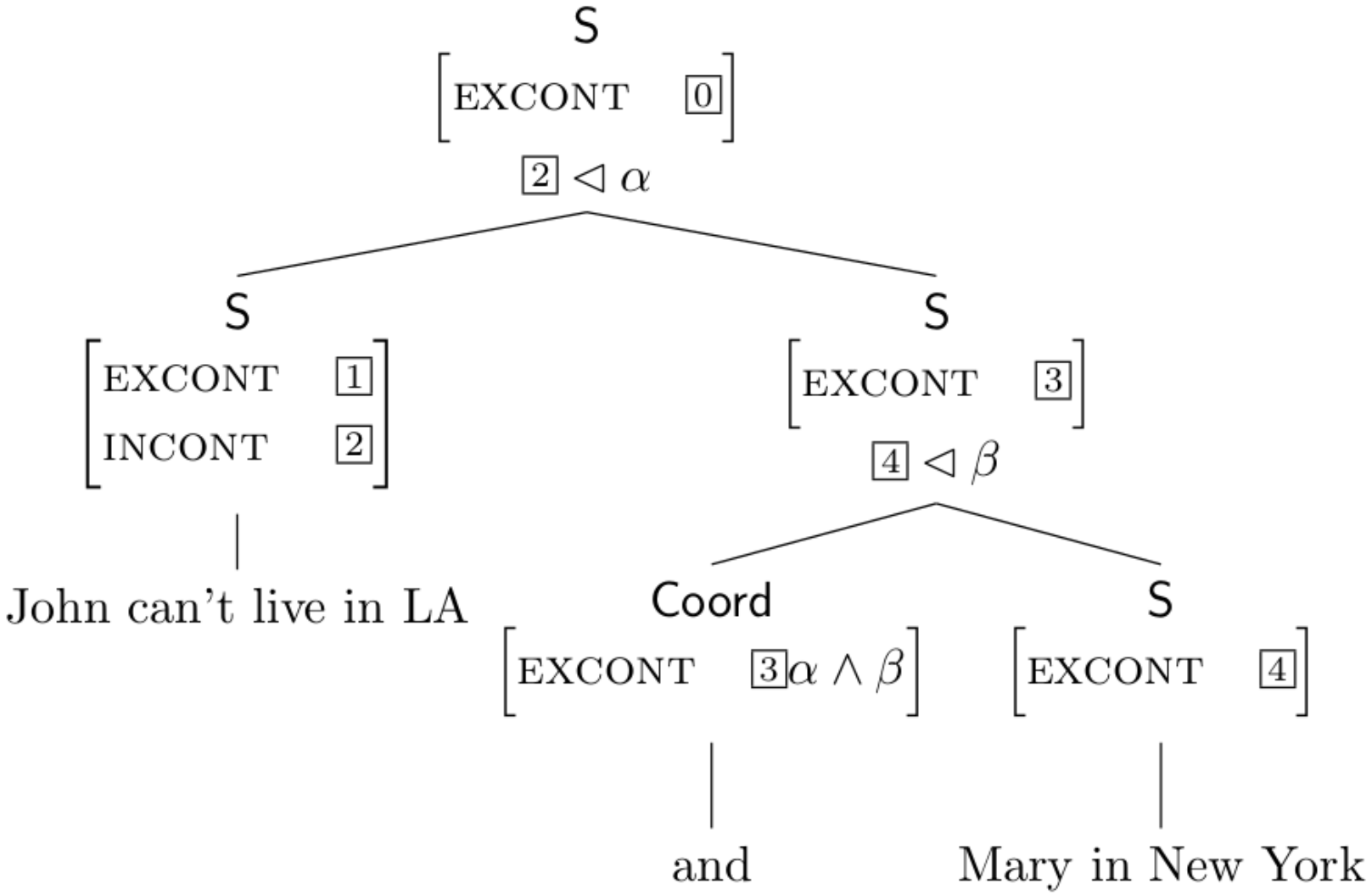
Some responses to the Hybrid TLG analyses of coordination from the HPSG community:

- [Yatabe and Tam, 2017] on NCC, building on and extending [Yatabe, 2001]'s earlier work
- [Park et al., 2018] propose an analysis of Gapping in Lexical Resource Semantics addressing the scope anomaly problem

Both of these proposals crucially involve underspecification.

Comparison with HPSG using underspecification (cont.)

[Park et al., 2018]'s analysis of Gapping



Comparison with HPSG using underspecification (cont.)

Some observations:

- [Park et al., 2018]'s HPSG analysis:
  - surface-oriented syntax
  - underspecification in semantics
- Hybrid TLG:
  - rigid mapping from (underlying) syntax to semantics
  - mapping from underlying syntax to surface syntax is somewhat complex

Comparison with HPSG using underspecification (cont.)

Some observations:

- [Park et al., 2018]'s HPSG analysis:
  - surface-oriented syntax
  - underspecification in semantics
- Hybrid TLG:
  - rigid mapping from (underlying) syntax to semantics
  - mapping from underlying syntax to surface syntax is somewhat complex

Some questions:

- What's the relationship between the two research strategies?
- Any reason to prefer one over the other?

Some known and unknown properties of Hybrid TLG

Some recent work investigating the formal properties of Hybrid TLG:

- Richard Moot's work on translating Hybrid TLG to an implicative fragment of linear logic with first-order quantifiers (MILL1) [Moot, 2014]
  - proof normalization
  - proof search in Hybrid TLG is decidable
  - parsing with Hybrid TLG is NP complete

Some known and unknown properties of Hybrid TLG

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  - proof normalization
  - proof search in Hybrid TLG is decidable
  - parsing with Hybrid TLG is NP complete
- Chris Worth, Jordan Needle and Carl Pollard's ongoing work on embedding Hybrid TLG in Linear Categorial Grammar [Worth, 2016] (continued by ongoing work by Needle/Pollard)
  - This work may shed light on the relationship between Hybrid TLG and λ grammars.

Some known and unknown properties of Hybrid TLG

- It would be illuminating to study the formal properties of the proof theory of Hybrid TLG itself.
- This is largely left for future work.

Open questions:

- Proof normalization in natural deduction?
- Cut elimination?
- Decidability?

Parser for Hybrid TLG: LinearOne [Moot, 2014, Moot, 2015]

- Theorem prover for MILL1
- Implemented in SWI Prolog
- Available at `https://github.com/RichardMoot/LinearOne`
- Works as a parser for Hybrid TLG due to the one-to-one correspondence between proofs in first-order linear logic and derivations in Hybrid TLG

Wide coverage parsing?

Should we care? There are already several excellent CCG parsers employing state-of-the-art NLP techniques, e.g.,

- C&C parser [Clark and Curran, 2004]
- EasyCCG [Lewis and Steedman, 2014]
- depCCG [Yoshikawa et al., 2017]

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Some reasons we may want to care about robust parsing in TLG:

- In a sense, TLG is closer to mainstream Chomskian syntax than CCG, due to its less surface-oriented nature.
- So, whether (or to what extent) large-scale parsing is possible with TLG is an inheritly interesting question.
- It may give us some ideas about how one might go about implementing parsers based on movement-based theories of grammar.

Challenge for wide coverage parsing

- Hypothetical reasoning is a very general rule.
  Note: CCG effectively decomposes hypothetical reasoning to a set of local composition rules.
- Some attempts in the TLG literature:
  - supertagging [Moot, 2017]
  - proof net parsing [Morrill, 2010]
  - using word vectors to eliminate structural ambiguity [Moot, 2017]
- Incorporating these results in Hybrid TLG parsing is another major remaining issue.

Conclusion

- Hybrid TLG is a new version of Type-Logical Grammar which
  - has wide coverage on complex empirical phenomena
  - models the notion of 'syntactic movement' with lambda binding in the prosodic component
- Computational and formal properties of Hybrid TLG still remain to be explored.
  - some basic formal properties (e.g. decidability, parsing complexity) need to be clarified.
  - robust parser?

Acknowledgement

- The present research is supported by JSPS KAKENHI Grant Number 15K16732.

Appendix A: Prosodic and semantic types

Mapping from syntactic to prosodic types

Directional type:

For any directional type A,

- $\mathbf{Pros}(A) = \mathbf{st}$ (with **st** for 'string')

Appendix A: Prosodic and semantic types

Mapping from syntactic to prosodic types

Directional type:

For any directional type A,

- $\mathbf{Pros}(A) = \mathbf{st}$ (with **st** for 'string')

Non-directional complex type:

For any complex syntactic type $A \upharpoonright B$,

- $\mathbf{Pros}(A \upharpoonright B) = \mathbf{Pros}(B) \rightarrow \mathbf{Pros}(A)$

Note:

- For the mapping from syntactic types to prosodic types, only $\upharpoonright$ is effectively interpreted as functional.

Appendix A: Prosodic and semantic types

Mapping from syntactic to semantic types

Atomic types:

- $\mathbf{Sem}(\mathsf{NP}) = e$
- $\mathbf{Sem}(\mathsf{S}) = t$
- $\mathbf{Sem}(\mathsf{N}) = e \to t$

Complex types:

$$\mathbf{Sem}(A/B) = \mathbf{Sem}(B\backslash A) = \mathbf{Sem}(A\restriction B) = \mathbf{Sem}(B) \to \mathbf{Sem}(A).$$

- The semantic types are 'read off' from syntactic types by taking all of $/$, $\backslash$, $\restriction$ to be type constructors for functions.

Appendix A: Prosodic and semantic types

Some examples

- $\mathbf{Sem}(\mathsf{S}\restriction\mathsf{NP}) = e \to t$
- $\mathbf{Pros}(\mathsf{S}\restriction\mathsf{NP}) = \mathbf{st} \to \mathbf{st}$

- $\mathbf{Sem}(\mathsf{S}\restriction(\mathsf{S}\restriction\mathsf{NP})) = (e \to t) \to t$
- $\mathbf{Pros}(\mathsf{S}\restriction(\mathsf{S}\restriction\mathsf{NP})) = (\mathbf{st} \to \mathbf{st}) \to \mathbf{st}$

Appendix A: Prosodic and semantic types

Some examples

- $\textbf{Sem}(\mathsf{S}\restriction\mathsf{NP}) = e \to t$
- $\textbf{Pros}(\mathsf{S}\restriction\mathsf{NP}) = \textbf{st} \to \textbf{st}$

- $\textbf{Sem}(\mathsf{S}\restriction(\mathsf{S}\restriction\mathsf{NP})) = (e \to t) \to t$
- $\textbf{Pros}(\mathsf{S}\restriction(\mathsf{S}\restriction\mathsf{NP})) = (\textbf{st} \to \textbf{st}) \to \textbf{st}$

- $\textbf{Sem}(\mathsf{S}/\mathsf{NP}) = e \to t$
- $\textbf{Pros}(\mathsf{S}/\mathsf{NP}) = \textbf{st}$

- $\textbf{Sem}(\mathsf{S}\restriction(\mathsf{S}/\mathsf{NP})) = (e \to t) \to t$
- $\textbf{Pros}(\mathsf{S}\restriction(\mathsf{S}/\mathsf{NP})) = \textbf{st} \to \textbf{st}$

Appendix B: (A bit) more on decidability

- Proving Cut elimination seems relatively straightforward.
- The tricky part is that proofs come with term labelling (where these terms are *not* proof terms).
- And it is not immediately clear whether there is a deterministic algorithm for specifying all the possible terms for each node of the proof tree when going from root to leaves.
- Cf. [Oehrle, 1994]:

  Does the proof [of decidability of **LP***] carry over directly to the system of labeled deduction considered here? There is one sticking point: the label of the left-hand premise of the rule L $\rightarrow$ is not determined by the sub-terms of its conclusion.*

$$L\rightarrow \qquad \frac{\Gamma \vdash_X \mathsf{u}\colon A \rightsquigarrow u' \quad (\mathsf{tu})\colon B \rightsquigarrow (t'u'), \Delta \vdash_{Y \dot{\sqcup} FA(A)} \mathsf{v}\colon C \rightsquigarrow v'}{\Gamma, \mathsf{t}\colon A \rightarrow B \rightsquigarrow t', \Delta \vdash_{X \dot{\sqcup} Y} \mathsf{v}\colon C \rightsquigarrow v'}$$

Appendix C: λ grammars and coordination

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

Coordination

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

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

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

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

Appendix C: λ grammars and coordination (cont.)

Coordination of **st**$\rightarrow$**st** functions:

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

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

(31)

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

Appendix C: λ grammars and coordination (cont.)

(32)

$$\dfrac{\dfrac{\mathtt{sandy};\ \mathbf{s};\ \mathsf{NP} \qquad \dfrac{\lambda\varphi_1\lambda\varphi_2.\varphi_2 \bullet \mathtt{met} \bullet \varphi_1;\ \mathbf{meet};\ (\mathsf{S}\restriction\mathsf{NP})\restriction\mathsf{NP} \qquad \begin{bmatrix}\varphi_1; \\ x;\ \mathsf{NP}\end{bmatrix}^1}{\lambda\varphi_2.\varphi_2 \bullet \mathtt{met} \bullet \varphi_1;\ \mathbf{meet}(x);\ \mathsf{S}\restriction\mathsf{NP}}\ \restriction\mathsf{E}}{\mathtt{sandy} \bullet \mathtt{met} \bullet \varphi_1;\ \mathbf{meet}(x)(\mathbf{s});\ \mathsf{S}}\ \restriction\mathsf{E}}{\lambda\varphi_1.\mathtt{sandy} \bullet \mathtt{met} \bullet \varphi_1;\ \lambda x.\mathbf{meet}(x)(\mathbf{s});\ \mathsf{S}\restriction\mathsf{NP}}\ \restriction\mathsf{I}^1$$

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

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

(35) *John bought and ate the fish.
'John bought the fish and the fish ate John.'

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