Data-Oriented Parsing and Discontinuous Constituents

Andreas van Cranenburgh

Huygens ING
Royal Netherlands Academy of Arts and Sciences

Institute for Logic, Language and Computation
University of Amsterdam

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This lecture

1. Context & context freedom
2. Parsing with . . .
   - discontinuous constituents:
     Linear Context-Free Rewriting Systems (LCFRS)
   - treebank fragments:
     Data-Oriented Parsing (DOP)
     Tree-Substitution Grammar (TSG)
3. Other non-context-free challenges

Context and Context Freedom

Two meanings for context-free:

1. Rewrite operations are independent from anything not being rewritten.
   Counterexamples: HPSG, LFG, &c.
   model theoretic syntax;
   unification based $\Rightarrow$ exp. time complexity

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1. Rewrite operations are independent from anything not being rewritten.
   Counterexamples: HPSG, LFG, &c.
   model theoretic syntax;
   unification based $\Rightarrow$ exp. time complexity
2. CFG: a grammar $\langle V, T, S, P \rangle$ with the above property, such that productions in P are of the form:

$$\alpha \rightarrow \beta_1 \ldots \beta_n$$

   Counterexamples: TAG, CCG, &c.

NB: a formalism can be context-free (1) without being Context-Free (2) ...

The Domain of Locality

Domain of Locality: the information which is available while applying rewrite operations

CFG: parent $\rightarrow$ nonterminals dominating adjacent terminals

LCFRS: parent $\rightarrow$ nonterminals dominating terminals regardless of position in sentence

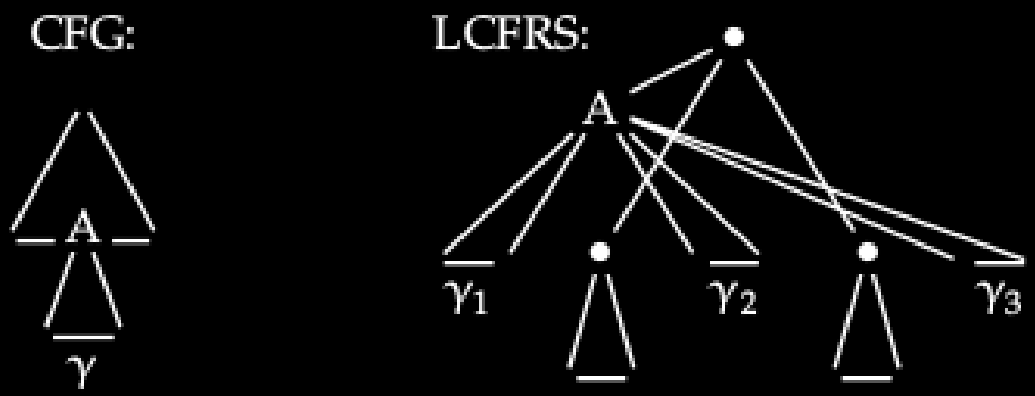


Figure 3
Different domains of locality.

Discontinuous Constituents

Example:

- Why did the chicken cross the road?
- The chicken crossed the road to get to the other side.

Non-local information in PTB: traces

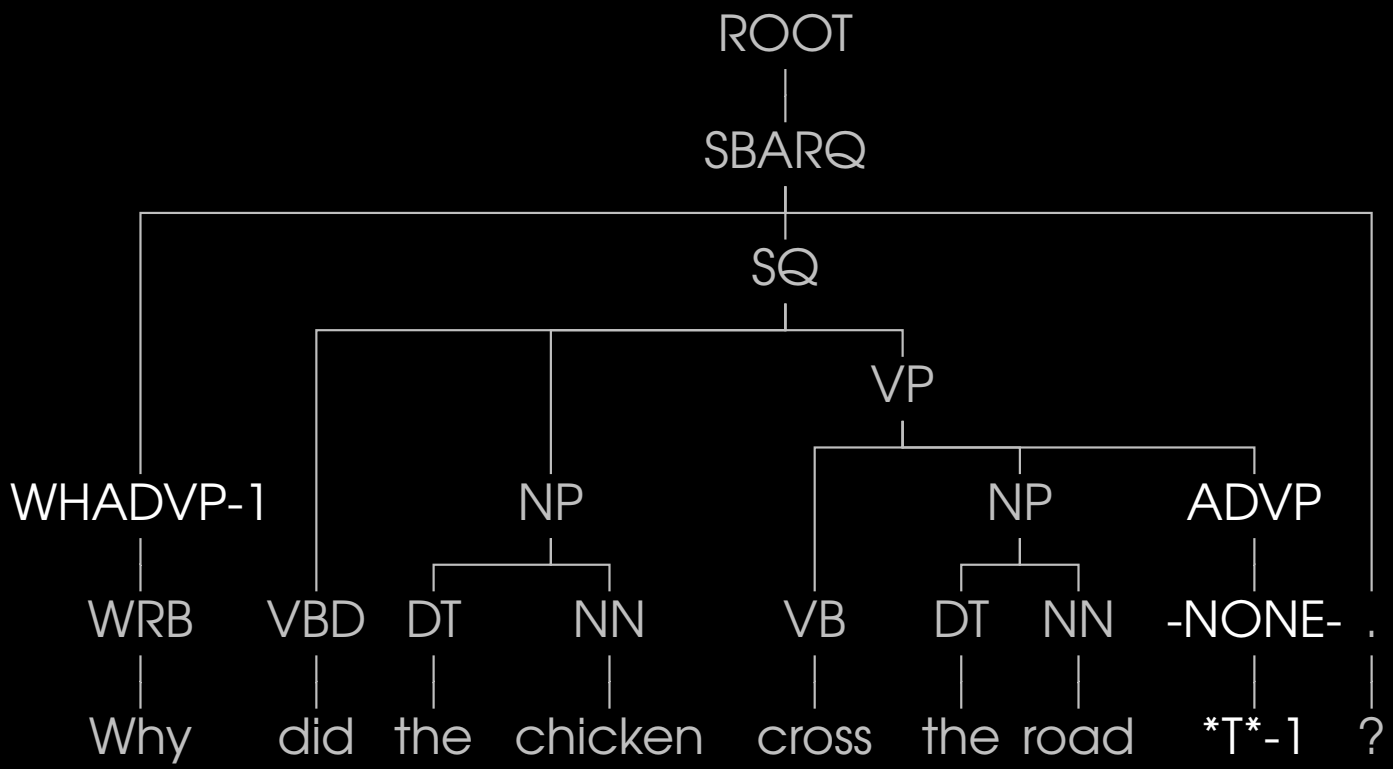


Figure : PTB-style annotation.

Discontinuous trees

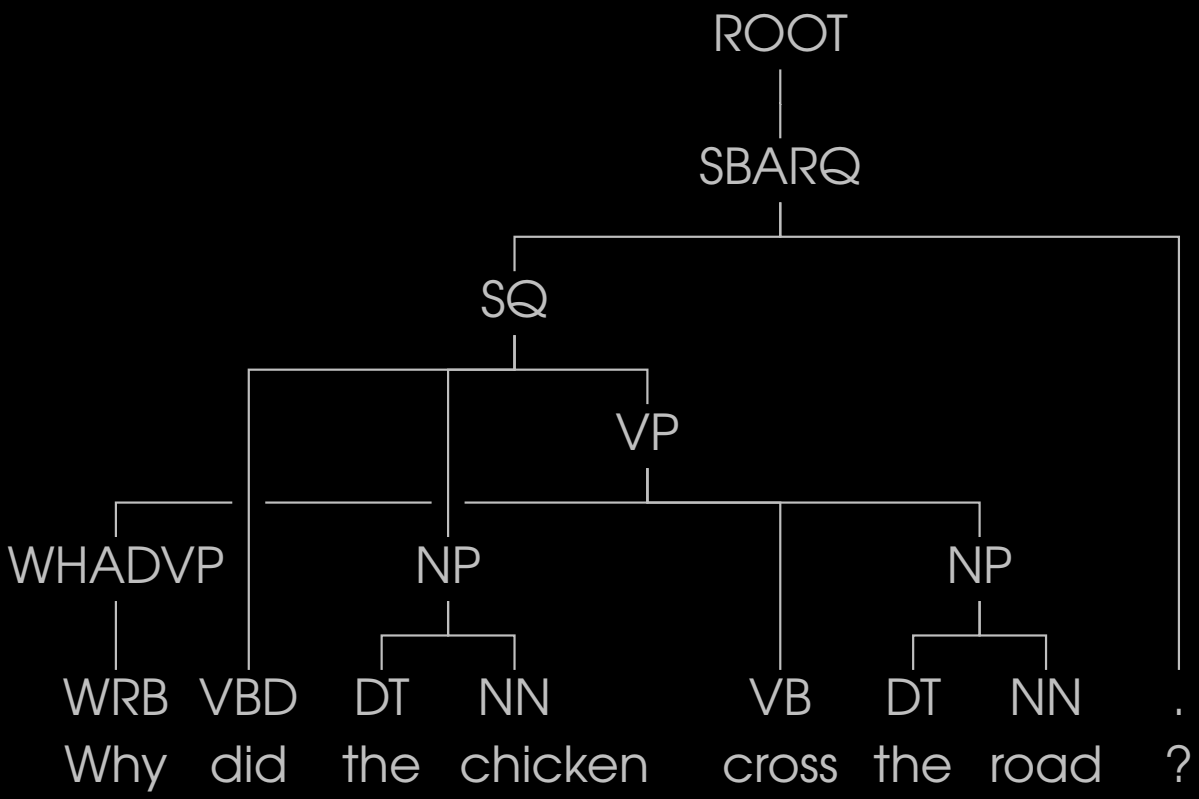


Figure : A tree with a discontinuous constituent.

Discontinuous constituents

Motivation:

- Handle flexible word-order, extraposition, &c.
- Capture argument structure
- Combine information from constituency & dependency structures

(NB: non-projectivity is a subset of discontinuous phenomena)

Discontinuous treebanks

Treebanks with discontinuous constituents:

German/Negra: Skut et al. (1997). An annotation scheme for free word order languages.

Dutch/Alpino: van der Beek (2002). The Alpino dependency treebank.

English/PTB (after conversion): Evang & Kallmeyer (2011). PLCFRS Parsing of English Discontinuous Constituents.

Swedish, Polish, ...

Discontinuous trees

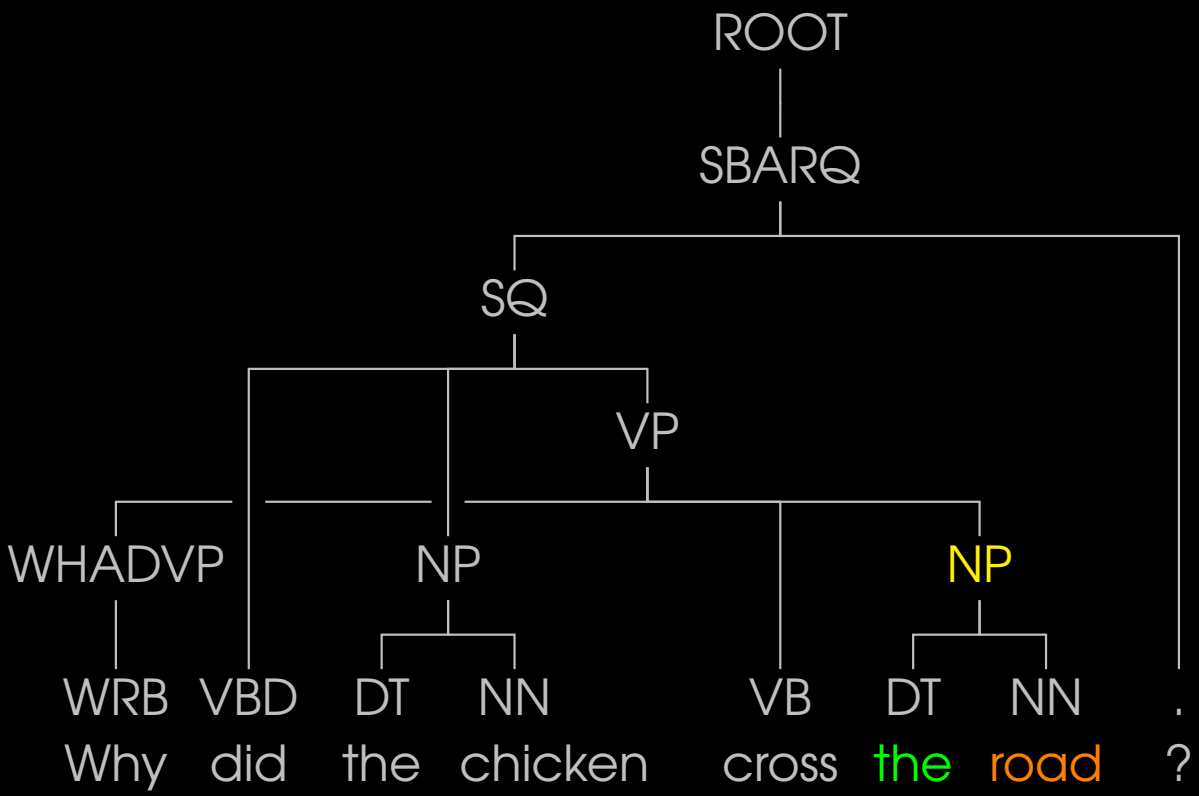


Figure : A tree with a discontinuous constituent.

Context-Free Grammar (CFG)

$NP(ab) \rightarrow DT(a)\ NN(b)$

Discontinuous trees

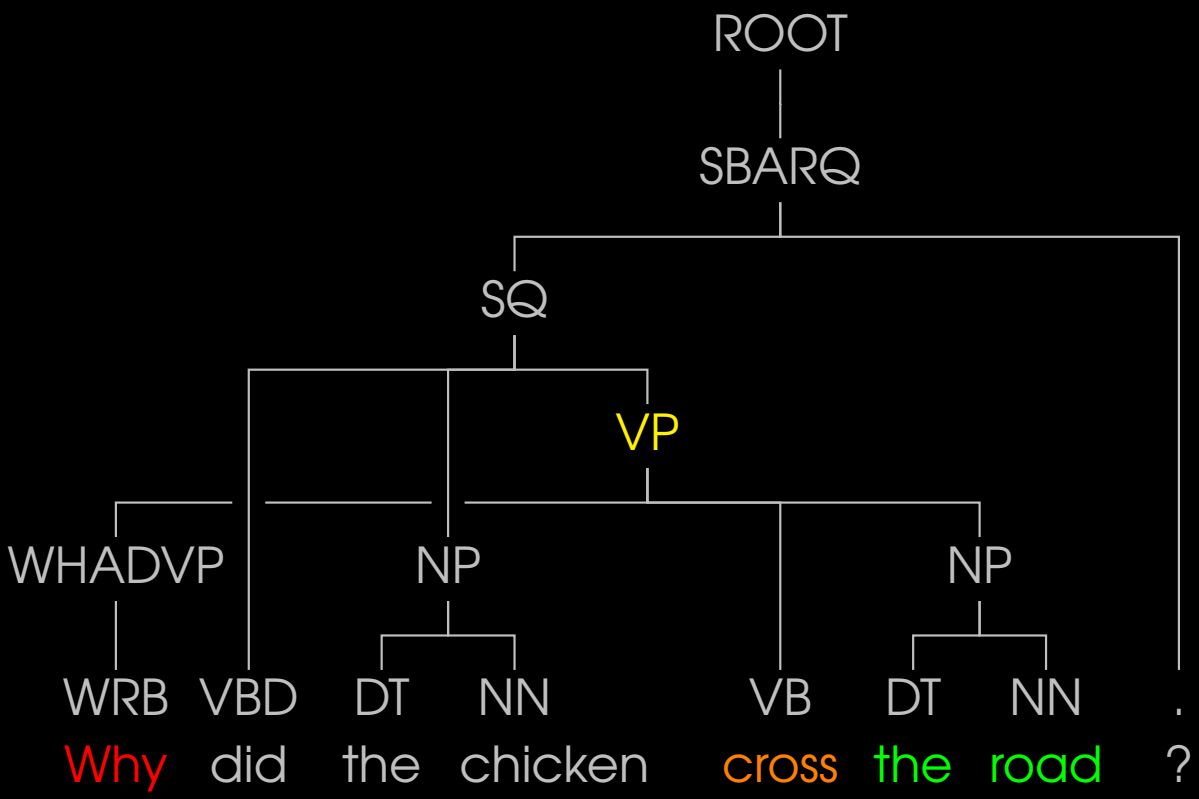


Figure : A tree with a discontinuous constituent.

Linear Context-Free Rewriting System (LCFRS)

$VP_2(a, bc) \rightarrow WHADVP(a)\ VB(b)\ NP(c)$

Discontinuous trees

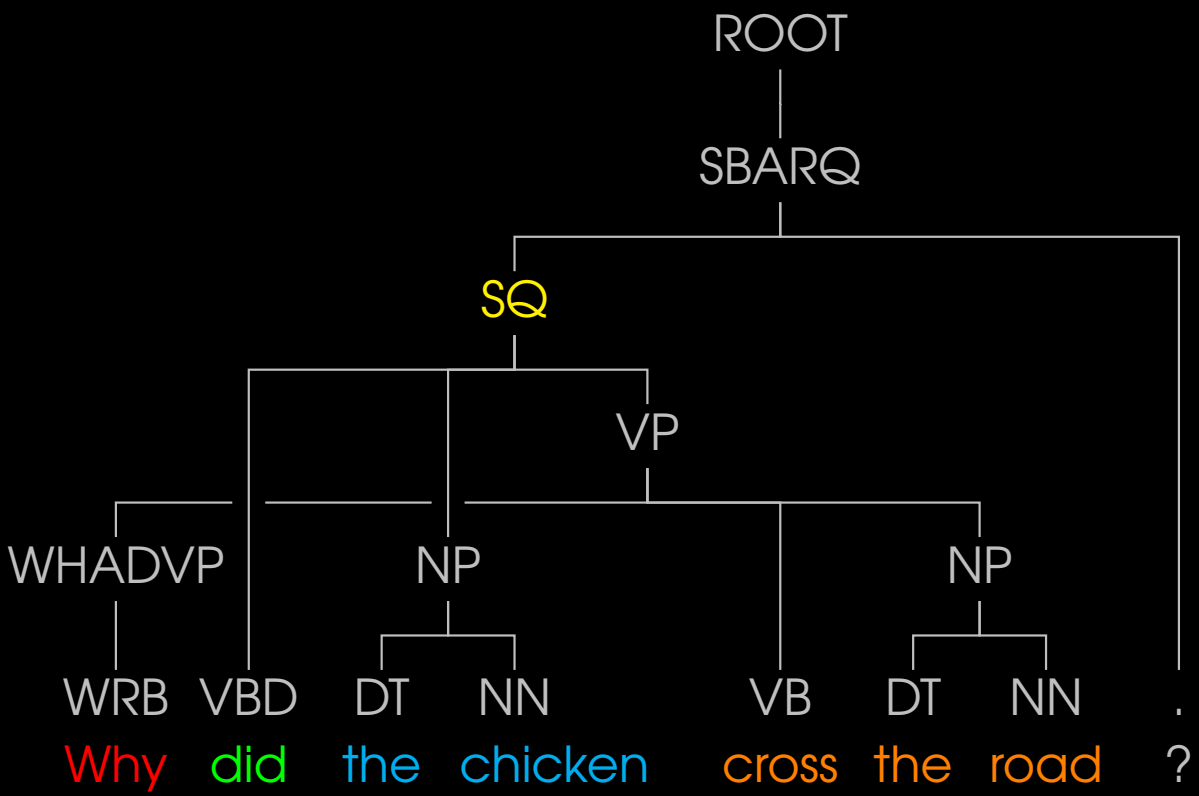


Figure : A tree with a discontinuous constituent.

Linear Context-Free Rewriting System (LCFRS)

$VP_2(a, bc) \rightarrow WHADVP(a)\ VB(b)\ NP(c)$

$SQ(abcd) \rightarrow VBD(b)\ NP(c)\ VP_2(a, d)$

Linear Context-Free Rewriting Systems: I

LCFRS are a generalization of CFG:
$\Rightarrow$ rewrite tuples, trees or graphs!

Vijay-Shanker, Weir, Joshi (1987): Structural descriptions produced by various grammar formalisms

Linear Context-Free Rewriting Systems: I

LCFRS are a generalization of CFG:
$\Rightarrow$ rewrite tuples, trees or graphs!

linear: each variable on the left occurs once on the right & vice versa

context-free: apply productions based on what they rewrite

rewriting system: i.e., formal grammar

Vijay-Shanker, Weir, Joshi (1987): Structural descriptions produced by various grammar formalisms

Linear Context-Free Rewriting Systems: II

LCFRS are weakly equivalent to:

- Combinatory Categorial Grammar
- Tree-Adjoining Grammar
- Synchronous Context-Free Grammar
- Multiple Context-Free Grammar
- Minimalist Grammar
- &c. . . .

$\Rightarrow$ LCFRS form a 'lingua franca' formalism.

Complexity of LCFRS parsing

- LCFRS are Mildly Context-Sensitive grammar formalisms.
- Parsing an LCFRS has polynomial time complexity:

$$\mathcal{O}(n^{r\varphi})$$

  where ...
  - r is the number of non-terminals (rank)
  - φ is the maximum number of components covered by a non-terminal (fan-out).

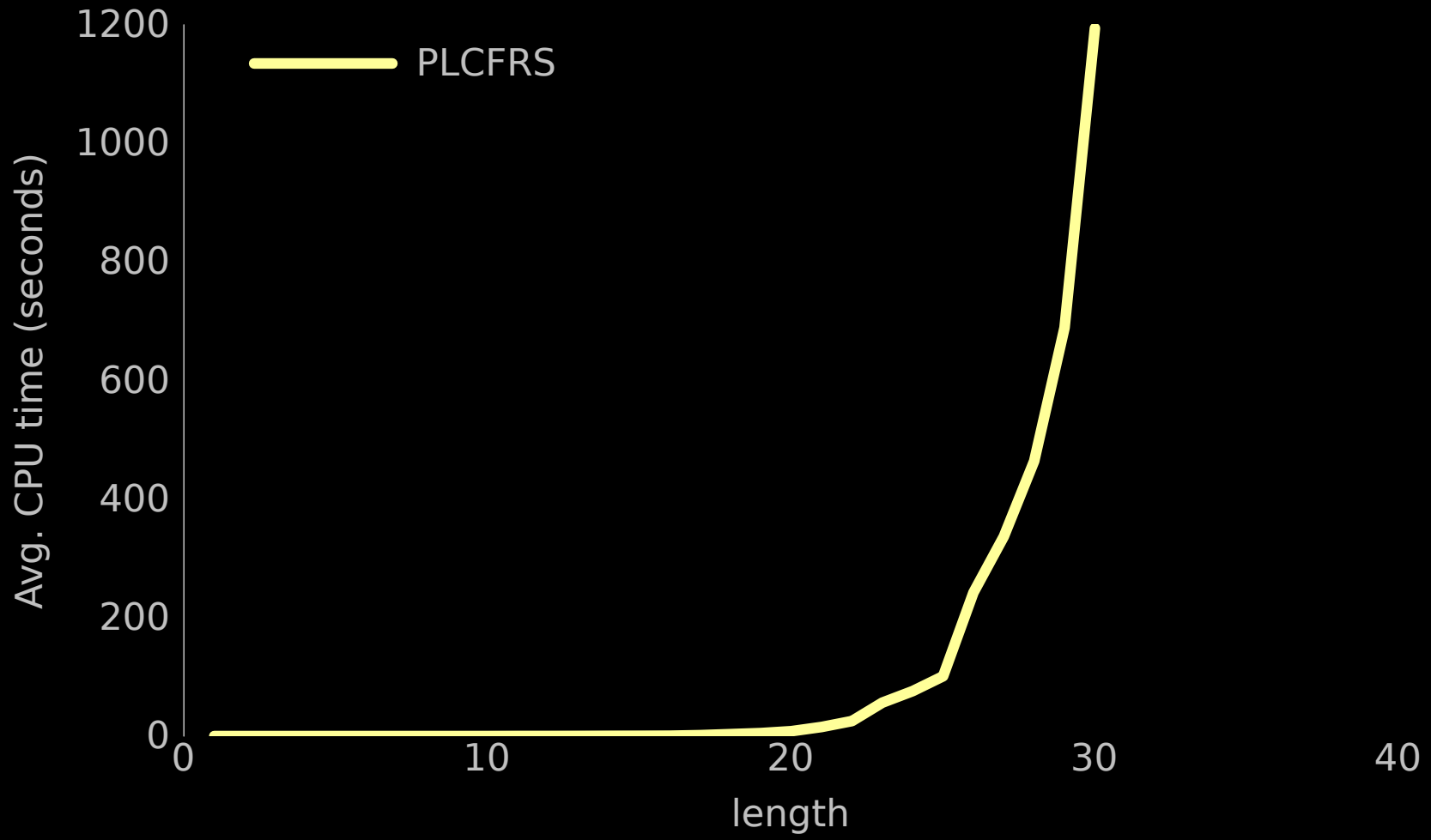
  $\Rightarrow$ infinite 2D hierarchy of languages between context-free and context-sensitive.
- Both CFG & LCFRS $\in$ LOGCFL

Parsing with LCFRS

- An LCFRS can be parsed with tabular parsing algorithm (similar to CKY):
- Agenda-based probabilistic parser for LCFRS (Kallmeyer & Maier 2010);
  extended to produce *k*-best derivations
- Rules can be read off from treebank,
  relative frequencies give probabilistic LCFRS (PLCFRS)

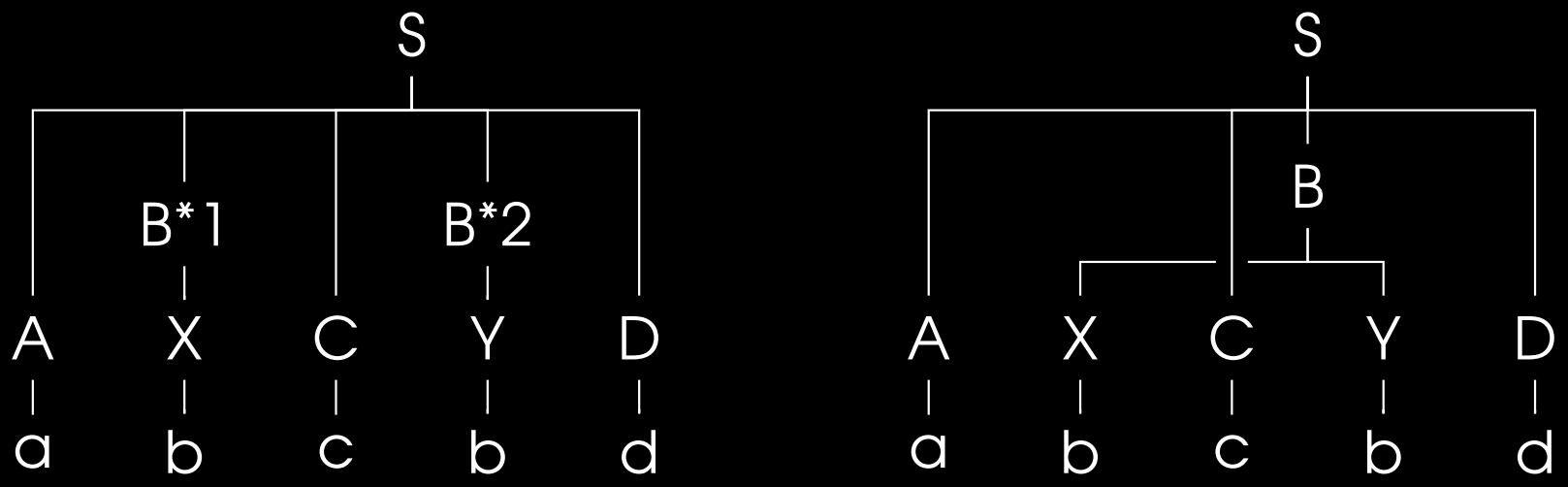
Kallmeyer & Maier (2010). Data-driven parsing with probabilistic linear context-free rewriting systems.

But . . .



Negra dev. set, gold tags

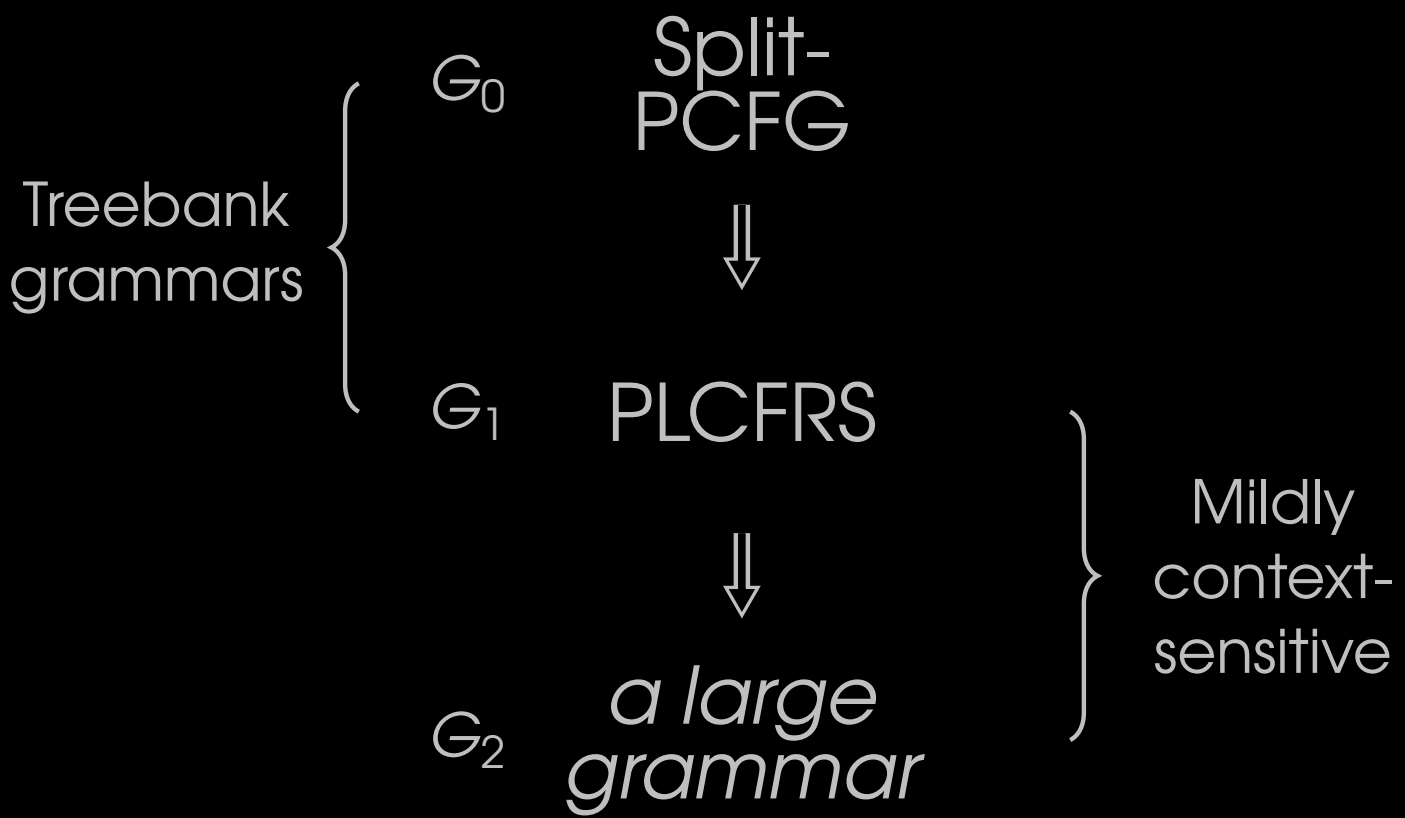
PCFG approximation of PLCFRS



- Transformation is reversible
- Increased independence assumption:
  $\Rightarrow$ every component is a new node
- Language is a superset of original PLCFRS
  $\Rightarrow$ coarser, overgenerating PCFG (`split-PCFG')

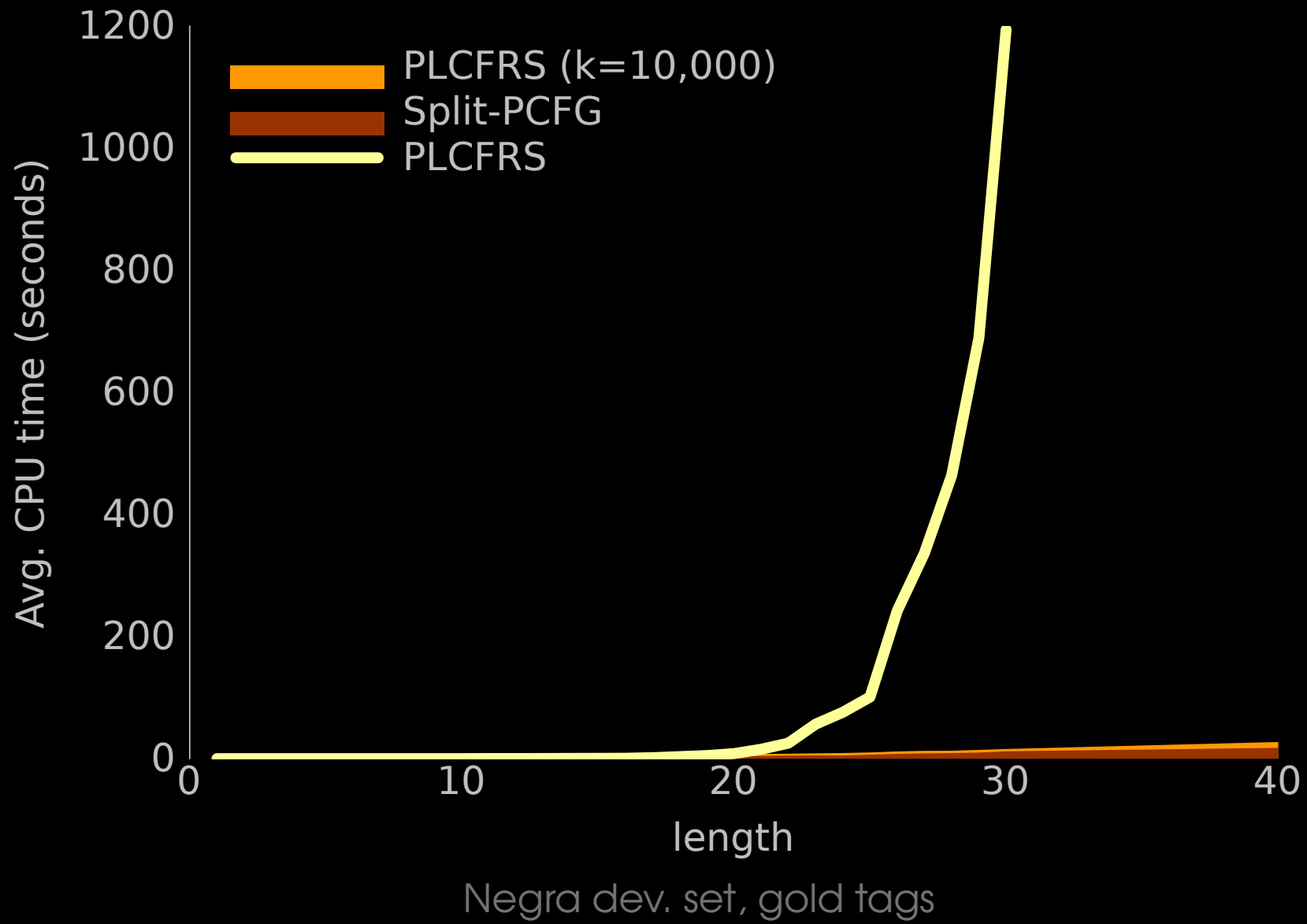
Boyd (2007). Discontinuity revisited.

Coarse-to-fine pipeline



prune parsing with G_{m+1} by only considering items in k-best G_m derivations.

With coarse-to-fine



Negra dev. set, gold tags

Data-Oriented Parsing

Treebank grammar

trees $\Rightarrow$ productions + rel. frequencies

$\Rightarrow$ problematic independence assumptions

Data-Oriented Parsing (DOP)

trees $\Rightarrow$ fragments + rel. frequencies

fragments are arbitrarily sized chunks from the corpus

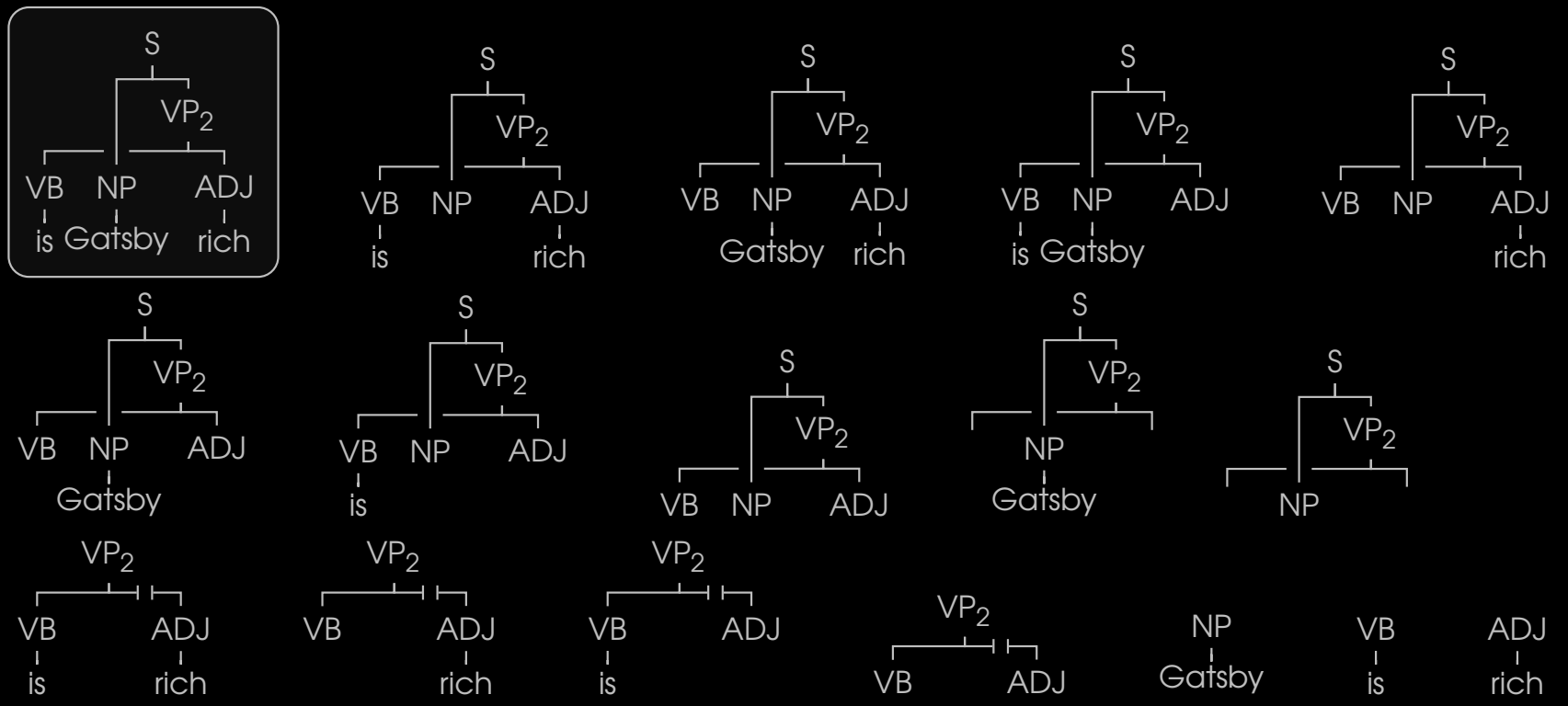
consider all possible fragments from treebank

. . . and "let the statistics decide"

Scha (1990): Lang. theory and lang. tech.; competence and performance

Bod (1992): A computational model of language performance

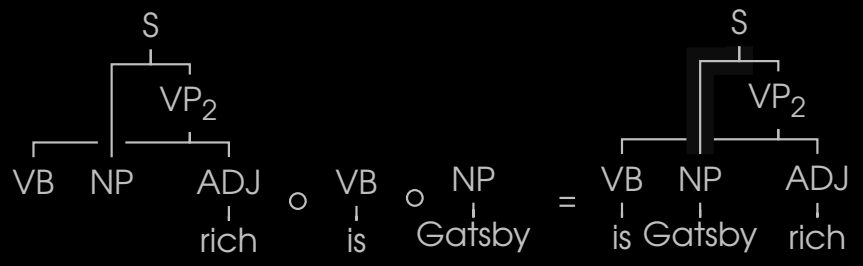
DOP fragments



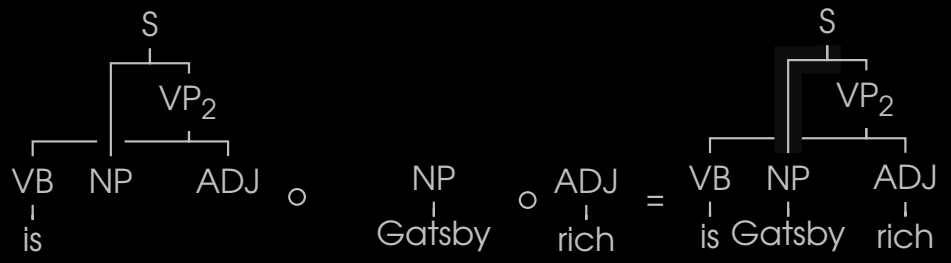
$$P(f) = \frac{\text{count}(f)}{\sum_{f' \in F} \text{count}(f')} \text{ where } F = \{ f' \mid root(f') = root(f) \}$$

Note: discontinuous frontier non-terminals mark destination of components

DOP derivation



$P(d) = 0.2$



$P(d) = 0.3$

Derivations for this tree $P(t) = 0.5$

$$P(d) = P(f_1 \circ \cdots \circ f_n) = \prod_{f \in d} p(f)$$

$$P(t) = P(d_1) + \cdots + P(d_n) = \sum_{d \in D(t)} \prod_{f \in d} p(f)$$

Tree-Substitution Grammar

This DOP model (Bod 1992) is based on
Tree-Substitution Grammar (TSG):

- Weakly equivalent to CFG; typically strongly equivalent as well; advantage is in stochastic power of Probabilistic TSG.
- Same Context-Free property as CFG, but multiple productions applied at once;
  $\Rightarrow$ captures more structural relations than PCFG.
- CFG backbone can be replaced with LCFRS to get Discontinuous Tree-Substitution Grammar ($\text{PTSG}_{\text{LCFRS}}$).

DOP implementation issues

Exponential number of fragments
due to all-fragments assumption

- Can use DOP reduction (Goodman 2003);
  weight of fragments spread over many productions
- Can restrict number of fragments
  by depth or frontier nodes &c.,
  $\Rightarrow$ but: not data-oriented!

Goodman (2003): Efficient parsing of DOP with PCFG-reductions

Double-DOP

- Extract fragments that occur at least twice in treebank
- For every pair of trees, extract maximal overlapping fragments
- Can be extracted in linear average time
- Number of fragments is small enough to parse with directly

Sangati & Zuidema (2011). Accurate parsing w/compact TSGs: Double-DOP
van Cranenburgh (2012). Extracting tree fragments in linear average time

From fragments to grammar

- Fragments mapped to unique rules, relative frequencies as probabilities
  - Remove internal nodes, leaves root node, substitution sites & terminals $X \rightarrow X_1 \ldots X_n$
- Reconstruct derivations after parsing

Sangati & Zuidema (2011). Accurate parsing w/compact TSGs: Double-DOP

Preprocessing

- Remove function labels
- Binarize w/markovization (h=1, v=1)
- Simple unknown word model
  - Rare words replaced by features (model 4 from Stanford parser)
  - Reserve probability mass for unseen (tag, word) pairs

Results w/Double-DOP

	F1 %
DOP reduction	74.3
Double-DOP	

(Negra dev set $\leq$ 40 words, gold tags)

Results w/Double-DOP

	F1 %
DOP reduction	74.3
Double-DOP	76.3

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Also: parsing 3$\times$ faster, grammar 3$\times$ smaller

Results w/Double-DOP

	k=50 F1 %	k=5000 F1 %
DOP reduction	74.3	73.5
Double-DOP	76.3	

(Negra dev set $\leq$ 40 words, gold tags)

What if we reduce pruning?

Results w/Double-DOP

	k=50 F1 %	k=5000 F1 %
DOP reduction	74.3	73.5
Double-DOP	76.3	77.7

(Negra dev set $\leq$ 40 words, gold tags)

What if we reduce pruning?
$\Rightarrow$ For Double-DOP, performance does not deterioriate with expanded search space.

Parsing results: test sets

Parser, treebank	F1	EX
GERMAN		
HaNi2008, Tiger	75.3	32.6
CrBo2013, Tiger	**78.8**	**40.8**
ENGLISH		
SaZu2011, wsj	87.9	33.7
EvKa2011, disc. wsj	79.0	
CrBo2013, disc. wsj	**85.6**	31.3
DUTCH		
CrBo2013, Lassy	77.0	35.2

CrBo: van Cranenburgh & Bod (2013);
HaNi: Hall & Nivre (2008); SaZu: Sangati & Zuidema (2011).

Can DOP handle discontuinity without LCFRS?

Split-PCFG

⇓

PLCFRS

⇓

PLCFRS Double-DOP

77.7 % F1

41.5 % EX

Split-PCFG

⇓

Split-Double-DOP

Can DOP handle discontuinity without LCFRS?

Split-PCFG

⇓

PLCFRS

⇓

PLCFRS Double-DOP

77.7 % F1

41.5 % EX

Split-PCFG

⇓

Split-Double-DOP

78.1 % F1

42.0 % EX

Answer: Yes!

Fragments can capture discontinuous contexts

Summary

Formally,	$\mathrm{CFG} = \mathrm{TSG}_{\mathrm{CFG}} \subset \mathrm{LCFRS}$
Stochastically,	$\mathrm{PCFG} \subset \mathrm{PTSG}_{\mathrm{CFG}}$
Empirically,	$\mathrm{PTSG}_{\mathrm{LCFRS}} \approx \mathrm{PTSG}_{\mathrm{CFG}}$

Limitations of parsing with (approximated) LCFRS

- Just as with CFG, an LCFRS production strictly covers a single configuration of constituents.
- Consider:
  A man who was seeking a unicorn walked into the room.
  vs.
  A man walked into the room who was seeking a unicorn.
- Discontinuous constituents are relatively rare
  $\Rightarrow$ sparse data problem

Unsupervised discontinuous parsing?

Problems:

- A sentence with n words has $O(n^2)$ possible continuous constituents. The same sentence may have $O(2^n)$ discontinuous constituents.

Unsupervised discontinuous parsing?

Problems:

- A sentence with n words has $O(n^2)$ possible continuous constituents.
  The same sentence may have $O(2^n)$ discontinuous constituents.
- For continuous constituents, adjacent co-occurrence is the key heuristic to determine constituency.
  Is there a surface heuristic for discontinuous constituency?
  $\Rightarrow$ Morphology in case of morphologically-rich languages.

Unsupervised discontinuous parsing

Rule-based: e.g., Yoshinaka (2010), Polynomial-time identification of multiple context-free languages from positive data and membership queries

Unsupervised discontinuous parsing

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Statistical: Stanford parser jointly parsers with a PCFG and a dependency model.
Same technique could be applied to induce a PCFG and a non-projective dependency model.

Other non-context-free challenges: supervised

Adjunction: More compact grammar and less sparsity when adjuncts can be inserted with an operation of the grammar formalism; e.g., Tree-Insertion Grammar.

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Grammatical functions: Most models reconstruct functions after parsing using machine learning

Other non-context-free challenges: supervised

Adjunction: More compact grammar and less sparsity when adjuncts can be inserted with an operation of the grammar formalism; e.g., Tree-Insertion Grammar.

Grammatical functions: Most models reconstruct functions after parsing using machine learning

Multiple parents: e.g., *John$_1$ walks and (John$_1$) talks to Mary*

Other non-context-free challenges: unsupervised

Free word-order: Separate surface from canonical structure by reordering.

But: Information on canonical order is not in treebanks.

Some order variation is pragmatic, some affects syntax/semantics.

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Condition on lexical relations as opposed to just structural relations.
But: which relations are relevant?

Other non-context-free challenges: unsupervised

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Condition on lexical relations as opposed to just structural relations.
But: which relations are relevant?

Exploit sentence context; e.g., current topic, other discourse effects

THE END

Codes: http://github.com/andreasvc/disco-dop

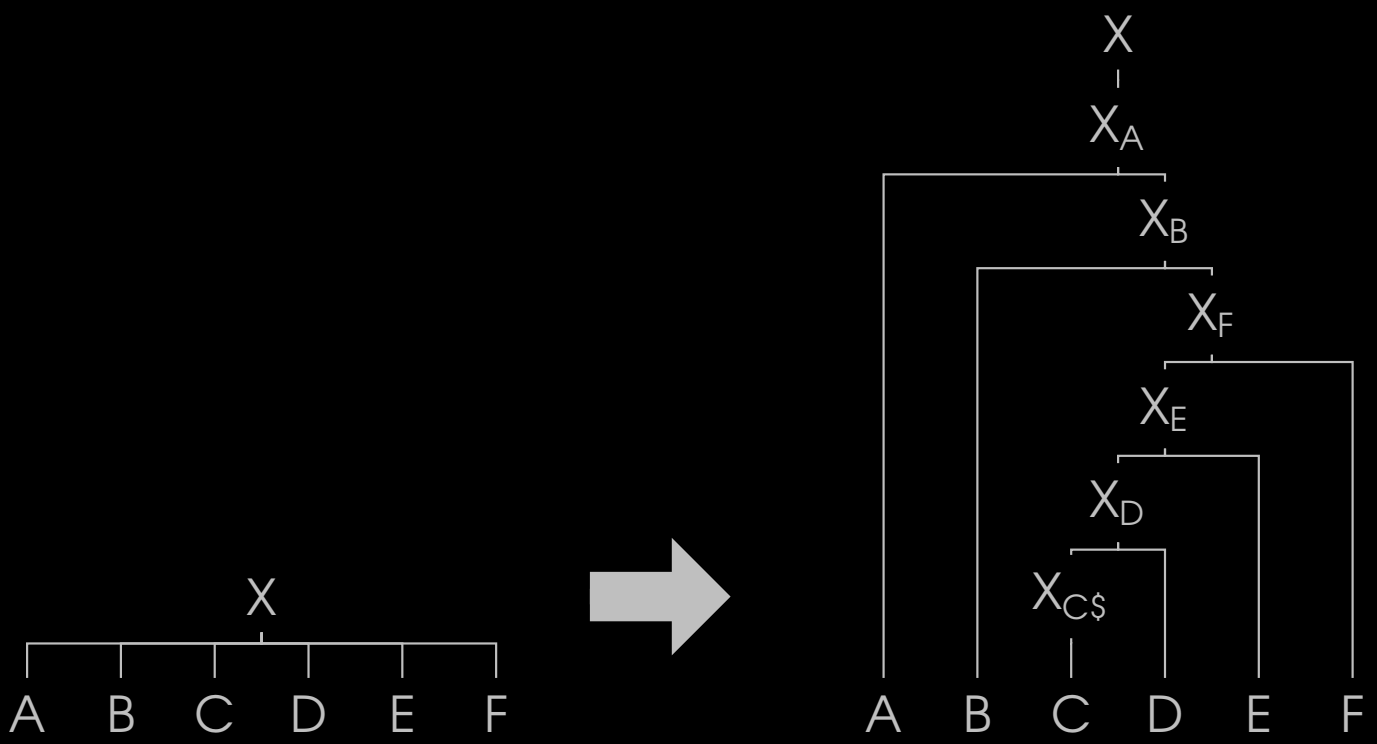
Papers: http://staff.science.uva.nl/~acranenb

Wait . . . there's more

BACKUP SLIDES

Binarization

- mark heads of constituents
- head-outward binarization (parse head first)
- no parent annotation: $v = 1$
- horizontal Markovization: $h = 1$



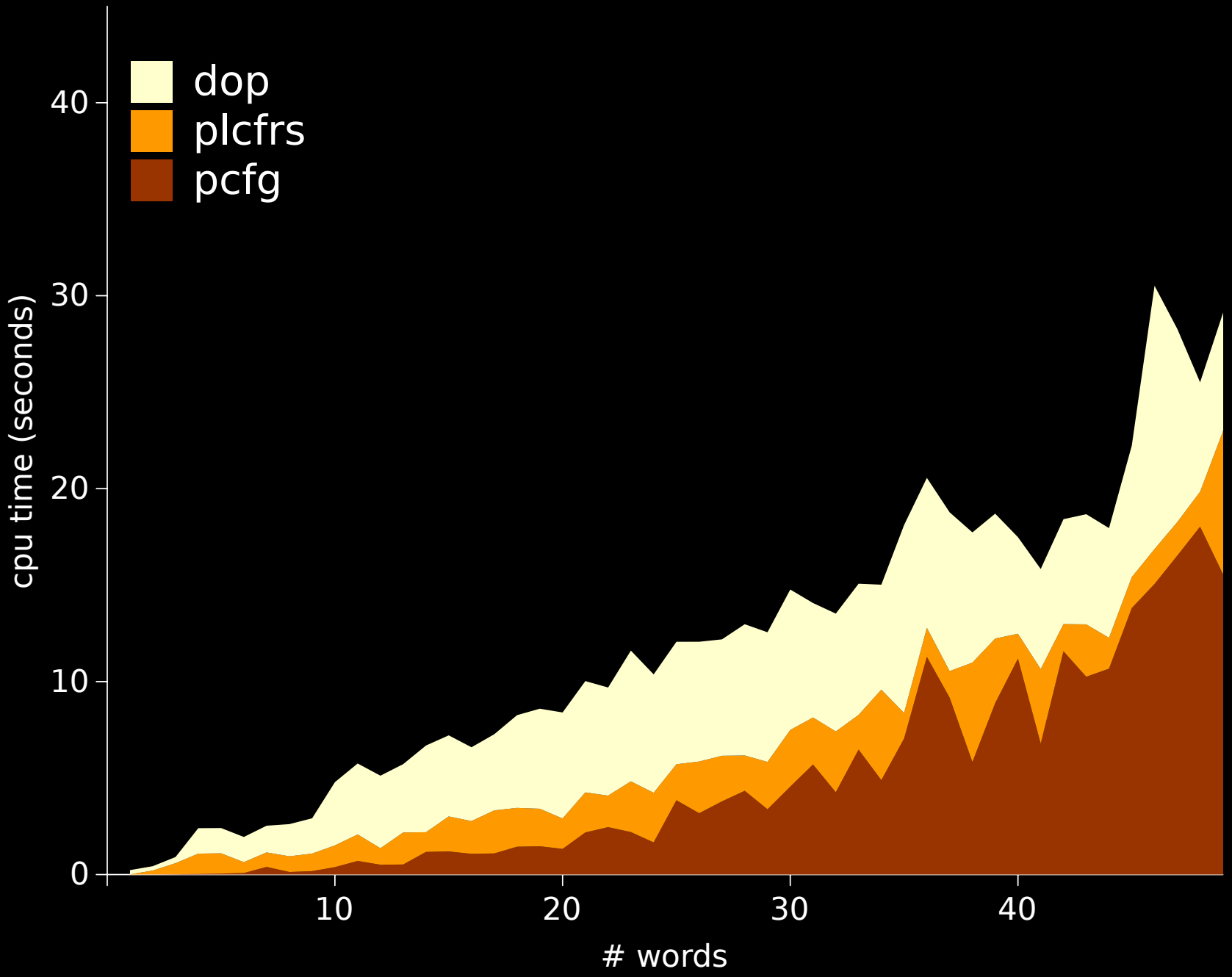
Klein & Manning (2003): Accurate unlexicalized parsing.

Implementation details

- Cython: combines best of both worlds
  C speed, Python convenience.
- Where it matters, manual memory management & layout;
- e.g., grammar rules & edges compactly packed in arrays of `structs`.
- 14k lines of code; FWIW:

Collins parser	C	3k	(!?)
bitpar	C++	6k	
Berkeley parser	Java	58k	
Charniak & Johnson parser	C++	62k	
Stanford parser	Java	151k	

Efficiency (Negra dev set)



Parser setup

```
traincorpus='wsj02-21.export',
testcorpus='wsj24.export',
corpusdir='../../dptb',
stages=[
    dict(
        name='pcfg', mode='pcfg',
        split=True, markorigin=True,
    ),
    dict(
        name='plcfrs', mode='plcfrs',
        prune=True, splitprune=True, k=10000,
    ),
    dict(
        name='dop', mode='plcfrs',
        prune=True, k=5000,
        dop=True, usedoubledop=True, m=10000,
        estimator='dop1', objective='mpp',
    ),
],
[...]
```

Web-based interface