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Abstract Categorial Grammars as a Model of the Syntax-Semantics Interface for TAG

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Overview

1. Introduction
   - Motivations
   - Mathematical Notions
2. Abstract Categorial Grammars
   - Definitions and Notations
   - Properties
   - ACG as a Model for the Syntax-Semantics Interface
3. TAG as ACG
   - Substitution and Adjunction as Function Application
   - Generalized Derivation Trees
   - Semantic Construction
   - TAG Encoding
4. Discussion

Abstract Categorial Grammars (de Groote 2001)

Main Features

- ACG is a (grammatical) framework
- An ACG $\mathscr{G}$ generates two languages:
  - The abstract language $\mathcal{A}(\mathscr{G})$
  - The object language $\mathcal{O}(\mathscr{G})$

  Abstract language: Admissible *structures*
  Object language: *Realizations* of the admissible structures
- Both languages are the same objects: sets of (linear) λ-terms

Remark (Examples)

Most of the examples of this presentation can be run with the he ACG toolkit from the example files (`http://calligramme.loria.fr/acg#Software` and `http://hal.inria.fr/hal-01583962/file/examples.zip`)

Affiliations (I)

A type-theoretic view on grammars and grammatical composition

- Finite set of atomic types (e.g., np, s, n, etc.)
- Type formation rules (e.g., $np \rightarrow s$ is a type)
- Grammatical composition follows typing rules (e.g., $np, np \rightarrow s \vdash s$, $np \leftarrow n, n \vdash np$)

Applications

Grammatical formalisms:

- AB and classical categorial grammars (Ajdukiewicz 1935; Bar-Hillel 1953): directed application
- Lambek grammars (Lambek 1958): hypothetical reasonning
- Formulas-as-types and proofs-as-terms (Howard 1980; Benthem 1986) to provide Lambek Grammars with Montague semantics

Types and Signatures

Definition (Implicative types)

Implicative types built upon A are $\mathscr{T}_A ::= A \mid \mathscr{T}_A \multimap \mathscr{T}_A \mid \mathscr{T}_A \to \mathscr{T}_A$

Definition (Higher-Order Signatures)

A *higher-order signature* Σ is a triple $\Sigma = \langle A, C, \tau \rangle$ where:

- A is a finite set of atomic types;
- C is a finite set of constants;
- $\tau : C \to \mathscr{T}_A$ is a function assigning types to constants.

Example

- $A = \{\mathsf{np}, \mathsf{n}, \mathsf{s}\}$
- $C = \{c_{John}, c_{sleeps}, \ldots\}$
- $\tau(c_{John}) = \mathsf{np}$, $\tau(c_{sleeps}) = \mathsf{np} \multimap \mathsf{s}$, ...

Terms

Definition (λ-Terms $\Lambda(\Sigma)$)

X an infinite countable set of λ-variables and $\Sigma = \langle A, C, \tau \rangle$ a signature. $\Lambda(\Sigma)$ consists of:

- $c \in C$
- $x \in X$
- $\lambda^{\circ} x.t$ (x occurs free in t exactly once);
- $\lambda x.t$
- $(t\ u)$

β-conversion

$$(\lambda^{\circ} x.t)\ u \rightarrow_{\beta} t[u/x]$$

Type System

Definition (Typing Judgment)

$\Gamma; \Delta \vdash_\Sigma t : \alpha$ where:

- Γ is a finite *set* of non-linear variable typing declarations of the form $x : \beta$;
- Δ is a finite *multi-set* of linear variable typing declarations of the form $x : \beta$.

Typing rules

$$\frac{}{\Gamma; x : \alpha \vdash_\Sigma x : \alpha}\ \text{(lin. var.)} \qquad \frac{}{; \vdash_\Sigma c : \tau(c)}\ \text{(const.)} \qquad \frac{}{\Gamma, x : \alpha; \vdash_\Sigma x : \alpha}\ \text{(var.)}$$

$$\frac{\Gamma; \Delta \vdash_\Sigma t : \beta}{\Gamma, x : \alpha; \Delta \vdash_\Sigma t : \beta}\ \text{(weak.)}$$

$$\frac{\Gamma; \Delta, x : \alpha \vdash_\Sigma t : \beta}{\Gamma; \Delta \vdash_\Sigma \lambda^\circ x.t : \alpha \multimap \beta}\ \text{(lin. abs.)} \qquad \frac{\Gamma; \Delta_1 \vdash_\Sigma t : \alpha \multimap \beta \quad \Gamma; \Delta_2 \vdash_\Sigma u : \alpha}{\Gamma; \Delta_1, \Delta_2 \vdash_\Sigma (t\ u) : \beta}\ \text{(lin. app.)}$$

$$\frac{\Gamma, x : \alpha; \Delta \vdash_\Sigma t : \beta}{\Gamma; \Delta \vdash_\Sigma \lambda x.t : \alpha \to \beta}\ \text{(abs.)} \qquad \frac{\Gamma; \Delta \vdash_\Sigma t : \alpha \to \beta \quad \Gamma; \vdash_\Sigma u : \alpha}{\Gamma; \Delta \vdash_\Sigma (t\ u) : \beta}\ \text{(app.)}$$

Notations

- $\lambda x.\lambda y.t = \lambda x\ y.t$
- $((t\ u)\ v)\ w) = t\ u\ v\ w$
- $\alpha \to (\beta \to (\gamma \to \delta)) = \alpha \to \beta \to \gamma \to \delta$
- infix notation: if + is a constant, $(+\ f)\ g = f + g$

Example: The Vocabulary of Strings $\Sigma_{strings}$

$\Sigma_{strings}$

Types

- o is the unique atomic type
- $\sigma = o \multimap o$ the type of strings (defined)

Constants

- $John, sleeps, a, b, \ldots : \sigma$
- $\# : o$
- we define
  - an infix operator $+ = \lambda^\circ f\ g.\lambda^\circ z.f(g\ z) : \sigma \multimap \sigma \multimap \sigma$
  - $\epsilon = \lambda^\circ x.x : \sigma$

Example (ϵ is neutral for +)

$$
\begin{aligned}
a + \epsilon &= + \ a \ \epsilon \\
&= (\lambda^\circ f\ g.\lambda^\circ z.f(g\ z))\ a\ \epsilon \\
&\rightarrow_\beta (\lambda^\circ g.\lambda^\circ z.a(g\ z))\ \epsilon \\
&\rightarrow_\beta \lambda^\circ z.a\ (\epsilon\ z) \\
&\rightarrow_\beta \lambda^\circ z.a\ z \\
&= a
\end{aligned}
$$

Example

Remark

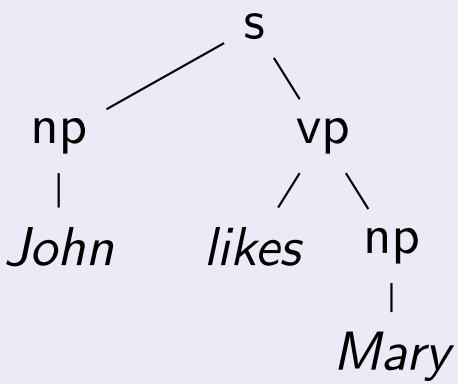
$$\begin{aligned}(t + u)\ z &= ((\lambda^\circ f\ g.\lambda^\circ z'.f\ (g\ z'))\ t\ u)\ z \\ &\rightarrow_\beta (\lambda^\circ z'.t\ (u\ z'))\ z \\ &\rightarrow_\beta t\ (u\ z)\end{aligned}$$

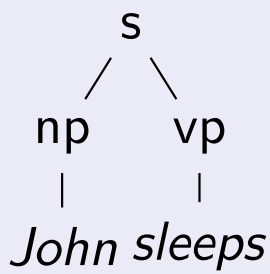
Example (Associativity of +)

$$\begin{aligned}f + (g + h) &= (\lambda^\circ f'\ g'.\lambda^\circ z.f'\ (g'\ z))\ f\ (g + h) \\ &\rightarrow_\beta \lambda^\circ z.f\ ((g + h)\ z) \\ &\rightarrow_\beta \lambda^\circ z.f\ (g\ (h\ z)) \\ (f + g) + h &= (\lambda^\circ f'\ g'.\lambda^\circ z.f'\ (g'\ z))\ (f + g)\ h \\ &\rightarrow_\beta \lambda^\circ z.(f + g)(h\ z) \\ &= \lambda^\circ z.f(g(h\ z))\end{aligned}$$

Example: The Vocabulary of Trees Σ_{trees}

Trees Built on a Ranked Alphabet





$s_2\ (np_1\ \textit{John})\ (vp_2\ \textit{likes}\ (np_1\ \textit{Mary}))$ $s_2\ (np_1\ \textit{John})\ (vp_1\ \textit{sleeps})$

Alphabet

- s of arity 2 (non-terminal)
- np of arity 1 (non-terminal)
- vp? vp_1 of arity 1 and vp_2 of arity 2 (non-terminals)
- *John* of arity 0 (terminal)

(Higher-Order) Signature

- $s_2 : \tau \multimap \tau \multimap \tau$
- $np_1 : \tau \multimap \tau$
- $vp_1 : \tau \multimap \tau$, $vp_2 : \tau \multimap \tau \multimap \tau$
- $\textit{John} : \tau$

Affiliations (II)

Two levels for the grammatical architecture (Curry 1961)

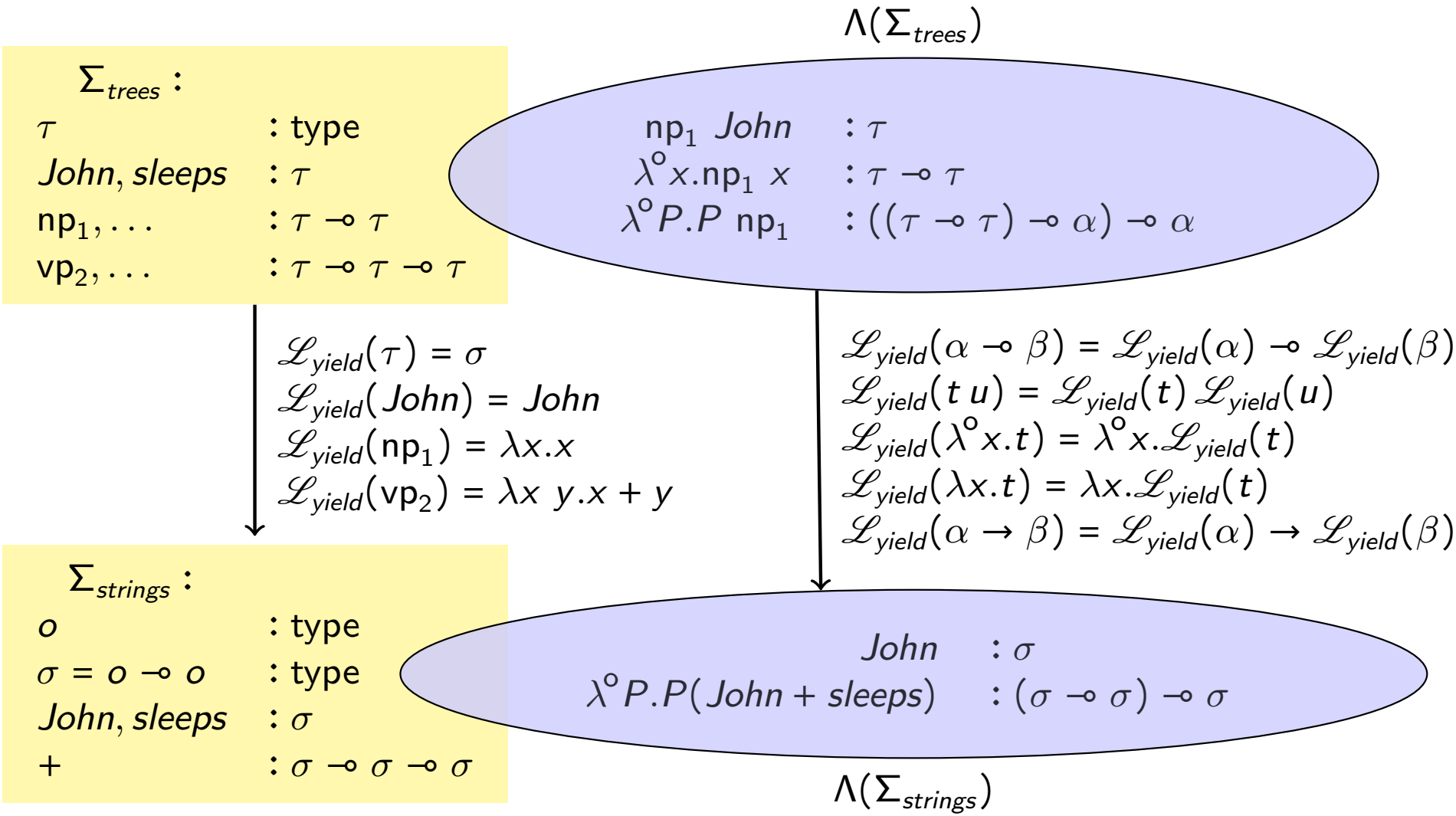
- Tectogrammatics: "the study of [abstract] grammatical structure in itself" (e.g., the derivations)
- Phenogrammatics: "the study of the way [abstract] phrases are represented by expressions" (e.g., the yields)

The combinatorial properties of words (e.g., transitive verbs expect two np) are not described at the same place as their combinations are (e.g., SVO, SOV, etc.). The functorial types can be undirected.

Applications

- Type theoretical grammar and GF (Ranta 1994; Ranta 2004)
- Labeled categorial systems (Oehrle 1994; Oehrle 1995),
- λ-grammars (Muskens 2001; Muskens 2003)
- etc.

Relating $\Lambda(\Sigma_{trees})$ to $\Sigma_{strings}$ with $\mathscr{L}_{yield}$



Abstract Categorial Grammars

Definition (Lexicon)

$\Sigma_1 = \langle A_1, C_1, \tau_1 \rangle$ and $\Sigma_2 = \langle A_2, C_2, \tau_2 \rangle$ are two higher-order signatures.
A *lexicon* $\mathscr{L} = \langle F, G \rangle$ from Σ_1 to Σ_2 is such that:

- $F : \mathscr{T}_{A_1} \to \mathscr{T}_{A_2}$ is an homomorphism
- $G : \Lambda(\Sigma_1) \to \Lambda(\Sigma_2)$ is an homomorphism
- F and G are such that for all $c \in C_1$, $\vdash_{\Sigma_2} G(c) : F(\tau_1(c))$ is provable.

Notation: We use $\mathscr{L}$ instead of F or G.

Abstract Categorial Grammars

(de Groote 2001)

Definition (Abstract Categorial Grammar)

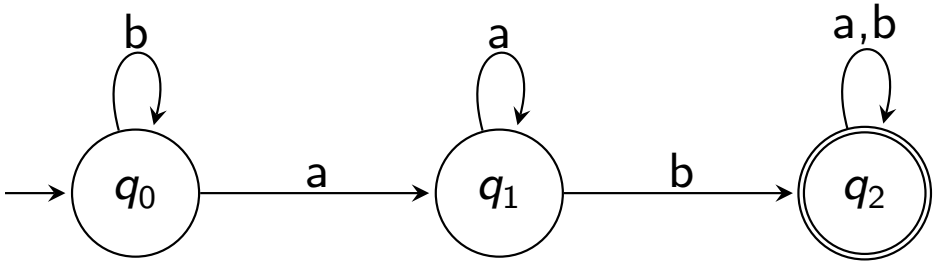
An *abstract categorial grammar* is a quadruple $\mathscr{G} = \langle \Sigma_1, \Sigma_2, \mathscr{L}, s \rangle$ where:

- Σ_1 and Σ_2 are higher-order signatures
- $\mathscr{L} : \Sigma_1 \to \Sigma_2$ is a lexicon.
- $s \in \mathscr{T}_{A_1}$ is the *distinguished type* of the grammar.

Notations:

$$\left.\begin{array}{ll} \mathscr{L}(\alpha) & = \beta \\ \mathscr{G}(\alpha) & = \beta \\ \alpha & := \beta \\ [\![\alpha]\!] & = \beta \end{array}\right\} \text{ all denote that the interpretation of } \alpha \text{ is } \beta$$

FSA Example



A signature Σ_{FSA} for transitions to q_2

Atomic Types q_0, q_1, and q_2

Constants

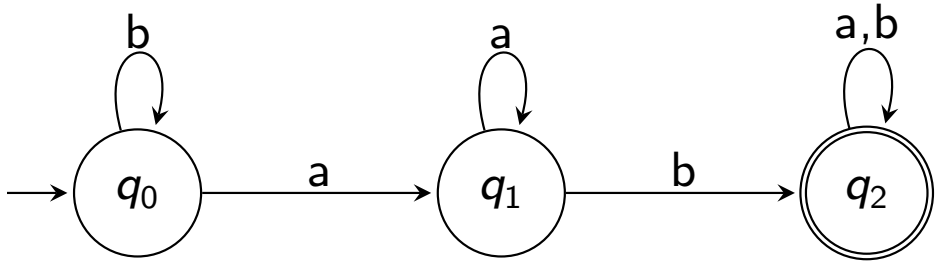
$$\begin{array}{llllll} \delta_{q_0,a} & : q_1 \multimap q_0 & \delta_{q_1,a} & : q_1 \multimap q_1 & \delta_{q_2,a} & : q_2 \multimap q_2 \\ \delta_{q_0,b} & : q_0 \multimap q_0 & \delta_{q_1,b} & : q_2 \multimap q_1 & \delta_{q_2,b} & : q_2 \multimap q_2 \\ F & : q_2 & & & & \end{array}$$

$$\delta_{q_0,a}\ \overbrace{(\delta_{q_1,a}\ \overbrace{(\delta_{q_1,b}\ F)}^{q_1})}^{q_1} : q_0$$

Remark

q_2 is reachable from q_i iff there exists $t : q_i \in \Lambda(\Sigma_{FSA})$

FSA Example (cont'd)



Σ_{FSA} :
$\delta_{q_0,a}\colon q_1 \multimap q_0$ $\delta_{q_1,a}\colon q_1 \multimap q_1$ $\delta_{q_2,a}\colon q_2 \multimap q_2$
$\delta_{q_0,b}\colon q_0 \multimap q_0$ $\delta_{q_1,b}\colon q_2 \multimap q_1$ $\delta_{q_2,b}\colon q_2 \multimap q_2$
$F\colon q_2$

$\Sigma_{strings}$: $a, b : o \multimap o$
$\# : o$

The $\mathscr{G}_{FSA}$ ACG

Type interpretation $q_0, q_1, q_2 :=_{FSA} o$

Constant interpretation

$\delta_{q_0,a} :=_{FSA} \lambda z.a\ z$ $\delta_{q_1,a} :=_{FSA} a$ $\delta_{q_2,a} :=_{FSA} a$
$\delta_{q_0,b} :=_{FSA} b$ $\delta_{q_1,b} :=_{FSA} b$ $\delta_{q_2,b} :=_{FSA} b$
$F :=_{FSA} \#$

Distinguished type q_0

$$\begin{aligned}\llbracket \delta_{q_1,b}\ F \rrbracket_{FSA} &= \llbracket \delta_{q_1,b} \rrbracket_{FSA}\ \llbracket F \rrbracket_{FSA} \\ &= b\ \#\end{aligned}$$

$$\begin{aligned}\delta_{q_1,a}(\delta_{q_1,b}\ F)) &:=_{FSA} a(b\ \#) \\ \delta_{q_0,a}\ (\delta_{q_1,a}(\delta_{q_1,b}\ F)) &:=_{FSA} a(a(b\ \#))\end{aligned}$$

Languages of an ACG

Definition (Abstract and Object Languages)

Let $\mathscr{G} = \langle \Sigma_1, \Sigma_2, \mathscr{L}, s \rangle$ be an ACG.
The *abstract language* is defined by

$$\mathcal{A}(\mathscr{G}) = \{t \in \Lambda(\Sigma_1) \mid \vdash_{\Sigma_1} t : s \text{ is derivable}\}$$

The *object language* is defined by

$$\mathcal{O}(\mathscr{G}) = \{u \in \Lambda(\Sigma_2) \mid \exists t \in \mathcal{A}(\mathscr{G}) \text{ s.t. } u = \mathscr{L}(t)\}$$

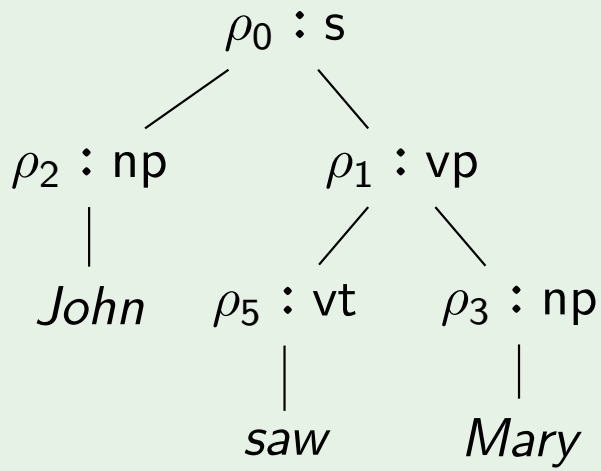
ACG parsing

- $u \in \Lambda(\Sigma_2)$
- Does $t \in \Lambda(\Sigma_1)$ exists such that $\mathscr{L}(t) = u$?

CFG into ACG Encoding

Example (CFG)

$\rho_0 : \quad s \quad \rightarrow np\ vp$
$\rho_1 : \quad vp \rightarrow vt\ np$
$\rho_2 : \quad np \rightarrow \mathit{John}$
$\rho_3 : \quad np \rightarrow \mathit{Mary}$
$\rho_4 : \quad vp \rightarrow \mathit{left}$
$\rho_5 : \quad vt \rightarrow \mathit{saw}$



	Σ_{Rules}		$\Sigma_{Strings}$	
np, vp, vt, s	: atomic types	$:=_{CFG}$	σ	
ρ_0	: np $\multimap$ vp $\multimap$ s	$:=_{CFG}$	$\lambda xy.x + y$	$: \sigma \multimap \sigma \multimap \sigma$
ρ_1	: vt $\multimap$ np $\multimap$ vp	$:=_{CFG}$	$\lambda xy.x + y$	$: \sigma \multimap \sigma \multimap \sigma$
ρ_2	: np	$:=_{CFG}$	*John*	$: \sigma$
ρ_3	: np	$:=_{CFG}$	*Mary*	$: \sigma$
ρ_4	: vp	$:=_{CFG}$	*left*	$: \sigma$
ρ_5	: vt	$:=_{CFG}$	*saw*	$: \sigma$

CFG into ACG Encoding (cont'd)

CFG as ACG

	Σ_{Rules}		$\Sigma_{Strings}$	
np, vp, vt, s	: atomic types	$:=_{CFG}$	σ	
ρ_0	: np $\multimap$ vp $\multimap$ s	$:=_{CFG}$	$\lambda xy.x + y$	: $\sigma \multimap \sigma \multimap \sigma$
ρ_1	: vt $\multimap$ np $\multimap$ vp	$:=_{CFG}$	$\lambda xy.x + y$	: $\sigma \multimap \sigma \multimap \sigma$
ρ_2	: np	$:=_{CFG}$	*John*	: σ
ρ_3	: np	$:=_{CFG}$	*Mary*	: σ
ρ_4	: vp	$:=_{CFG}$	*left*	: σ
ρ_5	: vt	$:=_{CFG}$	*saw*	: σ

$$
\begin{aligned}
\mathscr{L}_{CFG}(\rho_0\,\rho_2\,(\rho_1\,\rho_5\rho_3) : \mathrm{s}) &= (\lambda xy.x + y)\,John((\lambda xy.x + y)\,saw\,Mary) \\
&\rightarrow_\beta (\lambda y.John + y)((\lambda y.saw + y)\,Mary) \\
&\rightarrow_\beta (\lambda y.John + y)(saw + Mary) \\
&\rightarrow_\beta John + (saw + Mary)
\end{aligned}
$$

About Linearity

Can we generate $\{\omega\omega | \omega \in L\}$? Yes

Example (L is the langage of any sequence of a's and b's)

$$
\begin{array}{llll}
\mathsf{s}' & : \mathit{type} & :=_{Dup} & \sigma \\
\mathsf{s} & : \mathit{type} & :=_{Dup} & (\sigma \multimap \sigma \multimap \sigma) \multimap \sigma \\
\varepsilon & : \mathsf{s} & :=_{Dup} & \lambda f.f\ \epsilon\ \epsilon \\
A & : \mathsf{s} \multimap \mathsf{s} & :=_{Dup} & \lambda^{\circ} f.\lambda^{\circ} g.f(\lambda^{\circ} x\ y.g\ (a+x)\ (a+y)) \\
B & : \mathsf{s} \multimap \mathsf{s} & :=_{Dup} & \lambda^{\circ} f.\lambda^{\circ} g.f(\lambda^{\circ} x\ y.g\ (b+x)\ (b+y)) \\
C & : \mathsf{s} \multimap \mathsf{s}' & :=_{Dup} & \lambda^{\circ} f.f(\lambda^{\circ} x\ y.x+y)
\end{array}
$$

$$
C\ (A\ (B\ (B\ \varepsilon))) : \mathsf{s}' \quad :=_{Dup} \quad a+b+b+a+b+b : \sigma
$$

ACG Hierarchy

Definition (Order)

The order $\text{ord}(\tau)$ of a type $\tau \in \mathscr{T}_A$ is inductively defined as:

- $\text{ord}(a) = 1$ if $a \in A$
- $\text{ord}(\alpha \multimap \beta) = \text{ord}(\alpha \to \beta) = \max(1 + \text{ord}(\alpha), \text{ord}(\beta))$ otherwise

Ex:

- $\text{ord}(\text{np} \multimap \text{s}) = 2$
- $\text{ord}((\sigma \multimap \sigma \multimap \sigma) \multimap \sigma) = 4$ ($\sigma = o \multimap o$ is not atomic!)

Definition (Order and complexity of an ACG; ACG hierarchy)

- The *order* of an ACG is the maximum of the orders of its abstract constants.
- The *complexity* of an ACG is the maximum of the orders of the realizations of its atomic types.

ACG: Formal Properties

(Groote and Pogodalla 2004; Salvati 2006; Kanazawa and Salvati 2007; Kanazawa 2009), (Salvati 2007; Kanazawa 2007; Kanazawa 2008; Kanazawa 2017)

Generative Power

	String language	Tree language
$ACG_{(1,n)}$	finite	finite
$ACG_{(2,1)}$	regular	regular
$ACG_{(2,2)}$	context-free	linear contex-free
$ACG_{(2,3)}$	non-duplicating macro well-nested multiple context-free	$\subset$ 1-visit attribute grammar
$ACG_{(2,4)}$	mildly context-sensitive (multiple context-free)	hyperedge replacement gram.
$ACG_{(2,4+n)}$	$ACG_{(2,4)}$	$ACG_{(2,4)}$
$ACG_{(3,n)}$	MELL decidability	MELL decidability

Complexity

- $ACG_{(2,n)}$ parsing is polynomial, equivalent to datalog querying
- Reduces to best cases with standard techniques (magic set rewriting) with correct prefix Earley algorithms

Higher Order Logic as an Object Language

The Σ_{logic} vocabulary

Types e, t

Constants

Logical constants

$\wedge$	$: t \multimap t \multimap t$	$\vee$	$: t \multimap t \multimap t$
$\Rightarrow$	$: t \multimap t \multimap t$	$\neg$	$: t \multimap t$
$\exists$	$: (e \to t) \multimap t$	$\forall$	$: (e \to t) \multimap t$

Non-logical constants

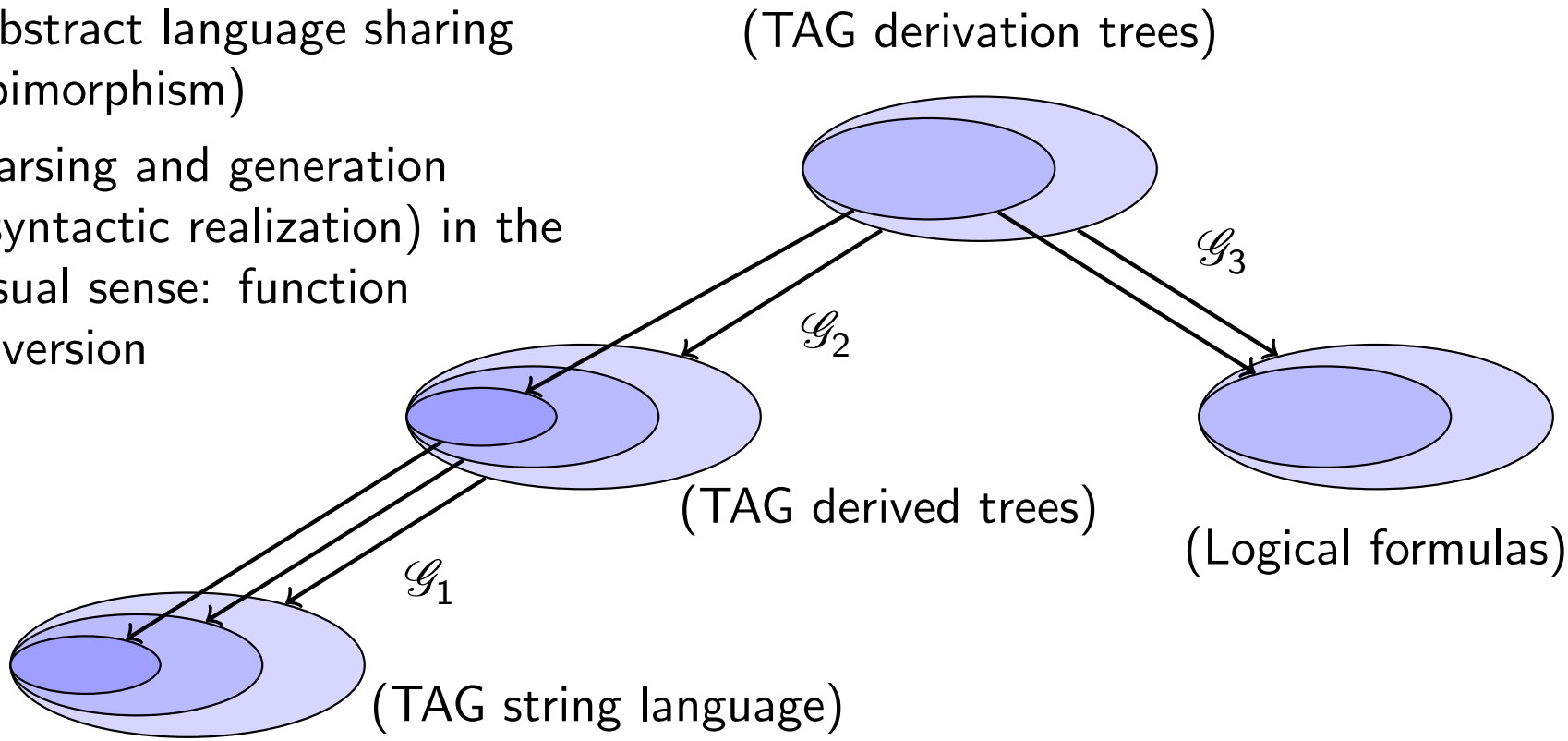
john	$: e$	love, chase	$: e \multimap e \multimap t$
sleep	$: e \multimap t$	seemingly, usually	$: t \multimap t$
seem	$: e \multimap (e \multimap t) \multimap t$	claim, think	$: e \multimap t \multimap t$
WHO	$: (e \multimap t) \multimap t$	big, black, dog, cat	$: e \multimap t$

ACG parsing works exactly the same, whatever the object language

ACG Architecture

Composition Ability

- Functional composition
- Abstract language sharing (bimorphism)
- Parsing and generation (syntactic realization) in the usual sense: function inversion

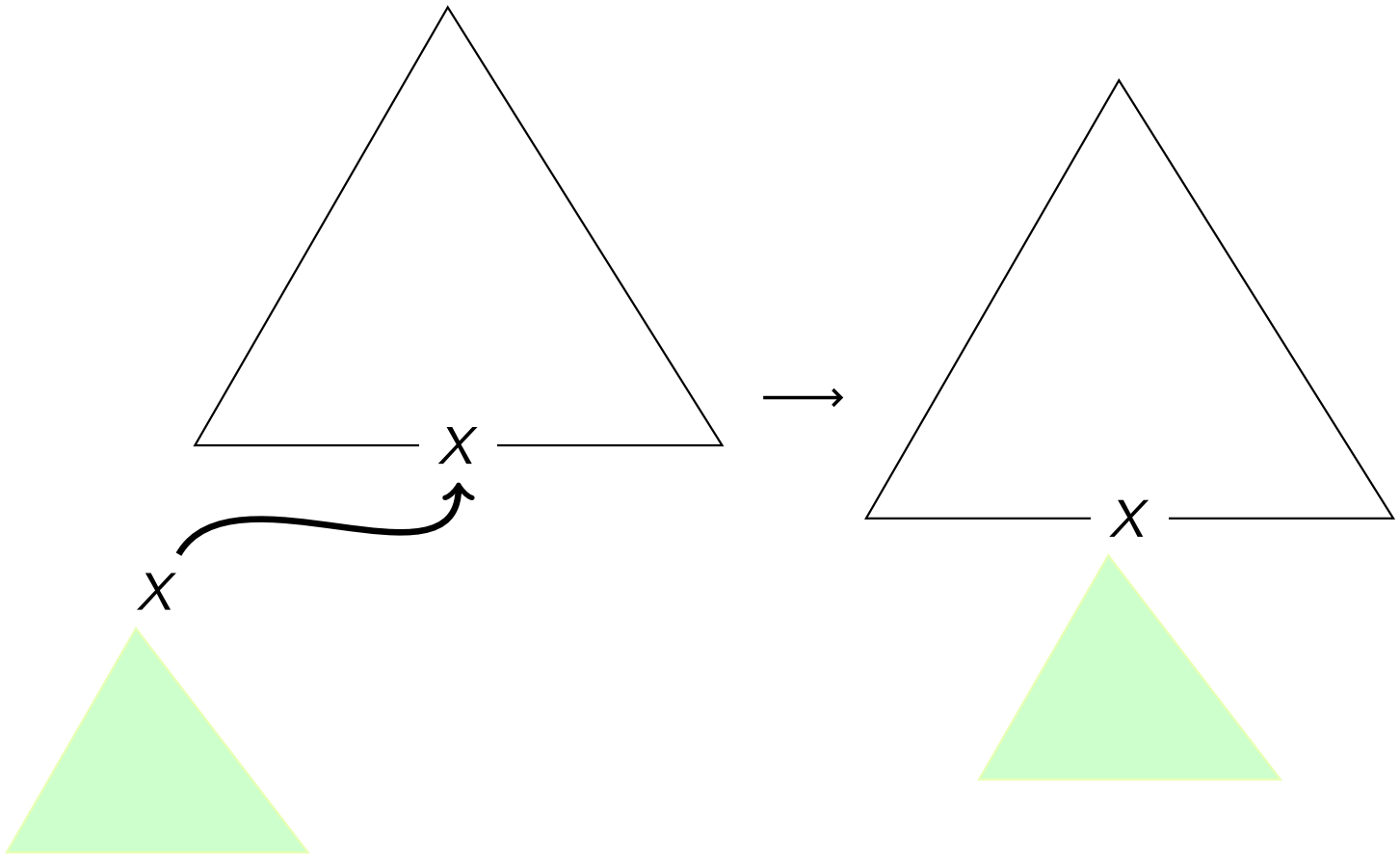


Tree Adjoining Grammars

Main features

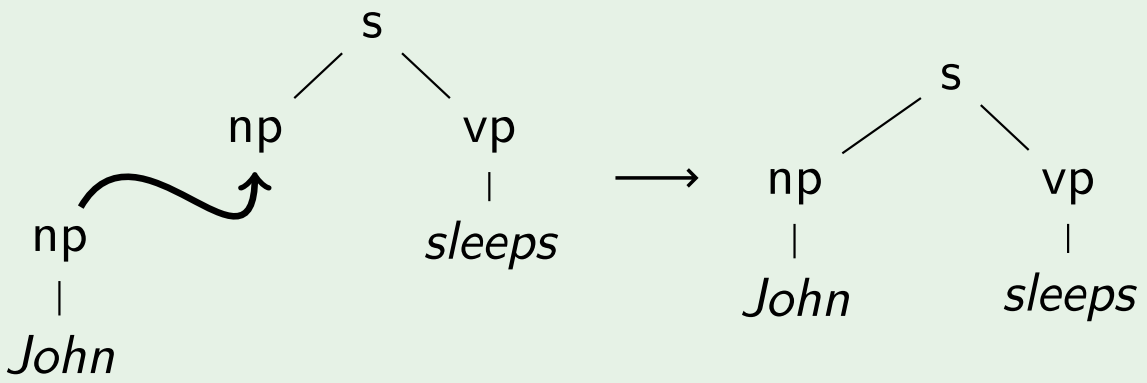
- Tree grammars with two operations
  - Substitution
  - Adjunction
- $L(CFG) \subsetneq L(TAG) \subsetneq L(WnMCFG)$
- Allows for an *extended domain of locality* (Joshi 1994): locally specify (syntactic and semantic) dependencies between parts that can occur arbitrarily far from each other at the surface level at the end of a derivation

Substitution



Substitution as Functional Application

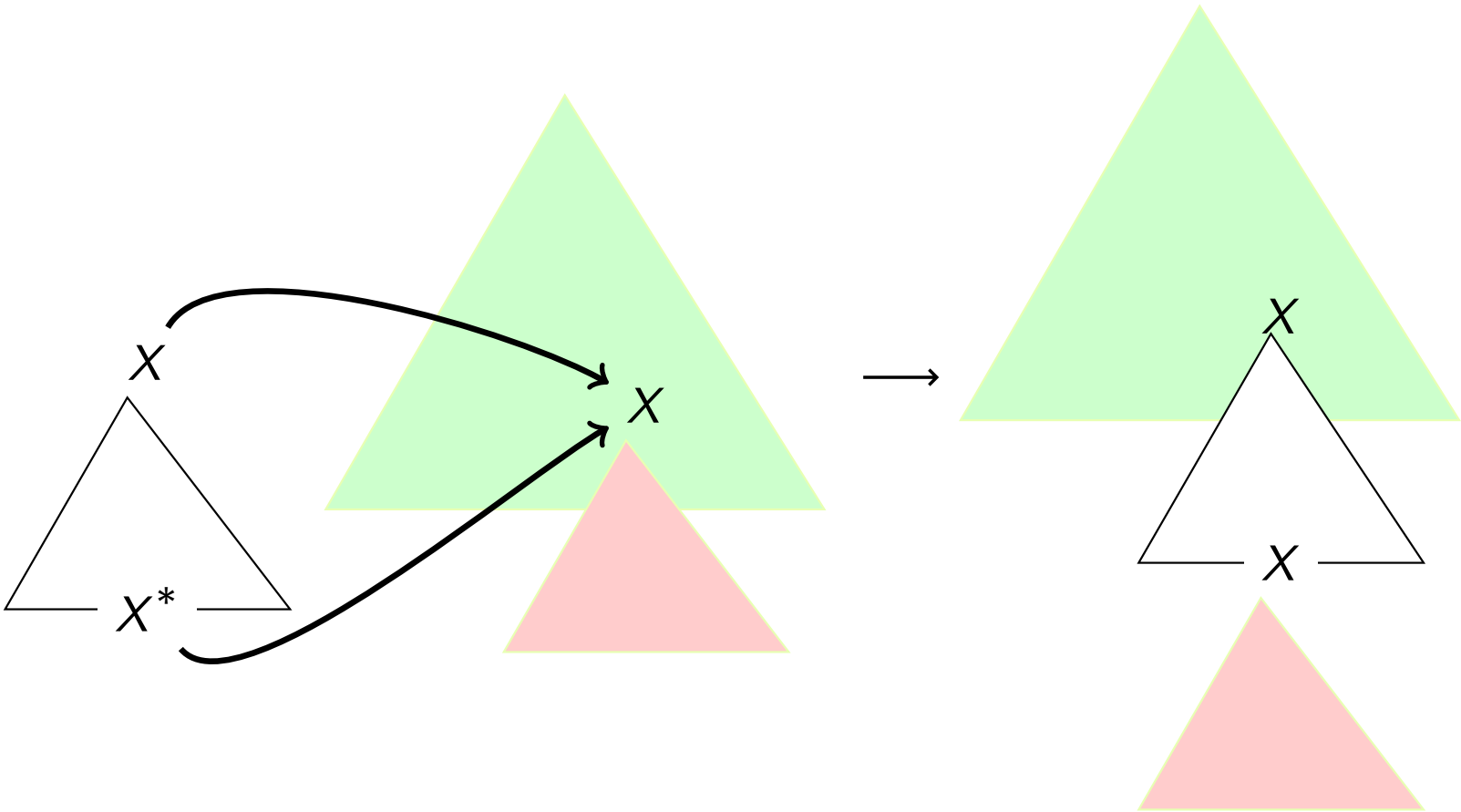
Example



$$\left(\lambda^{\circ}x.\ \begin{array}{ccc} & \mathsf{s} & \\ x & & \mathsf{vp} \\ & & \mid \\ & & \textit{sleeps} \end{array}\right) \quad \left(\begin{array}{c} \mathsf{np} \\ \mid \\ \textit{John} \end{array}\right) \quad \rightarrow_{\beta} \quad \begin{array}{ccc} & \mathsf{s} & \\ \mathsf{np} & & \mathsf{vp} \\ \mid & & \mid \\ \textit{John} & & \textit{sleeps} \end{array}$$

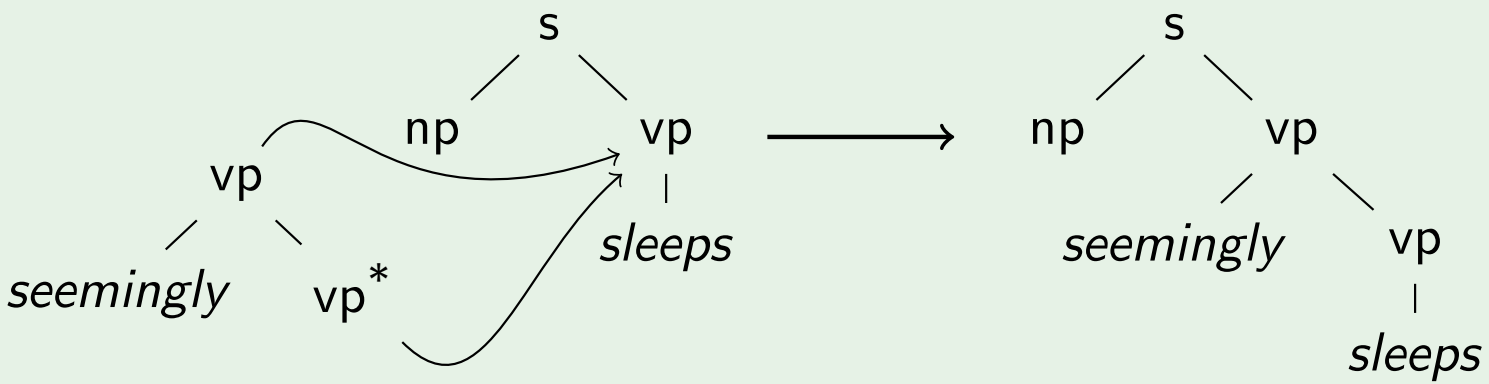
$$(\lambda^{\circ}x.\mathsf{s}_2\ x\ (\mathsf{vp}_1\ \textit{sleeps}))\quad (\mathsf{np}_1\ \textit{John}) \quad \rightarrow_{\beta} \quad \mathsf{s}_2\ (\mathsf{np}_1\ \textit{John})\ (\mathsf{vp}_1 \textit{sleeps})$$

Adjunction



Auxiliary Trees as Functions

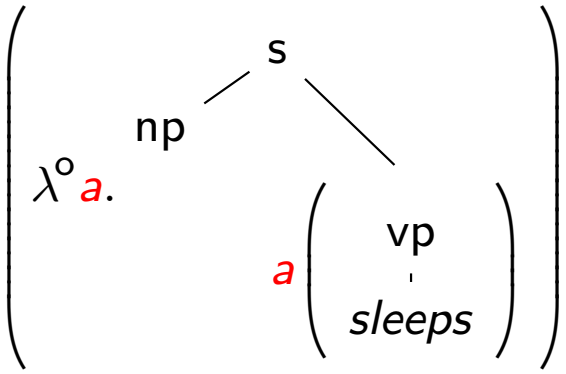
Example



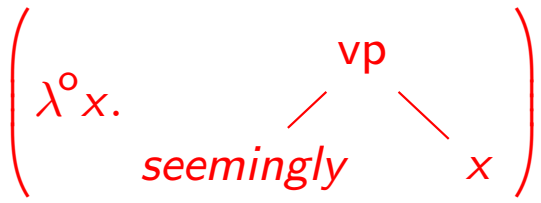
$$\left(\lambda^{\circ}x.\ \begin{array}{ccc} & \text{vp} & \\ \text{seemingly} & & x \end{array}\right)\ \begin{array}{c}\text{vp}\\ |\\ \textit{sleeps}\end{array} \rightarrow_{\beta} \begin{array}{ccc} & \text{vp} & \\ \text{seemingly} & & \text{vp} \\ & & | \\ & & \textit{sleeps} \end{array}$$

$$\left(\lambda a.\ \begin{array}{ccc} \text{np} & & a\left(\begin{array}{c}\text{vp}\\ |\\ \textit{sleeps}\end{array}\right) \end{array}\right)\left(\lambda^{\circ}x.\ \begin{array}{ccc} & \text{vp} & \\ \text{seemingly} & & x \end{array}\right)$$

Adjunction as Functional Application

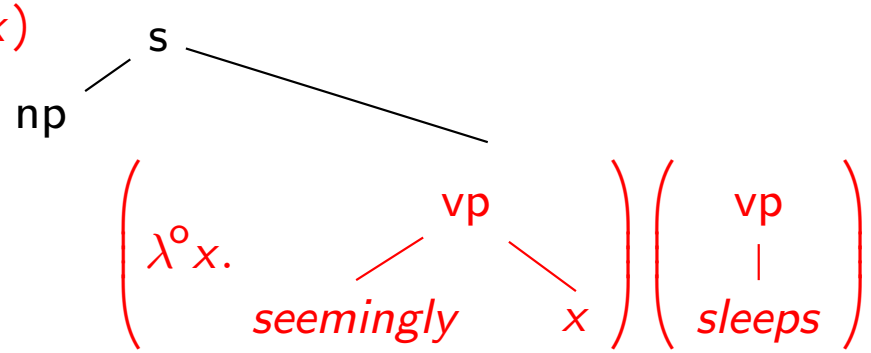


$(\lambda^\circ a.\mathrm{s}_2\ \mathrm{np}\ a(\mathrm{vp}_1\ \mathit{sleeps}))$



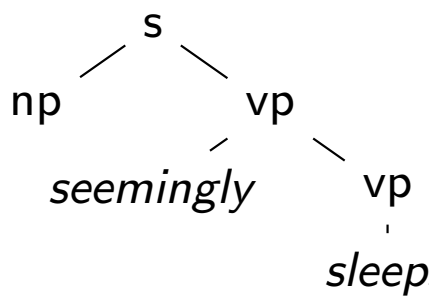
$(\lambda^\circ x.\mathrm{vp}_2\ \mathit{seemingly}\ x)$

$\rightarrow_\beta$



$\mathrm{s}_2\ \mathrm{np}\ ((\lambda^\circ x.\mathrm{vp}_2\ \mathit{seemingly}\ x)(\mathrm{vp}_1\ \mathit{sleeps}))$

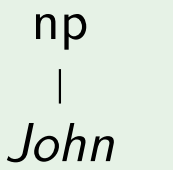
$\rightarrow_\beta$



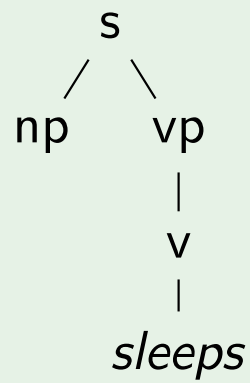
$\mathrm{s}_2\ \mathrm{np}\ (\mathrm{vp}_2\ \mathit{seemingly}\ (\mathrm{vp}_1\ \mathit{sleeps}))$

Terms (of $\Lambda(\Sigma_{trees})$) for TAG Operations

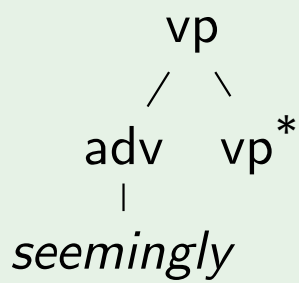
$\gamma_{John} \quad = \mathrm{np}_1\ \mathit{John} : \tau$



$\gamma_{sleeps} \quad = \lambda^{\circ} S\ a\ s.S\ (\mathrm{s}_2\ s\ (a\ (\mathrm{vp}_1\ (\mathrm{v}_1\ \mathit{sleeps}))))$
$\quad : (\tau \multimap \tau) \multimap (\tau \multimap \tau) \multimap \tau \multimap \tau$



$\gamma_{seemingly} \quad = \lambda^{\circ} a\ v.a\ (\mathrm{vp}_2\ (\mathrm{adv}_1\ \mathit{seemingly})\ v)$
$\quad : (\tau \multimap \tau) \multimap \tau \multimap \tau$



$I \quad = \lambda^{\circ} x.x : \tau \multimap \tau$

$\gamma_{sleeps}\ I\ (\gamma_{seemingly}\ I)\ \gamma_{John} \quad \rightarrow_{\beta} \mathrm{s}_2\ (\mathrm{np}_1\ \mathit{John})\ (\mathrm{vp}_2\ (\mathrm{adv}_1\ \mathit{seemingly})\ (\mathrm{vp}_1\ (\mathrm{v}_1\ \mathit{sleeps})))$
$\gamma_{sleeps}\ I\ (\gamma_{seemingly}\ I)\ \gamma_{John} \quad :=_{yield} \mathit{John} + \mathit{seemingly} + \mathit{sleeps}$

So far...

- A vocabulary for strings $\Sigma_{strings}$
- A vocabulary for trees Σ_{trees}
- Yield of a tree as an ACG $\mathscr{G}_{yield}$
- TAG operations on trees as applications of terms of $\Lambda(\Sigma_{trees})$

PB: Not only TAG derived trees (e.g., $\gamma_{seemingly}\ I : \tau \multimap \tau$ and $\gamma_{John} : \tau$)

TAG as ACG (1st part)

Category Induced Constraints

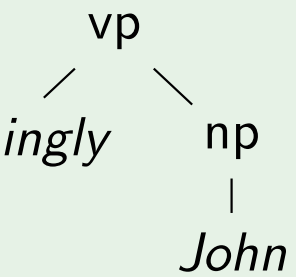
- The site of an adjunction has the same category as the root (and foot) node of the auxiliary tree
- The site of a substitution has the same category as the root node of the substituted tree

	$\Sigma_{derivations}$		$\Lambda(\Sigma_{trees})$
c_{John}	$: \mathrm{np}$	$:=_{\text{derived trees}}\ \gamma_{John}$	$: \tau$
$c_{seemingly}$	$: (\mathrm{vp} \multimap \mathrm{vp}) \multimap \mathrm{vp} \multimap \mathrm{vp}$	$:=_{\text{derived trees}}\ \gamma_{seemingly}$	$: (\tau \multimap \tau) \multimap \tau \multimap \tau$
$\mathrm{np}, \mathrm{vp}, \mathrm{s} \ldots$	$:$ types	$:=_{\text{derived trees}}\ \tau$	
I_{vp}	$: \mathrm{vp} \multimap \mathrm{vp}$	$:=_{\text{derived trees}}\ I$	$: \tau \multimap \tau$

Example

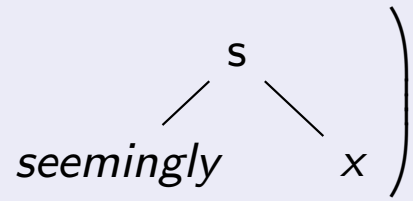
$c_{seemingly}\ I_{\mathrm{vp}}\ c_{John}$ is not well-typed

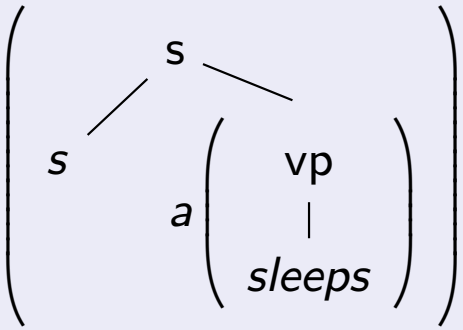
There is no $t : \mathrm{vp} \in \Lambda(\Sigma_{derivations})$ such that $t :=_{\text{derived trees}}$



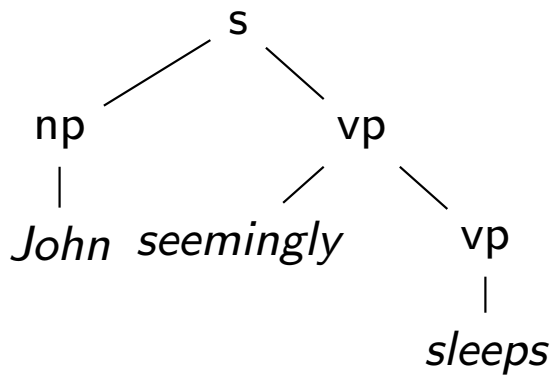
Control on the Derived Trees

$\mathscr{G}_{\textit{derived trees}} = \langle \Sigma_{\textit{derivations}}, \Sigma_{\textit{trees}}, \mathscr{L}_{\textit{derived trees}}, \mathrm{s} \rangle$

$c_{\textit{seemingly}} : (\mathrm{vp} \multimap \mathrm{vp}) \multimap \mathrm{vp} \multimap \mathrm{vp} \quad :=_{\textit{derived trees}} \lambda^{\circ} ax.a$ 

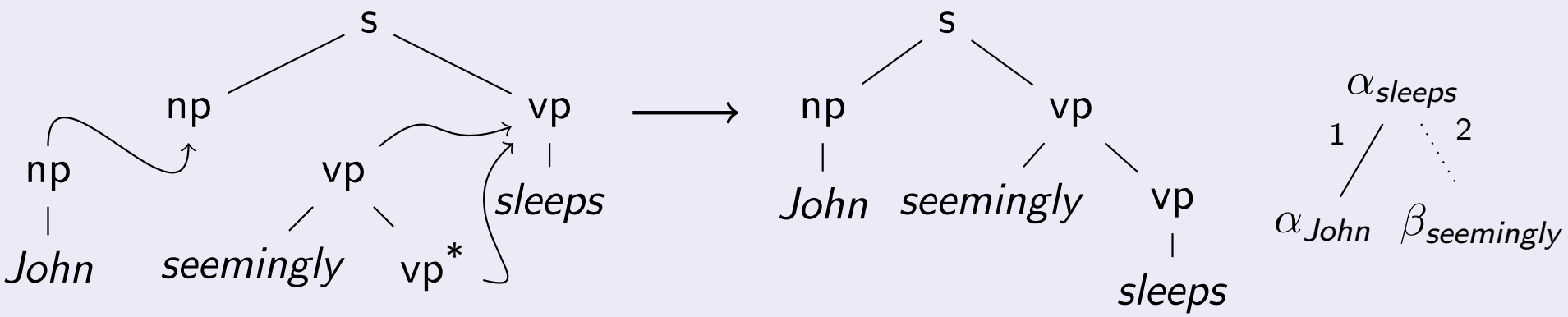
$c_{\textit{sleeps}} : (\mathrm{s} \multimap \mathrm{s}) \multimap (\mathrm{vp} \multimap \mathrm{vp}) \multimap \mathrm{np} \multimap \mathrm{s} \quad :=_{\textit{derived trees}} \lambda^{\circ} Sas.S$ 

$l_{\mathrm{vp}} : \mathrm{vp} \multimap \mathrm{vp}$

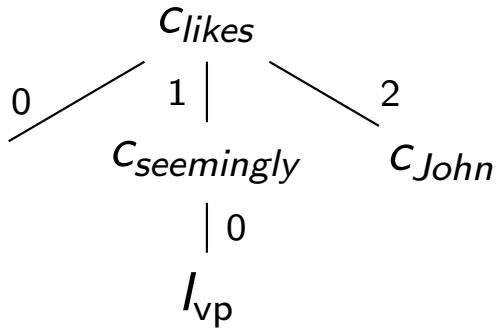
$c_{\textit{likes}}\ l_{\mathrm{s}}(c_{\textit{seemingly}}\ l_{\mathrm{vp}})\ c_{\textit{John}} : \mathrm{s} \quad :=_{\textit{derived trees}}$ 

TAG Derivation Trees as Abstract Terms

Derivation tree: to record the operations



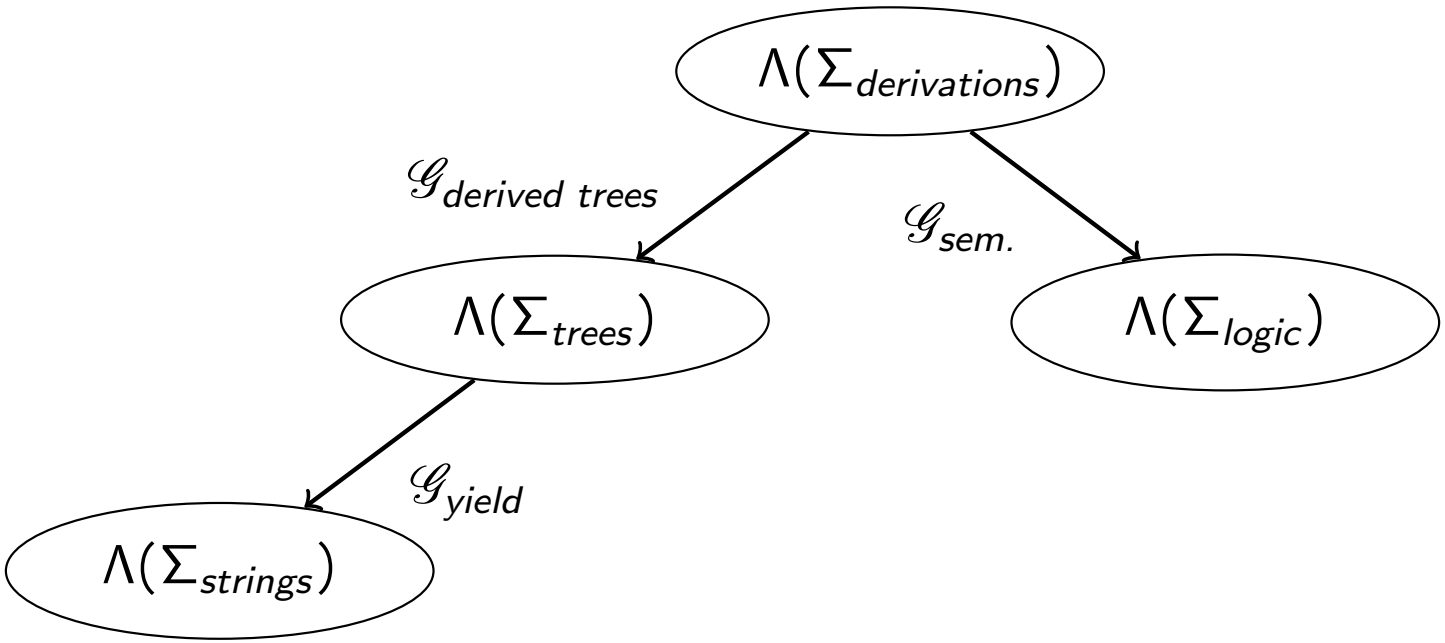
$c_{sleeps}\ l_s\ (c_{seemingly}\ l_{vp})\ c_{John} \quad = \quad l_s$



$c_{likes} \quad : \underbrace{(s \multimap s)}_{0} \multimap \underbrace{(vp \multimap vp)}_{2} \multimap \underbrace{np}_{1} \multimap s$

TAG as ACG

Intermediate Picture



Building a Semantic Representation

$\Sigma_{derivations}$

$c_{John} : \text{np}$

$c_{seemingly} : (\text{vp} \multimap \text{vp}) \multimap \text{vp} \multimap \text{vp}$

$c_{sleeps} : (\text{s} \multimap \text{s}) \multimap (\text{vp} \multimap \text{vp}) \multimap \text{np} \multimap \text{s}$

$I_{\text{vp}} : \text{vp} \multimap \text{vp}$

Σ_{logic}

$\wedge, \vee, \Rightarrow : t \multimap t \multimap t$

$\neg : t \multimap t$

$\exists, \forall : (e \to t) \multimap t$

$\text{john} : e$

$\text{sleep} : e \multimap t$

$\text{seemingly} : t \multimap t$

A standard interpretation *à la* Montague

s	$:=_{sem.} t$	np	$:=_{sem.} (e \to t) \multimap t$
vp	$:=_{sem.} e \to t$	n	$:=_{sem.} e \to t$
		c_{john}	$:=_{sem.} \lambda^{\circ} P.P\,\text{j}$
I_{s}	$:=_{sem.} \lambda^{\circ} x.x$	$c_{seemingly}$	$:=_{sem.} \lambda^{\circ} aP.a(\lambda x.\text{seemingly}\ (P\,x))$
I_{vp}	$:=_{sem.} \lambda^{\circ} x.x$	c_{likes}	$:=_{sem.} \lambda^{\circ} S\ a\ s.S\ (s\ (a\ (\lambda x.\text{seems}\ x)))$

$$c_{sleeps}\ I_{\text{s}}\ (c_{seemingly}\ I_{\text{vp}})\ c_{John} :=_{sem.} \text{seemingly}\ (\text{sleep j})$$

Long-Distance Dependencies

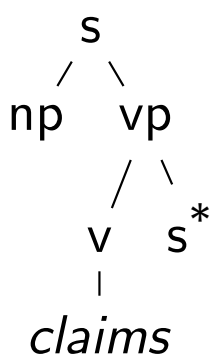
Example

(1) Paul claims John loves Mary

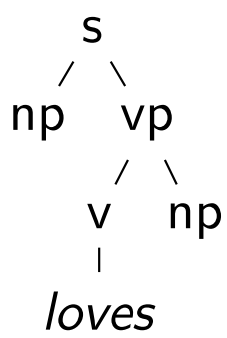
(2) Paul claims John seems to love Mary

(3) Who does Peter think Paul claims John seems to love

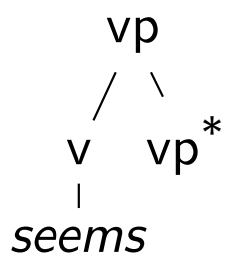
β_{claims} =



α_{loves} =

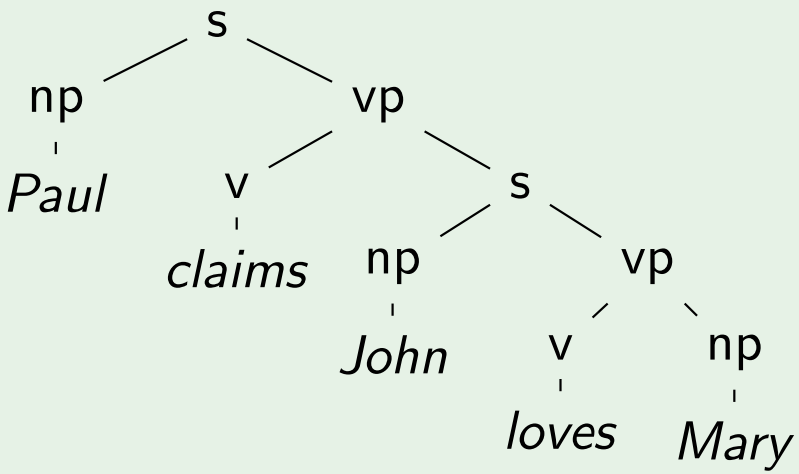


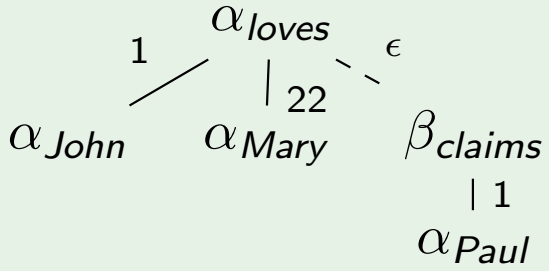
β_{seems} =



Long-Distance Dependencies

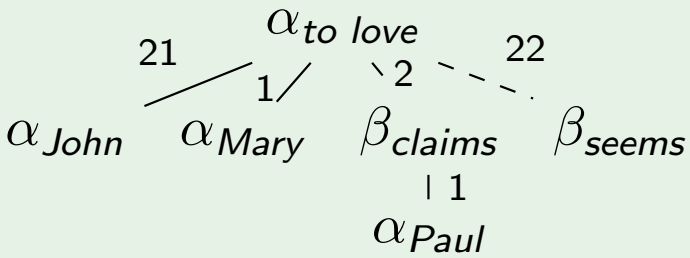
Example (Paul claims John loves Mary)





claim paul (love john mary)

Example (Paul claims John seems to love Mary)



claim paul (seem john (λx.love x mary))

Long-Distance Dependencies

The ACG Way

$$c_{claims} :=_{sem.} \lambda^{\circ} adv_s\ adv_{vp}\ subj\ comp.adv_s\ (subj\ (adv_{vp}\ (\lambda x.\text{claim}\ x\ comp)))$$
$$c_{seems} :=_{sem.} \lambda^{\circ} mod\ pred.mod\ (\lambda x.\text{seem}\ x\ pred)$$
$$c_{loves} :=_{sem.} \lambda^{\circ} adv_s\ adv_{vp}\ subj\ obj.adv_s\ (subj\ (adv_{vp}\ (\lambda x.obj\ (\lambda y.\text{love}\ x\ y))))$$
$$c_{to\ love} :=_{sem.} \lambda^{\circ} adv_s\ adv_{vp}\ obj\ subj.adv_s\ (subj\ (adv_{vp}\ (\lambda x.obj\ (\lambda y.\text{love}\ x\ y))))$$

See the demo!

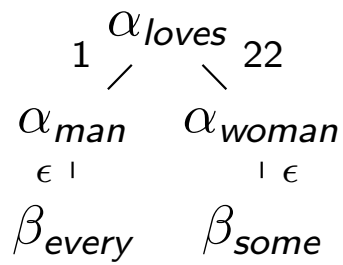
$$c_{loves}\ (c_{claims}\ l_s\ l_{vp}\ c_{Paul})\ l_{vp}\ c_{John}\ c_{Mary} :=_{sem.} \text{claim paul (love john mary)}$$

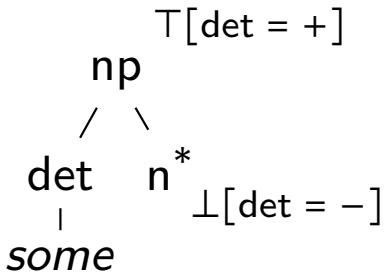
$$c_{to\ love}\ (c_{claims}\ l_s\ l_{vp}\ c_{Paul})\ (c_{seems}\ l_{vp})\ c_{Mary}\ c_{John} :=_{sem.} \text{claim paul (seem john } (\lambda x.\text{love } x \text{ mary}))$$

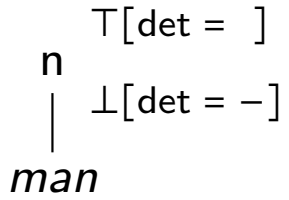
Quantification

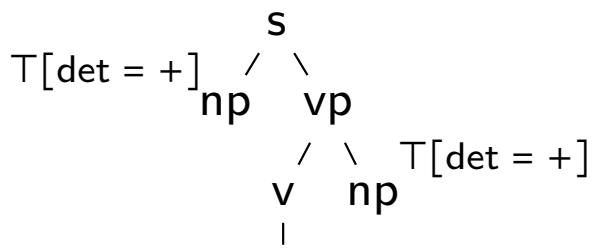
(4) *every man loves some woman*

$$\forall x.\mathsf{man}(x) \Rightarrow \exists y.\mathsf{woman}(x) \wedge \mathsf{love}(x, y)$$









$\mathsf{n}[-] \multimap \mathsf{n}[+]$

$\mathsf{n} \multimap \mathsf{np}$

$(\mathsf{n}[-] \multimap \mathsf{n}[+]) \multimap \mathsf{n}[+]$

$(\mathsf{n} \multimap \mathsf{np}) \multimap \mathsf{np}$

$(\mathsf{s} \multimap \mathsf{s}) \multimap (\mathsf{vp} \multimap \mathsf{vp}) \multimap \mathsf{n}[+] \multimap \mathsf{n}[+] \multimap \mathsf{s}$

$(\mathsf{s} \multimap \mathsf{s}) \multimap (\mathsf{vp} \multimap \mathsf{vp}) \multimap \mathsf{np} \multimap \mathsf{np} \multimap \mathsf{s}$

A Note on Feature Structures

- The ACG way corresponds to specifying adjunction constraints by *enumeration*
- Vijay-Shanker and Joshi (1988, p. 718):

  > *"... if we think of the auxiliary tree as corresponding to functions over feature structures (by λ-abstracting the variable corresponding to the feature structure for the tree that will appear below the foot node). Adjunction corresponds to applying this function to the feature structure corresponding to the subtree below the node where [it] takes place."*

Quantification

The ACG Way

Constants of $\Sigma_{derivations}$		By $\mathscr{G}_{derived\ trees}$	By $\mathscr{G}_{sem.}$
c_{man}	$: (\mathrm{n} \multimap \mathrm{np}) \multimap \mathrm{np}$	$\lambda^{\circ} d.d\ (\mathrm{n}_1 man)$	$\lambda^{\circ} Q.Q\ \mathrm{man}$
c_{some}	$: \mathrm{n} \multimap \mathrm{np}$	$\lambda^{\circ} n.\mathrm{np}_2\ (\mathrm{det}_1\ some)\ n$	$\lambda^{\circ} P\ Q.\exists x.(P\ x) \wedge (Q\ x)$
c_{every}	$: \mathrm{n} \multimap \mathrm{np}$	$\lambda^{\circ} n.\mathrm{np}_2\ (\mathrm{det}_1\ every)\ n$	$\lambda^{\circ} P\ Q.\forall x.(P\ x) \Rightarrow (Q\ x)$

$$c_{loves}\ I_{\mathrm{s}}\ I_{\mathrm{vp}}\ (c_{man}\ c_{every})\ (c_{woman}\ c_{some}) :=_{sem.} \forall x.(\mathrm{man}\ x) \Rightarrow (\exists y.(\mathrm{woman}\ y) \wedge (\mathrm{love}\ x\ y))$$

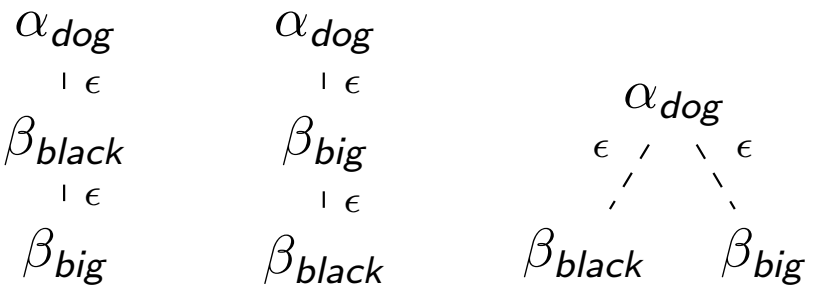
Multiple Modification

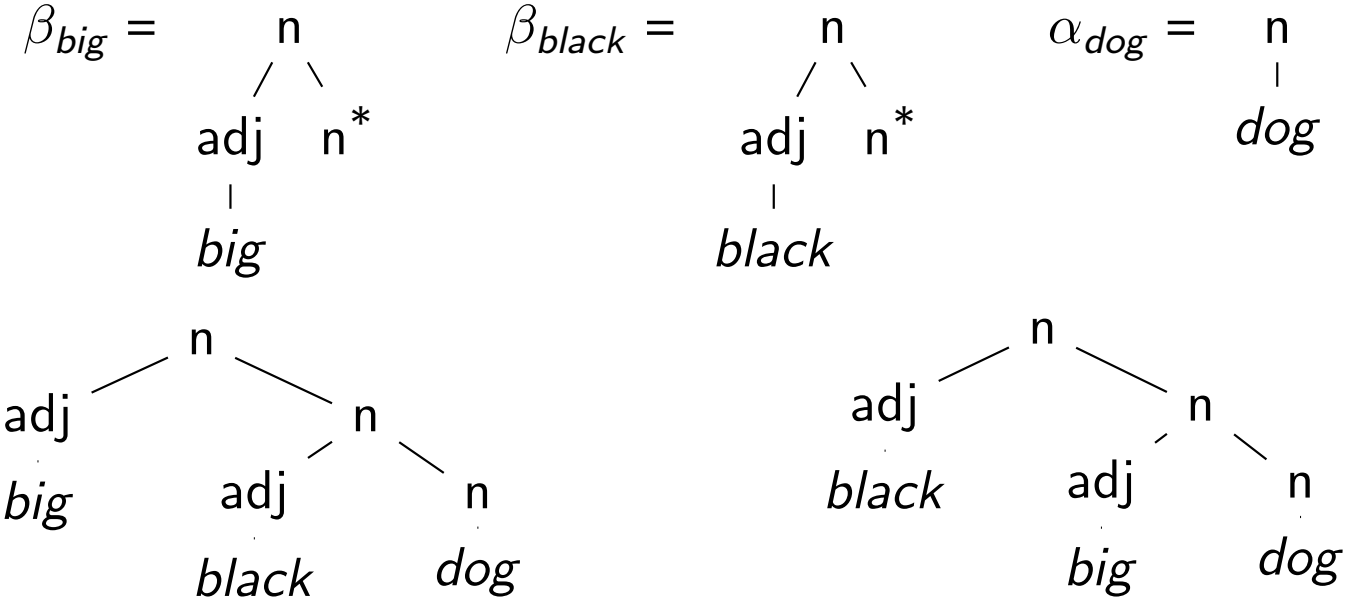
(5) *big black dog*

$\text{black}(x) \wedge \text{big}(x) \wedge \text{dog}(x)$

(6) *black big dog*

$\text{black}(x) \wedge \text{big}(x) \wedge \text{dog}(x)$





Multiple Adjunction

The ACG way

$$
\begin{array}{lll}
c_{big} & : (\mathsf{n} \multimap \mathsf{np}) \multimap \mathsf{n} \multimap \mathsf{np} & :=_{sem.} \ \lambda^{\circ} Q\ n.Q\ (\lambda x.(n\ x) \wedge (\mathsf{big}\ x)) \\
c_{black} & : (\mathsf{n} \multimap \mathsf{np}) \multimap \mathsf{n} \multimap \mathsf{np} & :=_{sem.} \ \lambda^{\circ} Q\ n.Q\ (\lambda x.(n\ x) \wedge (\mathsf{black}\ x)) \\
c_{dog} & : (\mathsf{n} \multimap \mathsf{np}) \multimap \mathsf{np} & :=_{sem.} \ \lambda^{\circ} Q.Q\ \mathsf{dog}
\end{array}
$$

$$\lambda^{\circ} D.c_{dog}\ (c_{black}\ (c_{big}\ D)) :=_{sem.} \lambda^{\circ} D.D\ (\lambda x.((\mathsf{big}\ x) \wedge (\mathsf{black}\ x)) \wedge (\mathsf{dog}\ x))$$
$$\lambda^{\circ} D.c_{dog}\ (c_{big}\ (c_{black}\ D)) :=_{sem.} \lambda^{\circ} D.D\ (\lambda x.((\mathsf{black}\ x) \wedge (\mathsf{big}\ x)) \wedge (\mathsf{dog}\ x))$$

Etc.

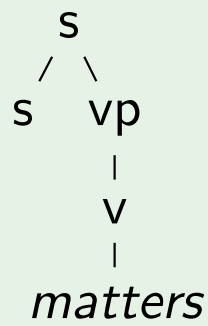
- Control verbs
- Idioms (based on Kobele 2012):
  $c_{\textit{kicked the bucket}} :=_{\textit{derived trees}} [\![\lambda^{\circ} s\ a\ \textit{subj}.c_{\textit{kicked}}\ s\ a\ \textit{subj}\ (c_{\textit{bucket}}\ c_{\textit{the}})]\!]_{\textit{derived trees}}$
- Subordinate Conjunctions
- Discourse connectives their syntax-semantics interface (Danlos, Maskharashvili, and Pogodalla 2016; Maskharashvili 2016)

Demo with:

- The ACG toolkit (`http://calligramme.loria.fr/acg#Software`)
- Signatures, lexicons, and scripts available from my publication page as related file to this presentation (`http://hal.inria.fr/hal-01583962/file/examples.zip`)

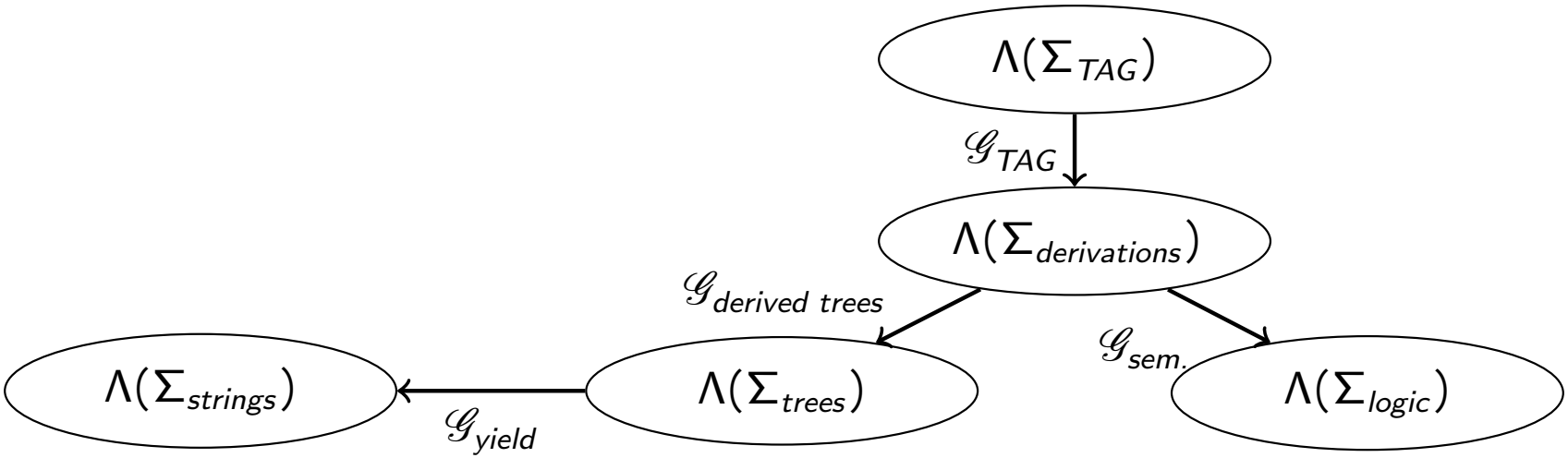
TAG as ACG: Completing the Encoding

Example (*To arrive on time matters*)



$c_{matters} : (\text{vp} \multimap \text{vp}) \multimap \text{s} \multimap \text{s}$

- Not 2nd-order!
- $c_{matters}\ l_{\text{vp}} : \text{s} \multimap \text{s}$ has the type of an auxilary tree. Overgeneration



$\mathscr{G}_{TAG} = \langle \Sigma_{TAG}, \Sigma_{derivations}, \mathscr{L}_{TAG}, \mathsf{s} \rangle$

(de Groote 2002)

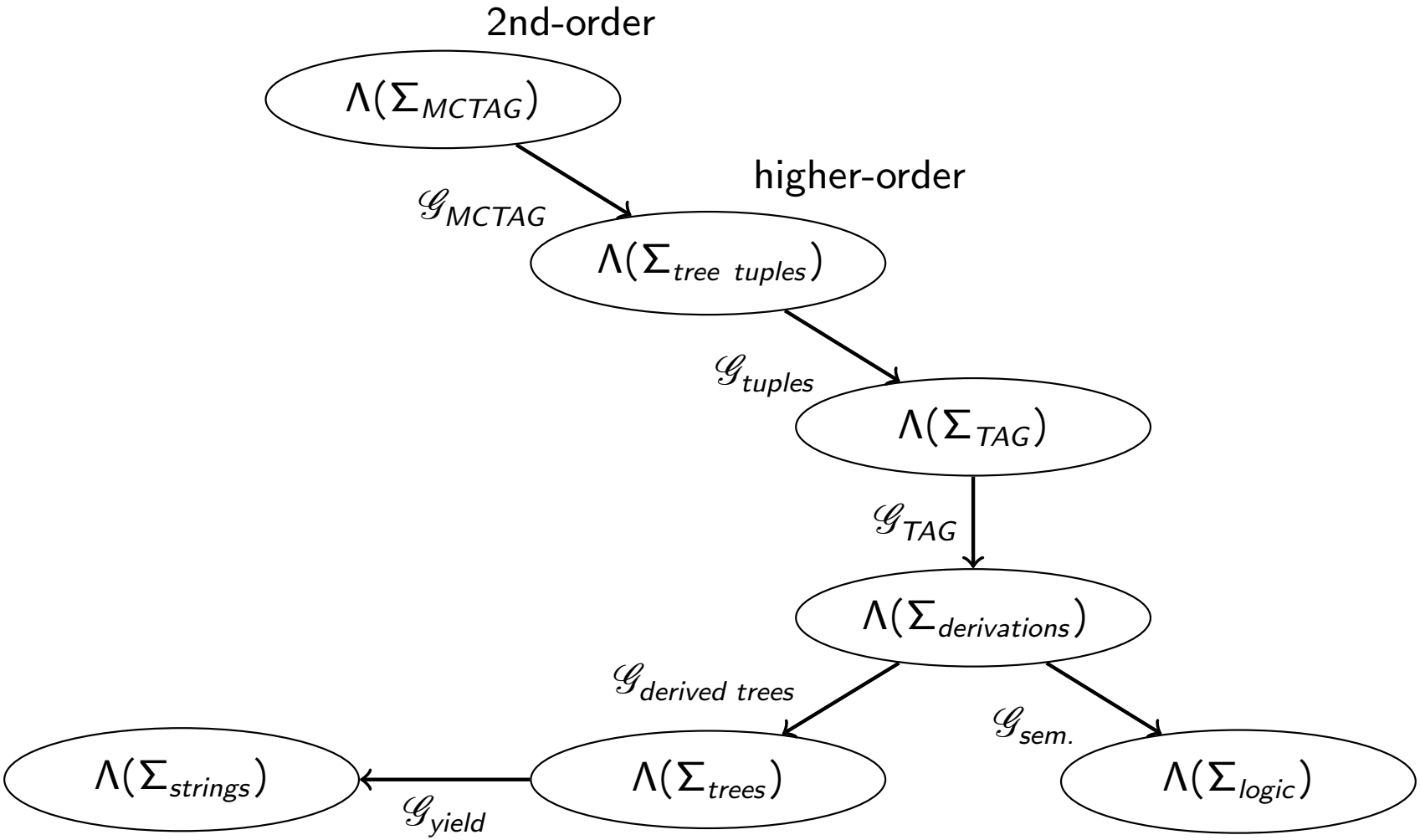
Types and constants of Σ_{TAG}		Their interpretations in $\Lambda(\Sigma_{derivations})$	
$\mathsf{np}, \mathsf{s}, \ldots$		$\mathsf{np}, \mathsf{s}, \ldots$	
vp_A		$\mathsf{vp} \multimap \mathsf{vp}$	
s_A		$\mathsf{s} \multimap \mathsf{s}$	
n_A		$\mathsf{n} \multimap \mathsf{np}$	
C_{sleeps}	$: \mathsf{s}_A \multimap \mathsf{vp}_A \multimap \mathsf{np} \multimap \mathsf{s}$	c_{sleeps}	$: (\mathsf{s} \multimap \mathsf{s}) \multimap (\mathsf{vp} \multimap \mathsf{vp}) \multimap \mathsf{np} \multimap \mathsf{s}$
$C_{seemingly}$	$: \mathsf{vp}_A \multimap \mathsf{vp}_A$	$c_{seemingly}$	$: (\mathsf{vp} \multimap \mathsf{vp}) \multimap \mathsf{vp} \multimap \mathsf{vp}$
I_{s}	$: \mathsf{s}_A$	I_{s}	$: \mathsf{s} \multimap \mathsf{s}$
I_{vp}	$: \mathsf{vp}_A$	I_{vp}	$: \mathsf{vp} \multimap \mathsf{vp}$
$C_{matters}$	$: \mathsf{vp}_A \multimap \mathsf{s} \multimap \mathsf{s}$	$c_{matters}$	$: (\mathsf{vp} \multimap \mathsf{vp}) \multimap \mathsf{s} \multimap \mathsf{s}$

$\mathscr{G}_{TAG}$ is 2nd-order:

- Parsing results apply
- Both from strings and from logical formulas! See the demo

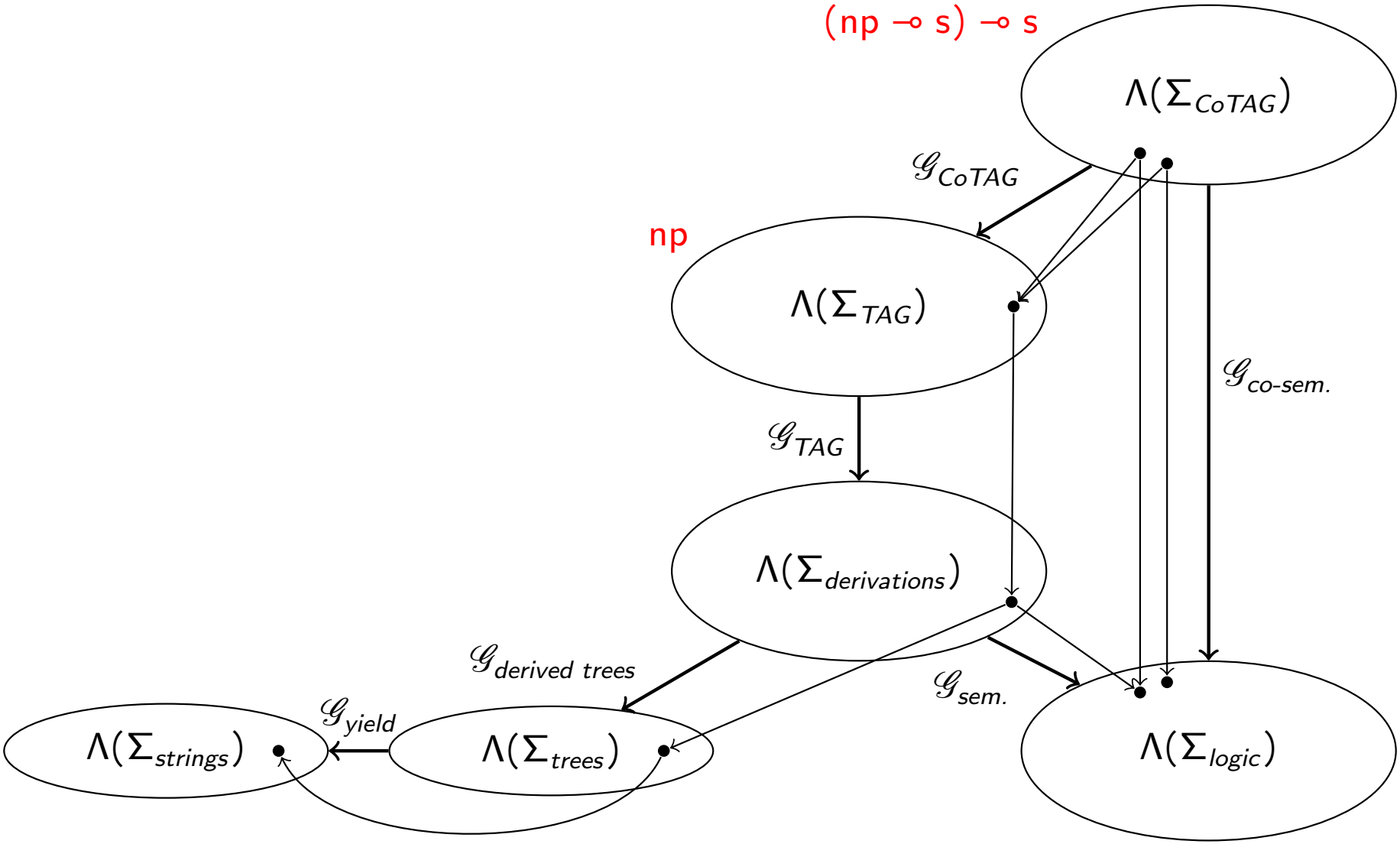
Playing with the ACG Architecture

Multi-Component TAG (MCTAG Weir 1988)



Playing with the ACG Architecture

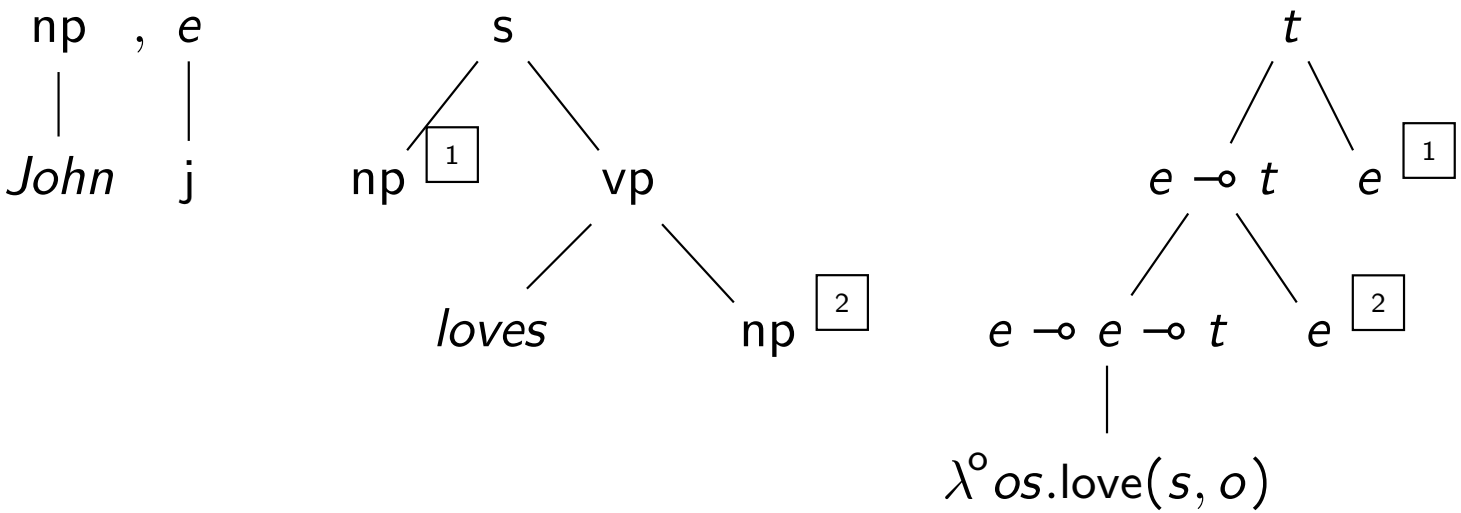
Scope Ambiguity: CoTAG (Barker 2010) as Type-raising (Pogodalla 2007b; Pogodalla 2007a; Kobele and Michaelis 2012)



Related Approaches

Synchronous TAG (Nesson and Shieber 2006; Nesson 2009)

Syntactic and semantic derivations are performed synchronously:



- Need to interpret the semantic tree as love(j, m)
- How to go from a logical formula f (β-reduced) to some possible semantic tree that gets interpreted as f?
- Similar with Interpreted Regular Tree Grammars (Koller and Kuhlmann 2011; Koller and Kuhlmann 2012)

Related Approaches

Semantics by Feature Unification (Gardent and Kallmeyer 2003; Kallmeyer and Romero 2004; Kallmeyer and Romero 2008)

Principles:

- Semantic features are added (typically [Ind = x], [P = l] where l is the label of some logical formula)
- A representation language specifying the relations between the labels is used to plug together the logical formulas

Limitations:

- No control on whether a feature that is asked at some node will be provided by another node (no static typing)
- Need to handle variable naming on-line (no α-conversion)
- The lack of functional application requires using labels (first-order unification)
- How to inverse the process?

Conclusion

ACGs

- Flexible framework
- Interesting computational properties
- Modularity by composition, and type-checking
- Provides a unified way to extend other formalisms
- Reversible
- Integrate well with type-theoretic base semantic modelling (discourse dynamics, intensionalization, etc.)

Work in progress

- Tractable 3rd-order fragments
- Logical equivalence (theoretically and practically)
- Optimization
- Semantics conservativity

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