# Model-theoretic syntax

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May 4, 2004
Guest lecture, CMPSCI 585,
Spring 2004 (Andrew McCallum)

# The plan

i. Have a quick look at what the goals of linguistics are and how linguists work.

ii. Contrast two ways of theorizing: one based in proof theory (formal languages) and the other based in model theory.

iii. Try to motivate a model-theoretic perspective.

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**What I would like from you** I am curious to learn the extent to which my criticisms of the proof-theoretic approaches hold for the kinds of grammars that you have looked at in this class.

## Pullum and Scholz and others

The ideas in these slides are mainly extracted from the work of Geoffrey K. Pullum and Barbara Scholz. No one has done more than Pullum and Scholz to clarify the issues surrounding model-theoretic syntax and its competitors.

If you are not convinced by some or all of my arguments, write to Pullum and Scholz for copies of their papers and manuscripts before passing a final judgment on the enterprise.

The specific grammars that I offer below are inspired by the work of Patrick Blackburn and his coauthors (cited in the references).

# A note on linguistics–CS links

Syntax is probably the area of theoretical linguistics that has the *fewest* connections with theoretical computer science.

- I mean this in the sense of sharing innovations, not foundational assumptions.

Results and techniques from theoretical computer science have often been incorporated into proposals in semantics and phonology.

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## Linguistic syntacticians at work

- **The enterprise** Broadly speaking, natural language syntacticians work to find precise, concise specifications of natural languages.
- **Universal Grammar** When we compare these language-specific descriptions, we should find a lot of overlap — recurrent patterns, similar categories, common general constraints.
- **Complexity in the features, not the principles** At present, most people assume that grammars should take the form of a small number of cross-linguistically valid principles plus a large number of stipulations about the lexicon.

# Linguistic syntacticians at work

**For example** Baker (1988, 1996) describes Mohawk in great depth. Mohawk is a strikingly agglutinative language. A single complex verb form can do the work of a full English sentence, and discontinuous constituents are common:

(1) Ka-nuhs-rakv [nehneh a-ak-ahninuʔ].
3N-**house**-white [that INDEF-3F-buy].
'House-white that she would buy.'
('That house that she would buy is white.')

Baker shows that familiar principles are at work here. The rich class of bound morphemes conspires (along with some variation in the general principles) to produce outputs that differ greatly from, e.g., English.

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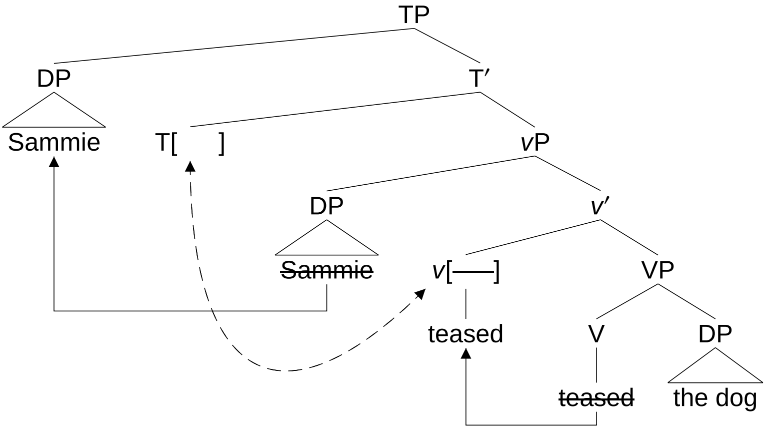
- The proper nature of syntactic theory is widely debated. Nearly everything is controversial. (This is less true for natural language semantics and phonology.)
- One commonality: **Everyone is talking about relational structures**. In general, these are singly-rooted, acyclic (multi-)graphs.

# The Minimalist Program

(2) Sammie teased the dog. [Simplified analysis!]



# Head-Driven Phrase Structure Grammar (HPSG)

(2) Sammie teased the dog. [Simplified analysis!]

⟨sami, tizd, ðə, dɔg⟩
S[*fin*]

- ⟨tizd, ðə, dɔg⟩
  VP[*fin*]
  - ⟨ðə, dɔg⟩
    NP[*acc*]
  - ⟨tizd⟩
    V[*fin*]
- ⟨sami⟩
  NP[*nom*]

## Categorial Grammar

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$$\dfrac{\mathrm{NP} \qquad \dfrac{(\mathrm{S}\backslash\mathrm{NP})/\mathrm{NP} \qquad \dfrac{\mathrm{NP}/\mathrm{N} \qquad \mathrm{N}}{\mathrm{NP}}}{\mathrm{S}\backslash\mathrm{NP}}}{\mathrm{S}}$$

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S
**teased**(**the**(**dog**))(**sammie**)

---

NP — **sammie**

S\NP — **teased**(**the**(**dog**))

---

(S\NP)/NP — **teased**

NP — **the**(**dog**)

---

NP/N — **the**

N — **dog**

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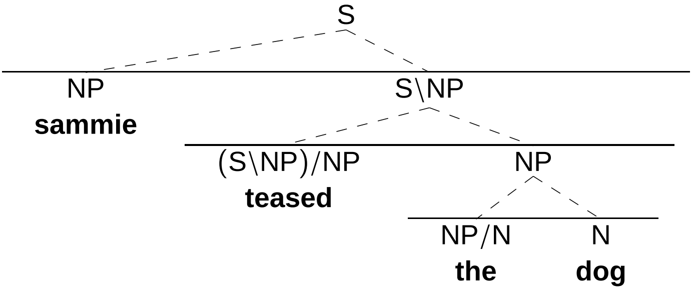

# Three modes of theorizing

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## Proof-theoretic

- Chomsky's (1964, 1965) original approach, heavily influenced by the nascent field of computer science and machine translation
- A grammar for a language $L$ is a recursive specification of the full set of well-formed objects for $L$.
- A sentence $S$ is grammatical according to a grammar $G$ iff $S$ is derivable in $G$.

# Three modes of theorizing

## Proof-theoretic: Examples

i. all the phrase-structure grammars in the Chomsky Hierarchy
ii. categorial grammars, which are generally context-free equivalent
iii. tree-adjoining grammars (intermediate between context-free and context-sensitive on the Chomsky Hierarchy)

# Three modes of theorizing

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- In the simplest case, the grammar for $L$ could be their logical conjunction: $\mathcal{G} = \gamma_1 \wedge \cdots \wedge \gamma_n$.
- A sentence $S$ is grammatical in language $L$ iff $\mathcal{S}$, the structure for $S$, is such that

$$\mathcal{S} \models \mathcal{G}$$

  That is, $S$ is grammatical iff $\mathcal{S}$ is a model of $\mathcal{G}$.

# Three modes of theorizing

## Model-theoretic: Examples

i. Arc-Pair Grammar (Johnson and Postal 1981)
ii. The earliest versions of Lexical-Functional Grammar (Kaplan and Bresnan 1982)
iii. Rogers (1998) (re)conceptualization of Government and Binding theory

# Three modes of theorizing

## Hybrids

The two modes can coexist and interact, just as they do in logic.

Hybrids of the proof-theoretic and model-theoretic approaches have an underlying phrase-structure system that generates lots of garbage that the constraints filter off.

i. HPSG

ii. the constraint-based Chomskian theories of the 1980s

# A context-free grammar (CFG)

i. $G = \langle T, N, S, R \rangle$

ii. $T = \left\{ \textit{Sally}, \textit{believes}, \textit{pigs}, \textit{fly} \right\}$

iii. $N = \left\{ S, NP, VP, V \right\}$

iv. Start symbol $= S$

v. $$R = \left\{ \begin{array}{rcl} S & \Rightarrow & NP\ VP \\ VP & \Rightarrow & V\ S \\ VP & \Rightarrow & V \\ NP & \Rightarrow & \textit{Sally} \mid \textit{pigs} \\ V & \Rightarrow & \textit{believes} \mid \textit{fly} \end{array} \right\}$$

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$$\begin{array}{cc} \multicolumn{2}{c}{S} \\ NP & VP \\ \textit{pigs} & VP \\ \textit{pigs} & V \\ \textit{pigs} & \textit{fly} \end{array} \qquad \begin{array}{cc} \multicolumn{2}{c}{S} \\ NP & VP \\ NP & V \\ NP & \textit{fly} \\ \textit{pigs} & \textit{fly} \end{array} \qquad \ldots$$

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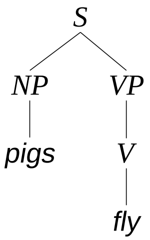
| | | | | |
|---|---|---|---|---|
| $S$ | | $S$ | | |
| $NP$ | $VP$ | $NP$ | $VP$ | |
| *pigs* | $VP$ | $NP$ | $V$ | ... |
| *pigs* | $V$ | $NP$ | *fly* | |
| *pigs* | *fly* | *pigs* | *fly* | |



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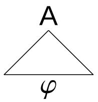


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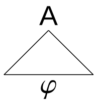


This view (re)emerged (also) in logicians' study of proofs as model-theoretic objects.

# A model-theoretic framework

## Ingredients

i. Trees (the models)
ii. A logic (for defining grammars)
iii. An interpretation scheme (so that we can use the logic to talk about the trees)

## Trees (our models)

A *tree* $\mathcal{T}$ is a relational structure $(N, D, r, V)$ where:

i. $N$ is a set of atomic points called nodes.
ii. $D$ is a binary relation on $T$ (the dominance relation).
iii. $r \in N$ is a distinguished *root* node: $\forall n \in N, \langle r, n \rangle \in D^*$.
iv. $D^*$ is acyclic.
v. Every $n \in N$ that is not the root has exactly one mother.
vi. $V$ is a valuation (labelling) function, taking formulae of our logic to subsets of $N$.

## A logic (our tool for grammar writing)

The logic $\mathcal{L}$ is defined as follows:

i. $T$ is a set of atomic propositions (terminal labels). If $\varphi \in T$, then $\varphi$ is a WFF.

ii. $N$ is a set of atomic propositions (nonterminal labels). If $\varphi \in N$, then $\varphi$ is a WFF.

iii. If $\varphi$ and $\psi$ are WFFs, then $\neg\varphi$ and $\varphi \rightarrow \psi$ are WFFs.

iv. If $\varphi$ and $\psi$ are WFFs, then $\triangle(\varphi)$ and $\triangle(\varphi\ \psi)$ are WFFs.

v. Nothing else is a WFF.

## Interpretation

$\mathcal{T}, n \models \varphi$ iff $n \in V(\varphi)$ for $\varphi \in (T \cup N)$

$\mathcal{T}, n \models \neg\varphi$ iff $\mathcal{T}, n \not\models \varphi$

$\mathcal{T}, n \models \varphi \rightarrow \psi$ iff $\mathcal{T}, n \not\models \varphi$ or $\mathcal{T}, n \models \psi$

$\mathcal{T}, n \models \triangle(\varphi)$ iff $n$ has exactly one daughter $n'$ and $\mathcal{T}, n' \models \varphi$

$\mathcal{T}, n \models \triangle(\varphi\, \psi)$ iff $n$ has exactly two daughters, $n'$ and $n''$, and $n'$ is to the left of $n''$ and $\mathcal{T}, n' \models \varphi$ and $\mathcal{T}, n'' \models \psi$

**Validity** Where $\varphi$ is true at all points in $\mathcal{T}$, we write $\mathcal{T} \models \varphi$.

# Defining the CFG in $\mathcal{L}$

The grammar $\mathcal{G}$:

i. $T = \{\mathit{Sally}, \mathit{believes}, \mathit{pigs}, \mathit{fly}\}$

ii. $N = \{S, NP, VP, V\}$

iii. $r \in V(S)$

iv. $\mathcal{G} =$

$$\left\{\begin{array}{l} S \rightarrow \triangle(NP\ VP) \\ VP \rightarrow \big(\triangle(V\ S) \vee \triangle(V)\big) \\ NP \rightarrow \big(\triangle(\mathit{Sally}) \vee \triangle(\mathit{pigs})\big) \\ V \rightarrow \big(\triangle(\mathit{believes}) \vee \triangle(\mathit{fly})\big) \end{array}\right\}$$

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$$\left\{ \begin{array}{l} \varphi \rightarrow \neg\Big(\triangle(\top) \vee \triangle(\top\ \top)\Big) \text{ for } \varphi \in T \\ \varphi \rightarrow \triangle(\top) \vee \triangle(\top\ \top) \text{ for } \varphi \in N \\ S \rightarrow \triangle(NP\ VP) \\ VP \rightarrow \Big(\triangle(V\ S) \vee \triangle(V)\Big) \\ NP \rightarrow \Big(\triangle(\textit{Sally}) \vee \triangle(\textit{pigs})\Big) \\ V \rightarrow \Big(\triangle(\textit{believes}) \vee \triangle(\textit{fly})\Big) \end{array} \right\}$$

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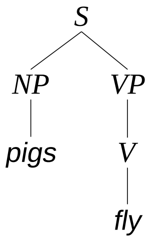



$\models \mathcal{G}$

# A translation scheme

The mapping from our CFG to $\mathcal{L}$ is transparent:

$$\begin{array}{rcl} A \Rightarrow B & \text{becomes} & A \rightarrow \triangle(B) \\ A \Rightarrow B\ C & \text{becomes} & A \rightarrow \triangle(B\ C) \\ A \mid B & \text{becomes} & A \vee B \end{array}$$

But the $\mathcal{L}$ treatment does not conflate the syntax of syntax (the proofs) with the semantics of syntax (the trees, or whatever relational structures we want to talk about).

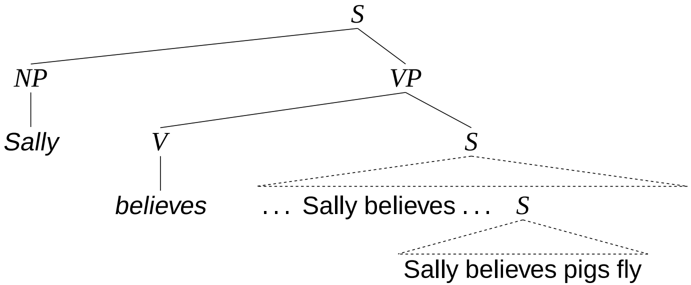
So we should look to the models to find differences.

# Phenomena that might favor a model-theoretic approach

i. Language size (is not a linguistic issue)
ii. Degrees of ungrammaticality (are an undeniable fact of language)
iii. Grammatical quandaries (when *nothing* works)
iv. Fragments

# Language size

Consider this **infinitely sized** tree:




- This cannot be generated by any CFG.
- It can be a model of $\mathcal{L}$.

# Language size

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- **But** Linguists determine whether something is grammatical based on speakers' intuitions.
- Language size is not something that speakers can have intuitions about.
- Thus, the question of language size is different in kind from the usual questions in linguistics.

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Languages are countably infinite.

**Langendoen and Postal object:**

There are English sentences of infinite size. Therefore, the class of all sentences is nondenumerably infinite.

Langendoen and Postal's argument is based on the notion that limiting sentences to finite size is stipulative.

# Language size

## Model-theoretic views can remain silent on the matter

The bulk of the work for a model-theoretic syntactician involves finding constraints for the grammar. This work can be done independently of a specific class of models. One might know that one wants tree models, but one need not specify whether they are finite models.

The model-theoretic syntactician can work as easily with finite corpora as with infinite classes. She can give a concise, precise description of exactly the class in question. No stipulations about language size appear in the grammar or as a consequence of the formalism. (Leave this question to the philosophers.)

# Degrees of ungrammaticality

The examples in (3) grow increasingly bad from top to bottom:

(3) a. *They probably did wanted you to leave.
b. **They probably does wanted you to leave.
c. $*^{500}$ Leave to you wanted probably they.

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A model-theoretic approach does much better. We simply assume that a grammar is not the logical conjunction of all its individual constraints, but rather a set of constraints. Then it is easy enough to keep track of which constraints are violated by a given structure, assign weights to the constraints, etc.

## Grammatical quandaries

(4)
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b. I am happy.
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**The conjunction of these principles creates a quandary.**

# Grammatical quandaries

(5) a. ??This is my and Ali's office.
b. ?This is mine and Ali's office.
c. ?This is Ali's and my office.
d. ??This is Ali's and mine office.

**For more quandaries** McCawley 1998

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In a $\mathcal{L}$-style approach, it is easy to define these as models of the full set of constraints. We could, for instance, relax the requirement that the root is labelled $S$.

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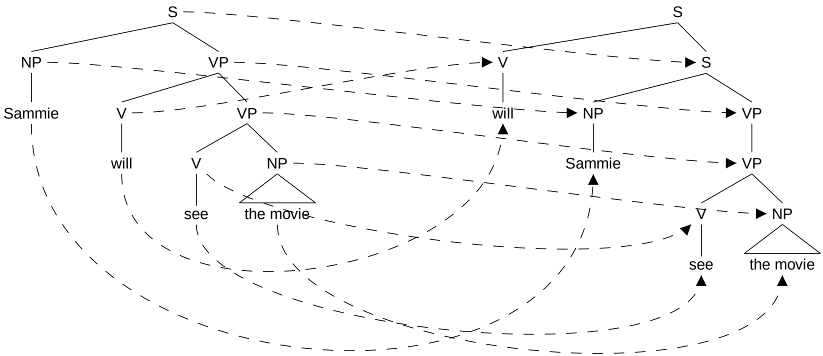
- Chomskian theories are typically based largely in **transformations**, which linguists conceive of as mapping trees into trees.
- A model-theoretic approach can make sense of this, by defining the objects of the theory as tuples of trees.
- The insight that this could be done dates to Lakoff 1971, and it was first given a solid formal foundation in the earliest work on Lexical-Functional Grammar (Kaplan and Bresnan 1982).

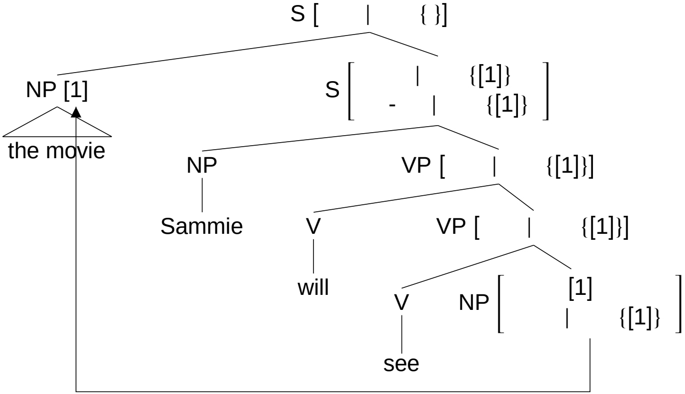
# Transformations, model-theoretically

The *transformation relation*, represented with dotted lines, is another binary relation nodes, formally like dominance.



# Movement or reentrancy?

Kracht (2001) show that, for a broad class of structures, the HPSG notion of reentrancy is identical to the movement conception favored by most transformationalists.



# References: Origins of model-theoretic syntax

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