Expressive power

Learnability and Language Acquisition

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Tuesday

Outline

The data

Chomsky hierarchy

- Swiss German

Bottom up

Problems

Conclusion

(Ed Stabler, Greg Kobele, Makoto Kanazawa)

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The data

Chomsky hierarchy
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Conclusion

What are the linguistic data?

- We observe sound/meaning pairs.

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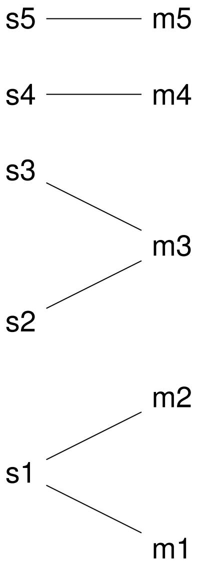
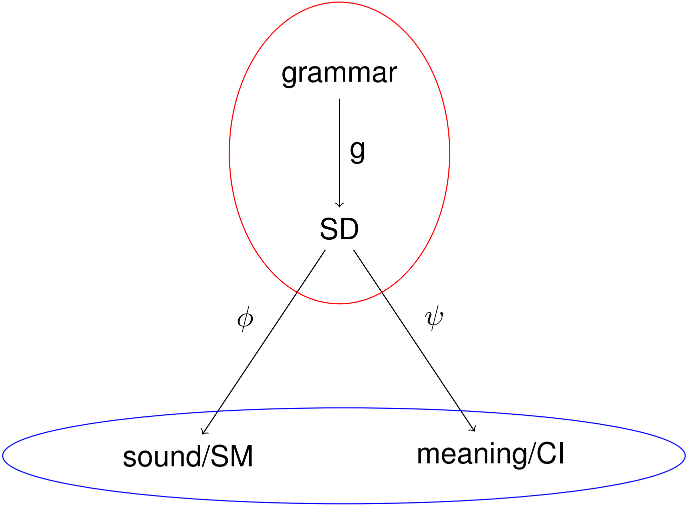
- We observe sound/meaning pairs.
- More precisely, we observe sounds/gestures.
- We don't observe the meanings, but we are aware of entailment relations between propositions. (or something similar)
- The sound/meaning relation is not one-to-one, but there is a lot of structure. (knowing what was said tells you a lot about the meaning!)

Sound/meaning pairs



Structural descriptions

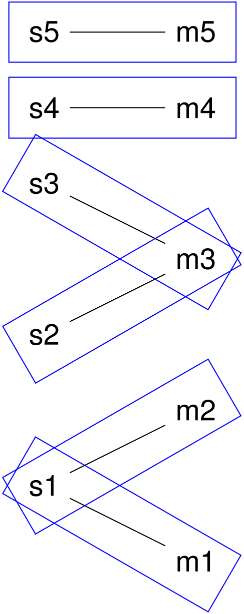
Traditional view



Example

- Grammar might be a context-free grammar, augmented with some compositional semantics.
- Structure might be a labeled derivation (parse) tree.
- ϕ is just the yield of the tree (a function).
- ψ just computes the semantics (another function).

Standard model



Issues

Description

If you are just describing the data, then you can stipulate this as a requirement.
If you are *learning* then you may not be able to learn grammars that satisfy this stipulation.
So you need to decide whether this stipulation is necessary.

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Description

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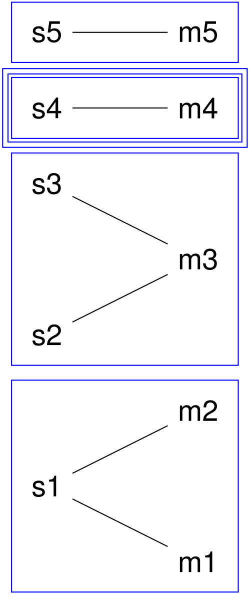
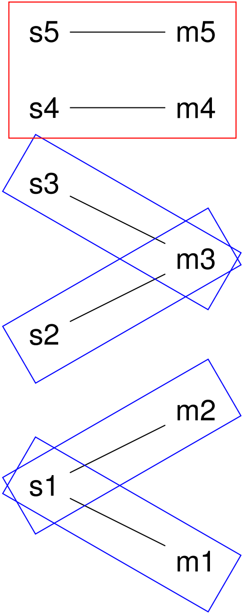
If you are *learning* then you may not be able to learn grammars that satisfy this stipulation.
So you need to decide whether this stipulation is necessary.

- Everybody here speaks two languages.
- Either way is fine.
- I gave him a cake and her a biscuit/I gave him a cake.
- John likes but Marys hates Sibelius/John likes Sibelius

Alternative model



Invalid structures



Weak and Strong

Weak generative capacity

Set of strings that a grammar can generate
Mathematically tractable

Strong generative capacity

Set of structures that a grammar can generate
Linguistically interesting but less tractable

From a learnability point of view, this is not so crucial: the data that the child sees consists of semantically well formed utterances.

Outline

Chomsky hierarchy of rewriting systems

Chomsky, 1959

Rewriting rules of the form $\alpha \to \beta$

Type 0	Unrestricted rewriting systems
Type 1	Context sensitive grammars
Type 2	Context free grammars
Type 3	Regular grammars/finite automata

- Classes of *representations*
- Purely "syntactic" hierarchy

Rules

Terminal symbols

Σ: a, b, c observed

nonterminal symbols

V: N, P, Q unobserved

Rules: $\alpha \rightarrow \beta$

$N \rightarrow abc$
$N \rightarrow Pbc$
$N \rightarrow aPb$
$N \rightarrow PaQ$
$aNb \rightarrow aPQb$
$NabP \rightarrow QcRS$

Finite languages

Grammar rules

Simple list of all sentences in the language

$N \rightarrow abc$

analogy: Monkey vocalisations

Language class

All finite languages

Languages with a finite number of sentences

Regular languages

Grammar rules

$N \rightarrow aP$

Only one nonterminal on the rhs, and all terminals on the left.

Language class

All regular languages

DFAs, NFAs, regular languages, generated by a regular language, finite Myhill-Nerode congruence, ...

(Predates the Chomsky Hierarchy)

Linear languages

Grammar rules

$N \rightarrow aPbc$

Only one nonterminal on the rhs

Language class

All linear languages

Between regular languages and context-free languages

Example $L = \{a^n b^n | n > 0\}$

Context-free grammars

Grammar rules

$N \rightarrow aPbQc$

Only one nonterminal on the lhs, any number on the rhs

Language class

Context-free languages
Polynomially parsable
regular grammars applied to trees

Examples of context-free languages

$(ab)^+$

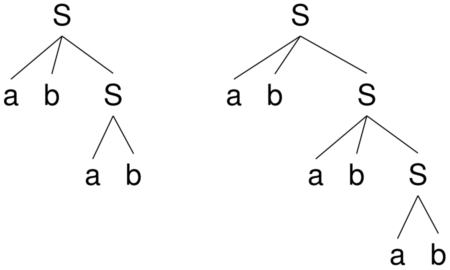
Examples of context-free languages

$(ab)^+$

Grammar 1

$S \rightarrow ab$

$S \rightarrow abS$



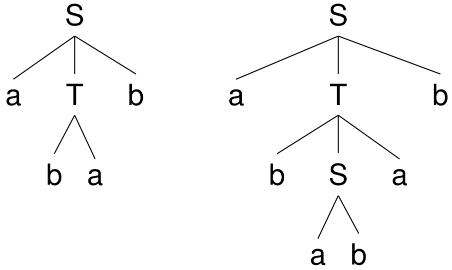
Examples of context-free languages

$(ab)^+$

Grammar 2

$S \rightarrow ab$ and $S \rightarrow aTb$

$T \rightarrow ba$ and $T \rightarrow bSa$

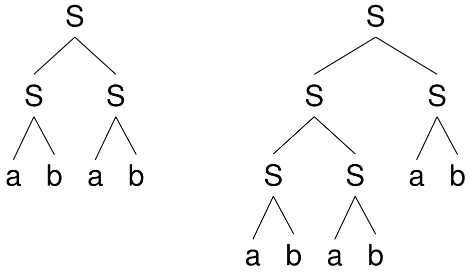


Examples of context-free languages

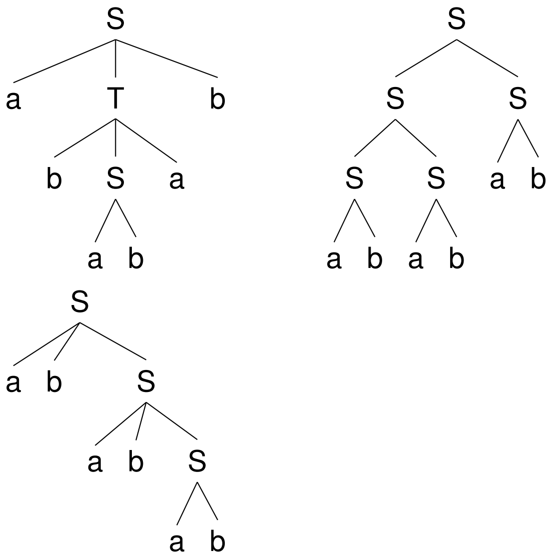
$(ab)^+$

Grammar 3

$S \rightarrow ab$ and $S \rightarrow SS$



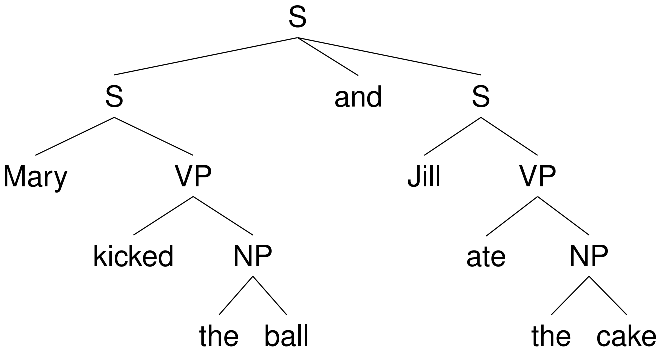
Which is the 'right' structure?



English example

Which structure gives you the right dependencies?

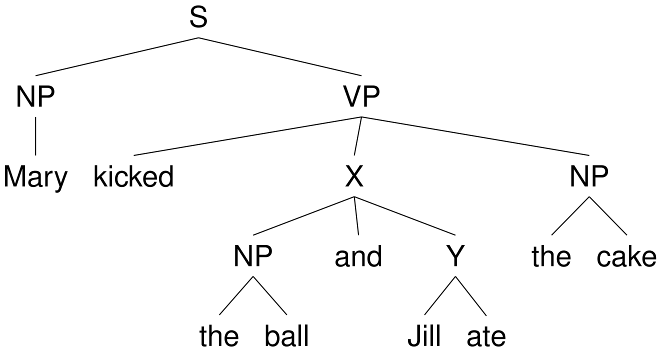
- Mary kicked the ball and Jill ate the cake



English example

Which structure gives you the right dependencies?

- Mary kicked the ball and Jill ate the cake



Semantically well-formed

- Mary kicked the ball and Jill ate the cake
- # Mary fed the ball and Jill ate the cake
- # Mary kicked the cake and Jill ate the cake
- # Mary fed the ball and Jill ate the cat
- Mary fed the cat and Jill ate the cake

Crucial to consider semantic wellformedness, not just syntactic wellformedness, especially when we come to think about learnability.

Examples of (properly) context-free languages

$a^n b^n | n > 0$

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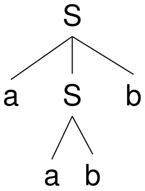
Grammar 1

$S \rightarrow ab$

$S \rightarrow aSb$

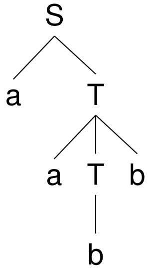


Examples of context-free languages

$a^n b^n | n > 0$

Grammar 2

$S \rightarrow ab$ and $S \rightarrow aT$
$T \rightarrow b$ and $T \rightarrow aTb$



Argument that a language is not regular

Facts:

- If L and R are regular languages, then $L \cap R$ is also regular.

General structure of correct argument

We want to show that L is not regular, but L is very complex
Take a simple regular language R
$L \cap R$ is a simple but infinite subset of L
Show that $L \cap R$ is not regular
Therefore L is not regular

English is not regular

Example – Shuly Wintner

A white male hired another white male

A white male – whom a white male hired – hired another white male

Define R

$R =$
$\{\text{A white male(whom a white male)}^*\text{(hired)}^*\text{hired another white male}\}$

Subset of English

$L \cap R =$
$\{\text{A white male(whom a white male)}^n\text{(hired)}^n\text{hired another white male} | n > 0\}$

Argument that a language is not context free

Facts:

- If L is CF and R is regular, then $L \cap R$ is also CF.

General structure of correct argument

We want to show that L is not CF, but L is very complex
Take a simple regular language R
$L \cap R$ is a simple but infinite subset of L
Show that $L \cap R$ is not CF
Therefore L is not CF

Swiss German

Shieber, 1985

...	das	mer	d'chind	em Hans	es huus	lönd	hälfe	aastriiche
...	that	we	the children-ACC	Hans-DAT	house-ACC	let	help	paint

'... that we let the children help Hans paint the house'

Proof

This language is not CF

abcd, aabccd, aaabcccd, abbcdd, . . .
number of *a*s equals number of *c*s and
number of *b*s equals number of *d*s
$a^n b^m c^n d^m$

Proof

This language is not CF

abcd, aabccd, aaabcccd, abbcdd, . . .
number of *a*s equals number of *c*s and
number of *b*s equals number of *d*s
$a^n b^m c^n d^m$

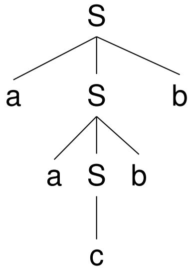
Pick regular language

a is accusative noun, b is dative noun
c is verb that needs accusative, d is verb that needs dative
$R = a^* b^* c^* d^*$

Outline

Derivation tree

Top-down versus Bottom-up



Top down versus bottom up

Kanazawa (2011)

Top down

Chomsky (1956, 1959)

- $N \rightarrow PQ$
- Rewrite N as PQ

Bottom up derivations

Smullyan (1961), Chomsky (1995), Stabler (1997)

- $N \leftarrow PQ$
- Combine P and Q to make N
- $N(xy) := P(x), Q(y)$

Minimalist program and MERGE

External merge

Combine X and Y to make a new object.

Internal merge

Y is part of X

Minimalist Grammars (Stabler, 1997)

Tractable formalisation of this approach.

Mildly context sensitive languages

Joshi

Slightly vague and informal definition:

Definition

A class of languages is MCS if:

- Not too complex: Efficiently parsable (in P)
- Constant growth property/semilinearity
- Includes some classes of crossing dependencies
- (includes all context-free languages)

Convergence of MCS formalisms

Joshi et al. (1990)

A crucial result for linguistics: all of the then current proposals turned out to be weakly equivalent:

- Linear indexed grammars
- Tree adjoining grammars
- Head grammars
- Combinatory categorial grammars

The derivation structures can all be described using LCFRs (we will use Multiple Context Free Grammars instead)

Movement

MCFGs and MGs

See handout.

Outline

Argument that a language is not MCF

Facts (Seki et al.):

- If L is MCF and R is regular, then $L \cap R$ is also MCF.

General structure of correct argument

We want to show that L is not MCF, but L is very complex
Take a simple regular language R
$L \cap R$ is a simple but infinite subset of L
Show that $L \cap R$ is not MCF
Therefore L is not MCF

Old Georgian

Kracht and Michaelis

Suffixaufnahme/Stacking in Old Georgian

A word can have a number of case-suffixes that depends on how deeply embedded it is
WME- word marking English
Verb 'run', and noun 'son', case marker 'gen'

- son run
- son songen run
- son songen songengen run
- son songen songengen songengengen run.

See Joshi's rebuttal and Pesetsky's recent work

Chinese number names

Radzinski, 1991

Data

wu = 5, zhao $= 10^{12}$

wu zhao zhao wu zhao $= 5 \times 10^{24} + 5 \times 10^{12}$

*wu zhao wu zhao zhao

Language intersected with $\{\text{wu}, \text{zhao}\}^*$

$\{wuzhao^{k_1} wuzhao^{k_2} \ldots wuzhao^{k_n} | k_1 > k_2 \cdots > k_n\}$

This is not semilinear

Yoruba

Kobele, 2006 (and MCFG2 2011)

Relative clauses

- Olu ra adie ti o go
- Olu buy chicken that 3s dumb
- Rira adie ti o go to Olu ra adie ti o go ko da
- buying chicken that 3s dumb that Olu buy chicken that 3s dumb not good
- * Rira adie ti o go to Olu ra adie ti o kere ko da

Recursive copying: intersection with appropriate R gives 2^n copies of 'adie'

Outline

Conclusion

- Broad consensus that somewhere in the MCFG hierarchy is correct
- Some problematic cases but all a bit marginal
- Possibly we need some true copying operation as well
  $N_1(uu) \leftarrow P_1(u)$
  Also for full stem reduplication in morphology?
- Alternatively there might be some nontrivial operation at Spellout.
- We will make the default assumption here that MCFGs are adequate.