Synchronous Grammars and Translation

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Slides courtesy of Philipp Koehn

Tree-Based Models

- Phrase Based MT models operate on sequences of words

- Many translation problems can be best explained by conditioning on syntax
  - reordering, e.g., verb movement in German–English translation
  - long distance agreement (e.g., subject-verb) in output

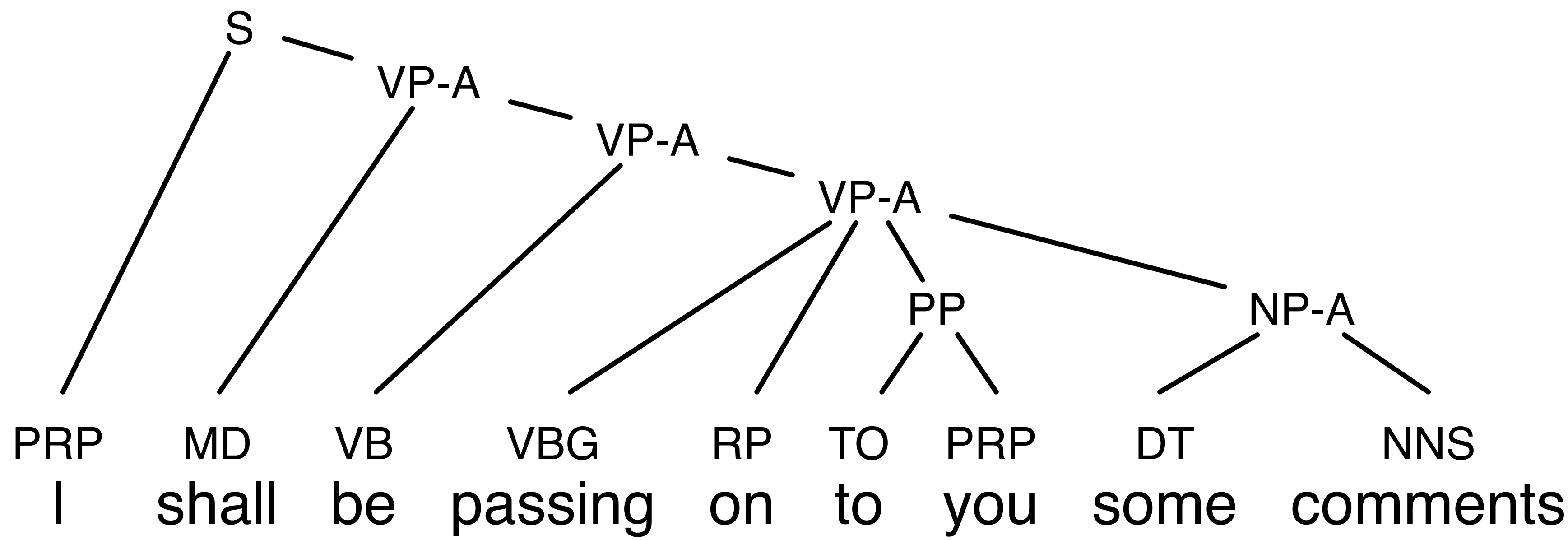
⇒ Translation models based on tree representations of language
  - a dominant theme of recent research
  - state-of-the art for some language pairs

Phrase Structure Grammar

- Phrase structure
  - noun phrases: the big man, a house, ...
  - prepositional phrases: at 5 o'clock, in Edinburgh, ...
  - verb phrases: going out of business, eat chicken, ...
  - adjective phrases, ...

- Context-free Grammars (CFG)
  - non-terminal symbols: phrase structure labels, part-of-speech tags
  - terminal symbols: words
  - production rules: NT → [NT,T]+
    example: NP → DET NN

Phrase Structure Grammar



Phrase structure grammar tree for an English sentence
(as produced by Collins' parser)

Synchronous Phrase Structure Grammar

- English rule

$$\text{NP} \rightarrow \text{DET JJ NN}$$

- French rule

$$\text{NP} \rightarrow \text{DET NN JJ}$$

- Synchronous rule (indices indicate alignment):

$$\text{NP} \rightarrow \text{DET}_1 \ \text{NN}_2 \ \text{JJ}_3 \mid \text{DET}_1 \ \text{JJ}_3 \ \text{NN}_2$$

Synchronous Grammar Rules

- Nonterminal rules

$$\text{NP} \rightarrow \text{DET}_1\ \text{NN}_2\ \text{JJ}_3 \mid \text{DET}_1\ \text{JJ}_3\ \text{NN}_2$$

- Terminal rules

$$\text{N} \rightarrow \text{maison} \mid \text{house}$$

$$\text{NP} \rightarrow \text{la maison bleue} \mid \text{the blue house}$$

- Mixed rules

$$\text{NP} \rightarrow \text{la maison}\ \text{JJ}_1 \mid \text{the}\ \text{JJ}_1\ \text{house}$$

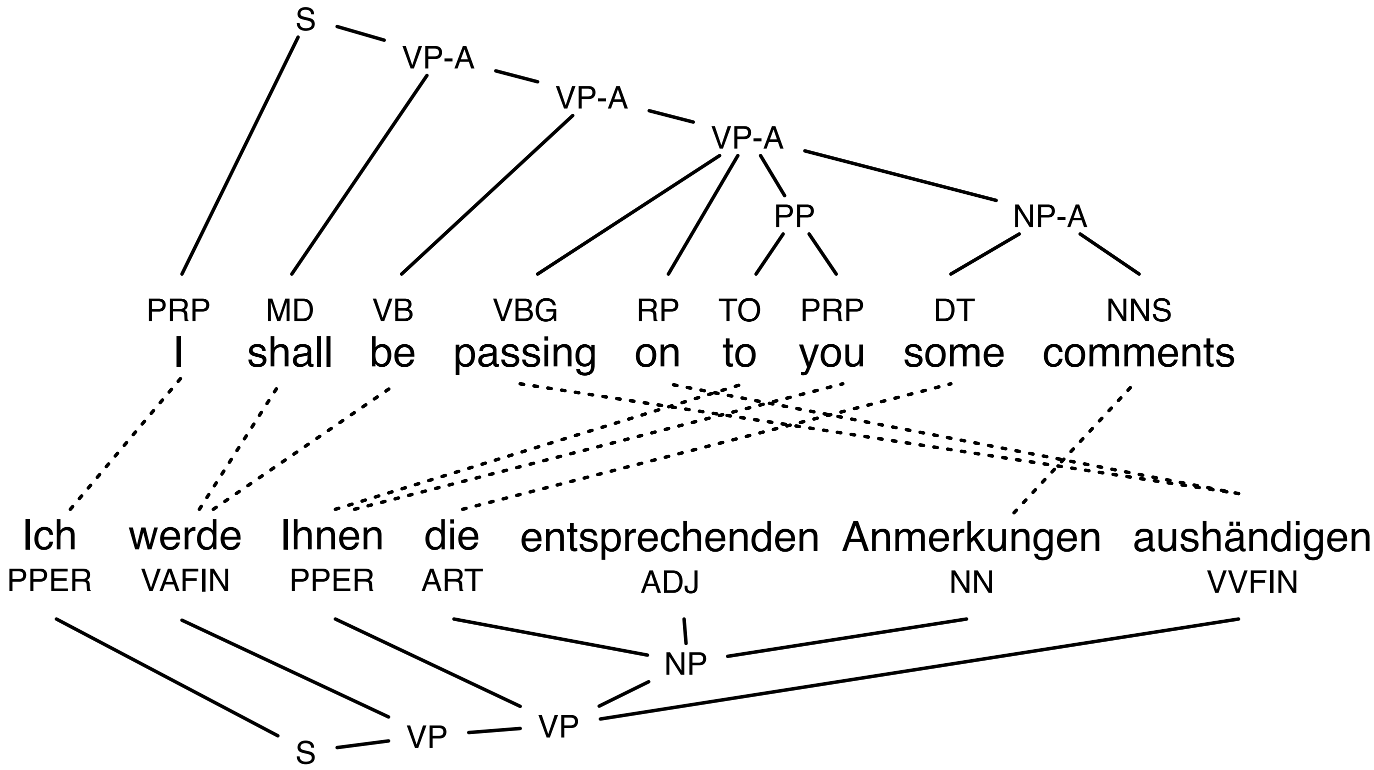
Tree-Based Translation Model

- Translation by parsing
  - synchronous grammar has to parse the entire input sentence
  - output tree is generated at the same time
  - process is broken up into a number of rule applications
- Translation probability

$$\mathsf{p}(\text{TREE}, \text{E}, \text{F}) = \prod_i \mathsf{p}(\text{RULE}_i)$$

- Many ways to assign probabilities to rules

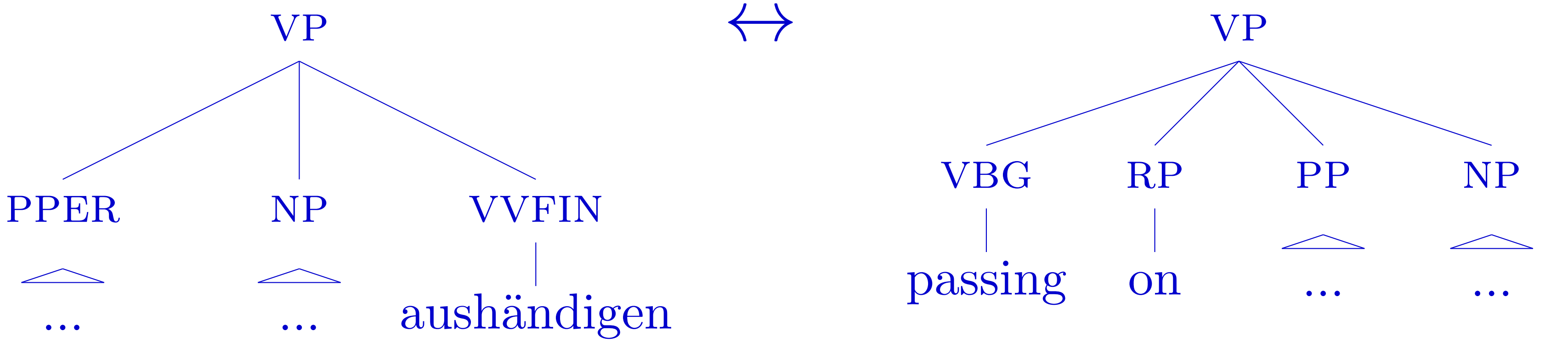
Aligned Tree Pair



Phrase structure grammar trees with word alignment
(German–English sentence pair.)

Reordering Rule

- Subtree alignment



- Synchronous grammar rule

$$\text{VP} \rightarrow \text{PPER}_1 \ \text{NP}_2 \ \text{aushändigen} \ \mid \ \text{passing on PP}_1 \ \text{NP}_2$$

- Note:
  - one word aushändigen mapped to two words passing on ok
  - but: fully non-terminal rule not possible (one-to-one mapping constraint for nonterminals)

Another Rule

- Subtree alignment

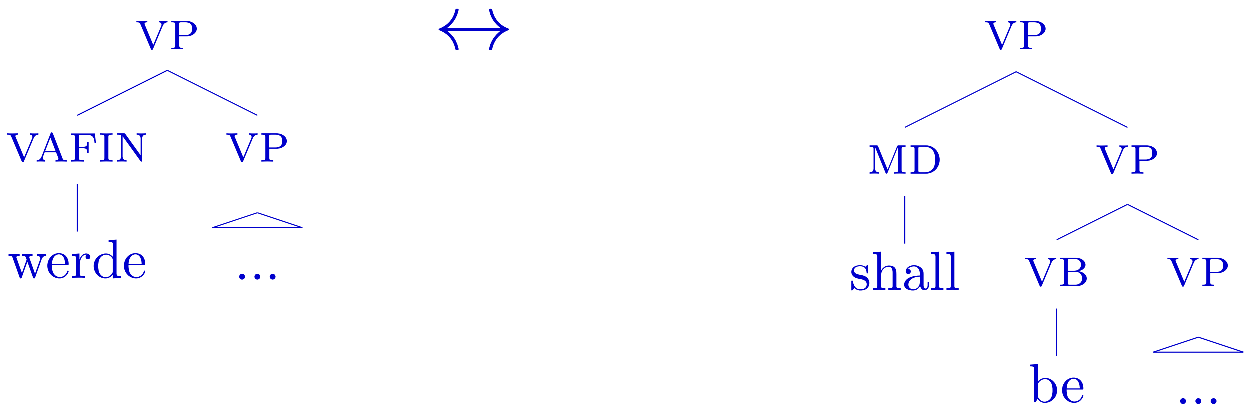
- Synchronous grammar rule (stripping out English internal structure)

$$\text{PRO/PP} \rightarrow \text{Ihnen} \;|\; \text{to you}$$

- Rule with internal structure

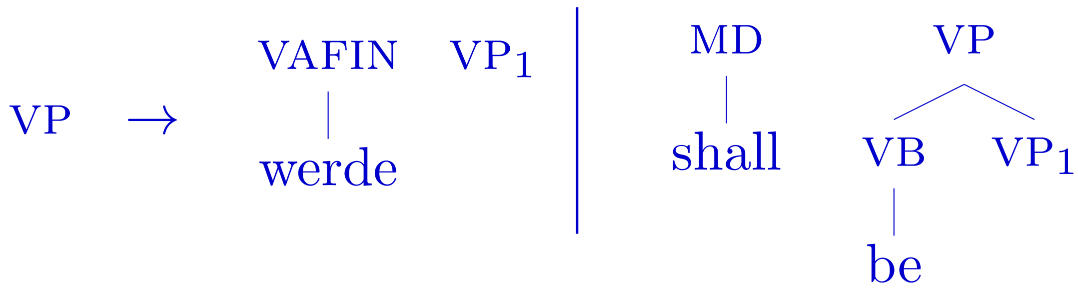
Another Rule

- Translation of German werde to English shall be



- Translation rule needs to include mapping of VP

⇒ Complex rule



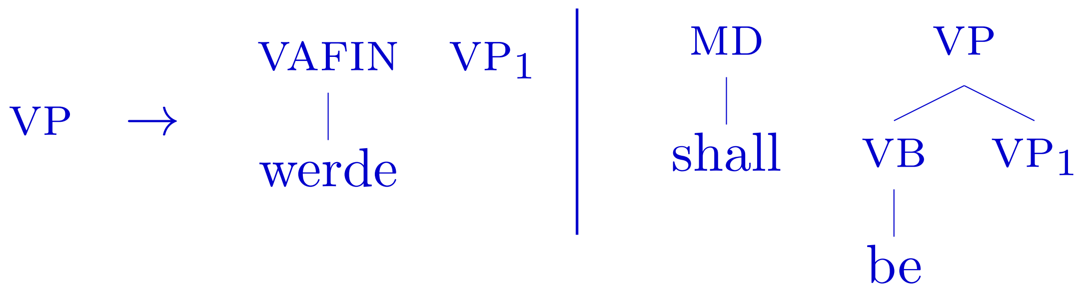
Internal Structure

- Stripping out internal structure

$$\text{VP} \rightarrow \text{werde VP}_1 \mid \text{shall be VP}_1$$

$\Rightarrow$ synchronous context free grammar

- Maintaining internal structure



$\Rightarrow$ synchronous tree substitution grammar

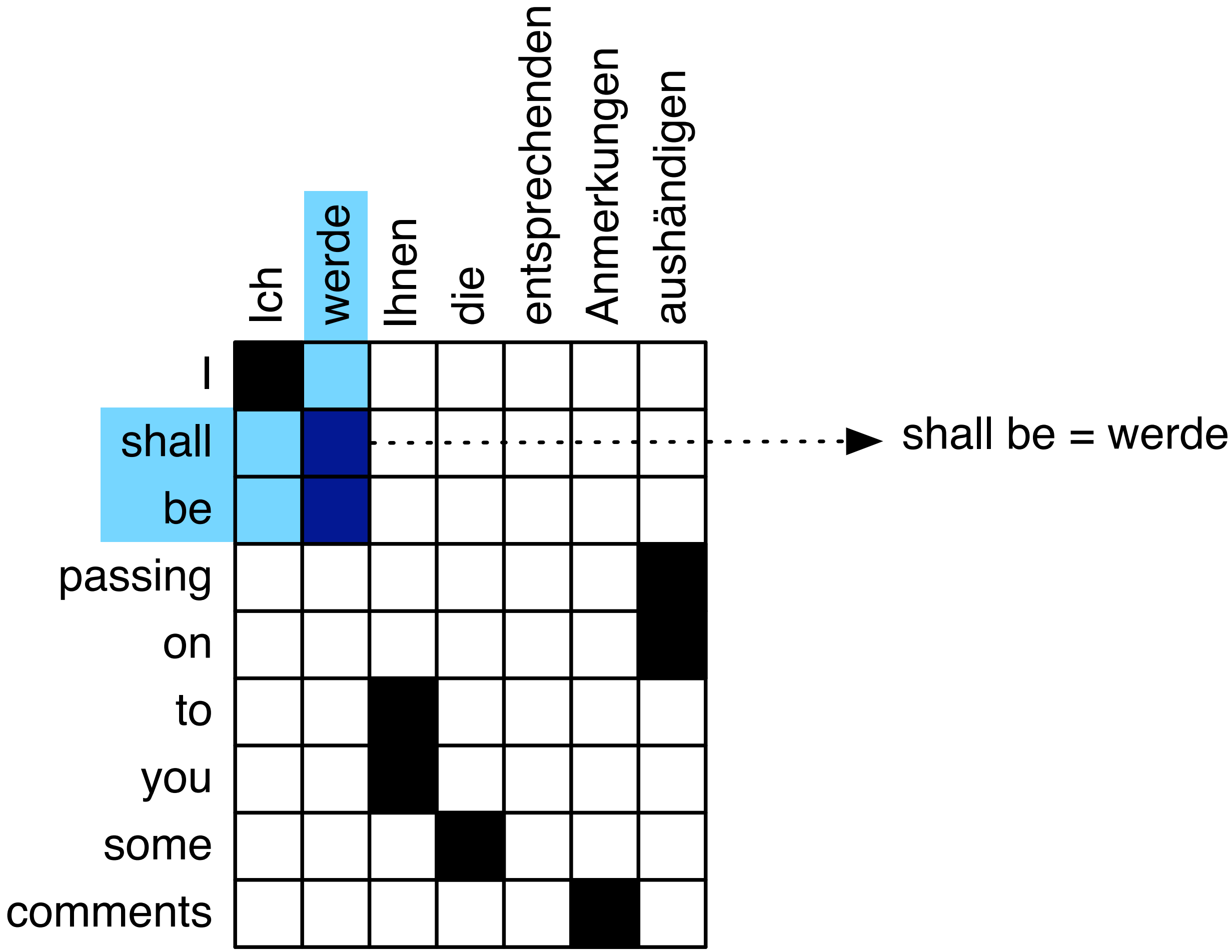
Learning Synchronous Grammars

- Extracting rules from a word-aligned parallel corpus

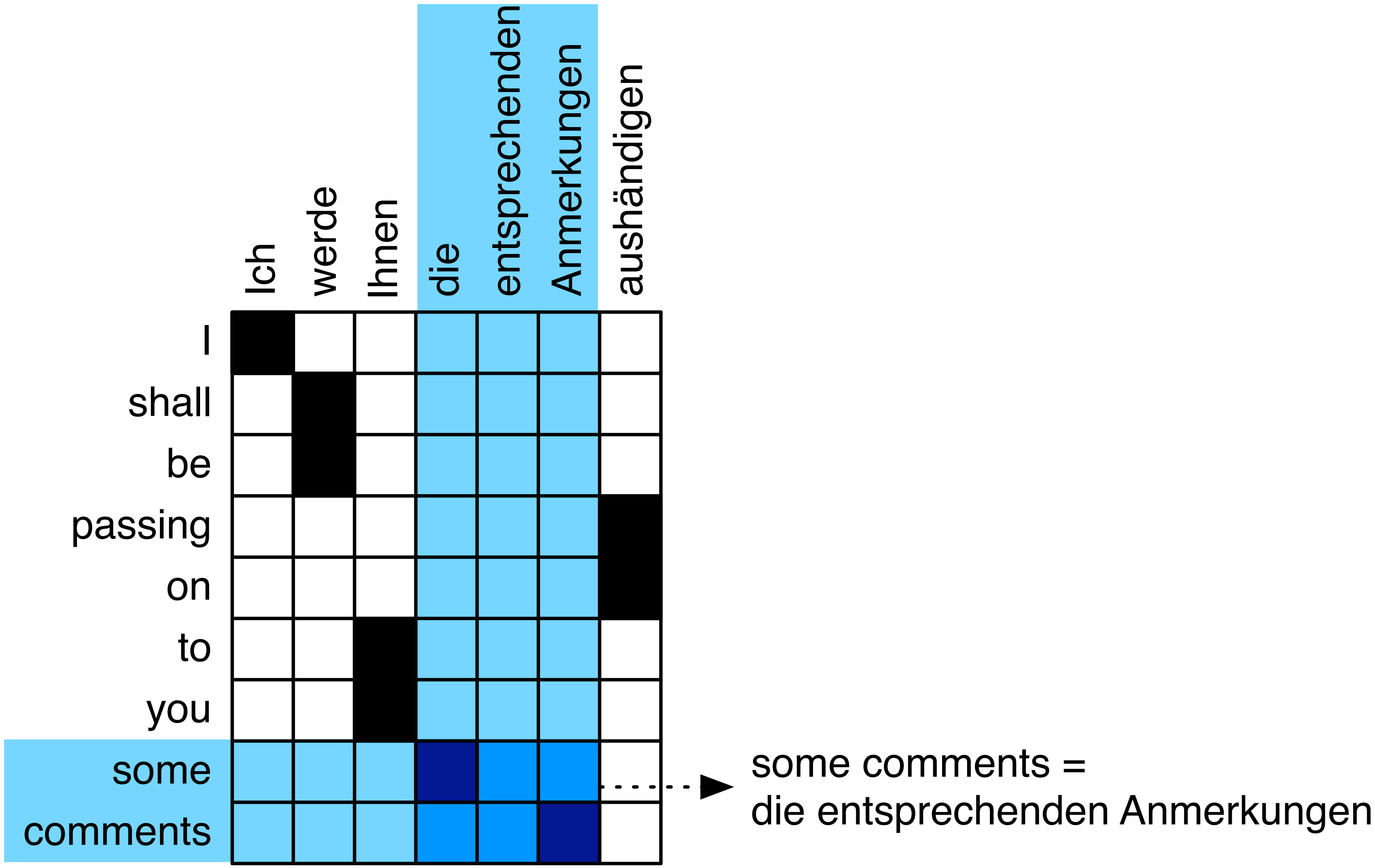
- First: Hierarchical phrase-based model
  - only one non-terminal symbol X
  - no linguistic syntax, just a formally syntactic model

- Then: Synchronous phrase structure model
  - non-terminals for words and phrases: NP, VP, PP, ADJ, ...
  - corpus must also be parsed with syntactic parser

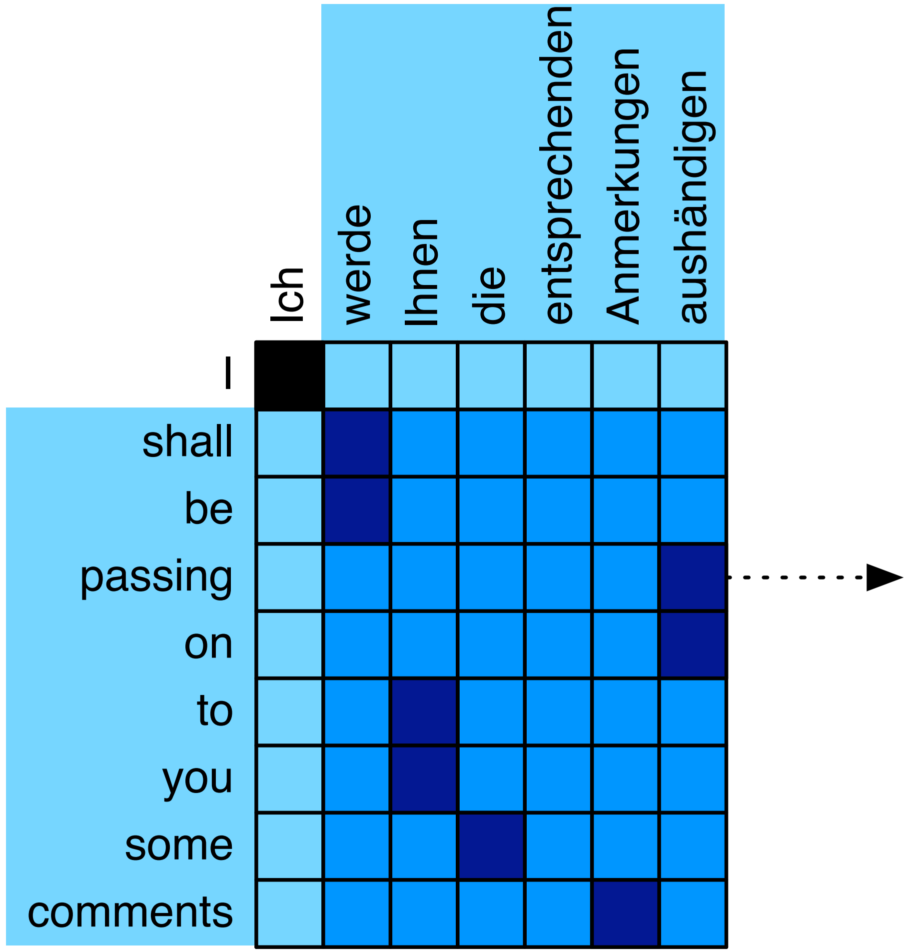
Extracting Phrase Translation Rules



Extracting Phrase Translation Rules

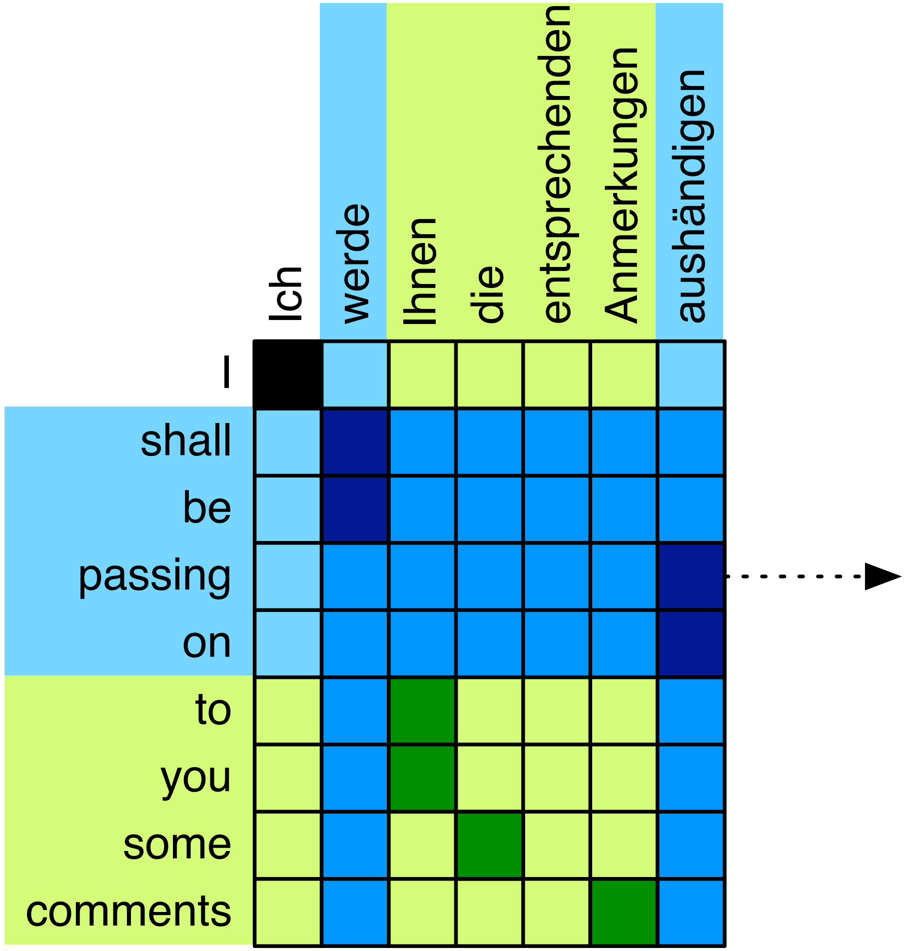


Extracting Phrase Translation Rules



werde Ihnen die entsprechenden Anmerkungen aushändigen
= shall be passing on to you some comments

Extracting Hierarchical Phrase Translation Rules



subtracting subphrase

werde X aushändigen
= shall be passing on X

Formal Definition

- Recall: consistent phrase pairs

$$(\bar{e}, \bar{f}) \text{ consistent with } A \Leftrightarrow$$
$$\forall e_i \in \bar{e} : (e_i, f_j) \in A \rightarrow f_j \in \bar{f}$$
$$\text{AND } \forall f_j \in \bar{f} : (e_i, f_j) \in A \rightarrow e_i \in \bar{e}$$
$$\text{AND } \exists e_i \in \bar{e}, f_j \in \bar{f} : (e_i, f_j) \in A$$

- Let P be the set of all extracted phrase pairs $(\bar{e}, \bar{f})$

Formal Definition

- Extend recursively:

$$\text{if } (\bar{e}, \bar{f}) \in P \text{ AND } (\bar{e}_{\text{SUB}}, \bar{f}_{\text{SUB}}) \in P$$

$$\text{AND } \bar{e} = \bar{e}_{\text{PRE}} + \bar{e}_{\text{SUB}} + \bar{e}_{\text{POST}}$$

$$\text{AND } \bar{f} = \bar{f}_{\text{PRE}} + \bar{f}_{\text{SUB}} + \bar{f}_{\text{POST}}$$

$$\text{AND } \bar{e} \neq \bar{e}_{\text{SUB}} \text{ AND } \bar{f} \neq \bar{f}_{\text{SUB}}$$

$$\text{add } (e_{\text{PRE}} + \text{X} + e_{\text{POST}}, f_{\text{PRE}} + \text{X} + f_{\text{POST}}) \text{ to } P$$

(note: any of e_{PRE}, e_{POST}, f_{PRE}, or f_{POST} may be empty)

- Set of hierarchical phrase pairs is the closure under this extension mechanism

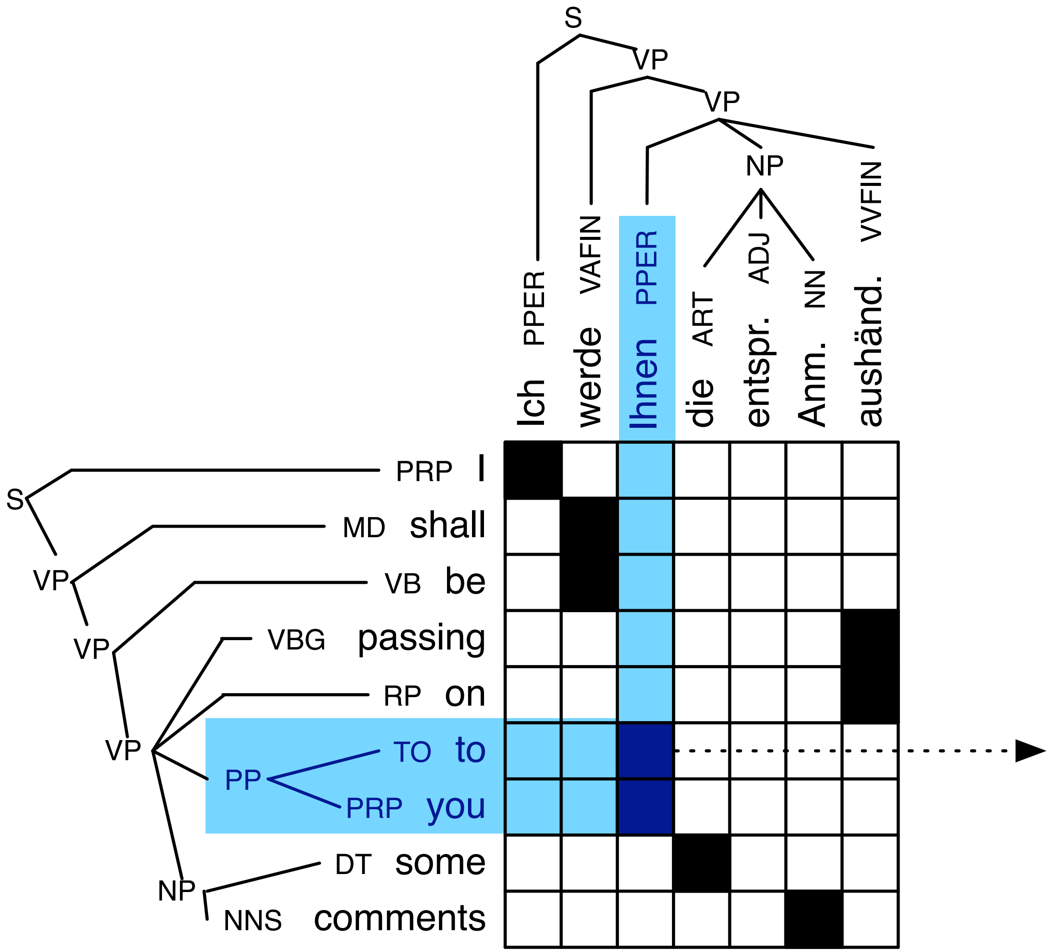
Comments

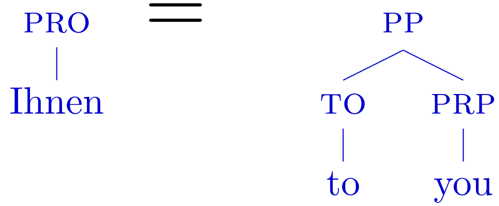
- Removal of multiple sub-phrases leads to rules with multiple non-terminals, such as:

$$\text{Y} \rightarrow \text{X}_1 \ \text{X}_2 \ \mid \ \text{X}_2 \ \textit{of} \ \text{X}_1$$

- Typical restrictions to limit complexity [Chiang, 2005]
  - at most 2 nonterminal symbols
  - at least 1 but at most 5 words per language
  - span at most 15 words (counting gaps)

Learning Syntactic Translation Rules

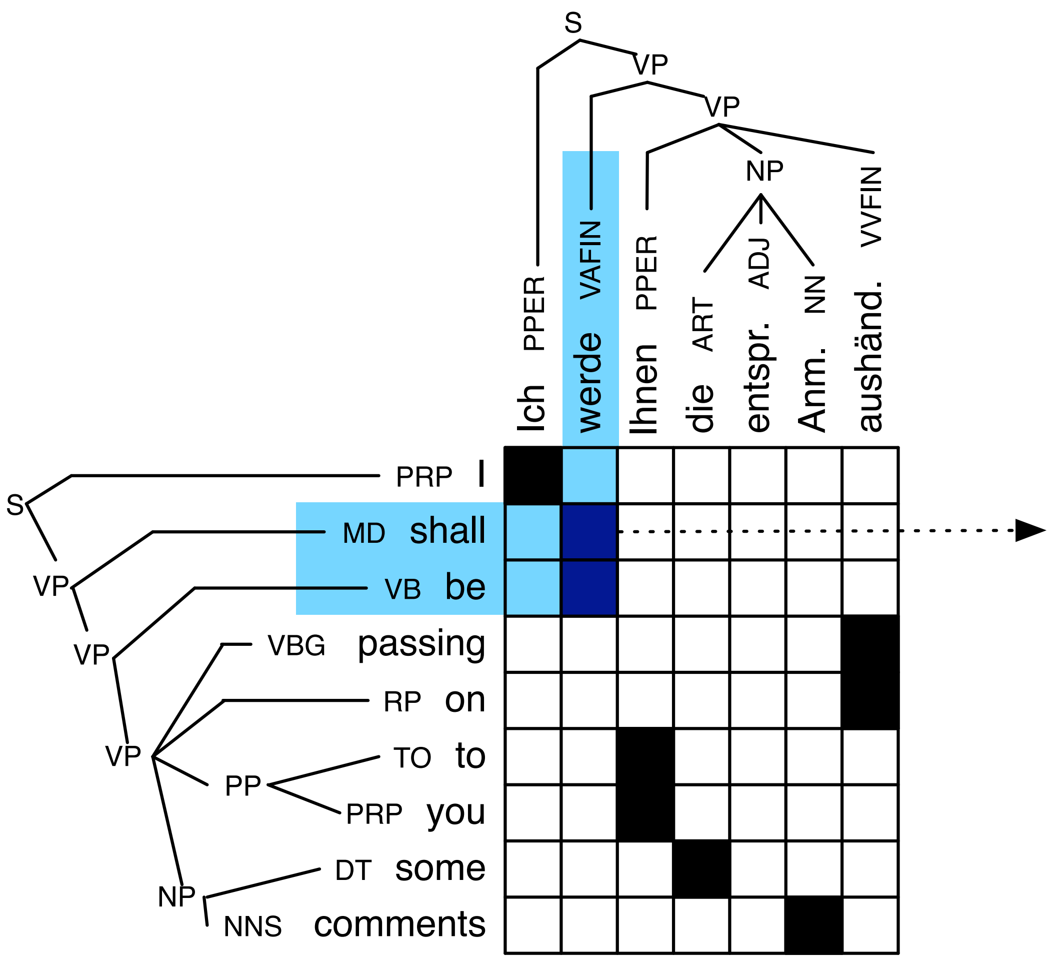




Constraints on Syntactic Rules

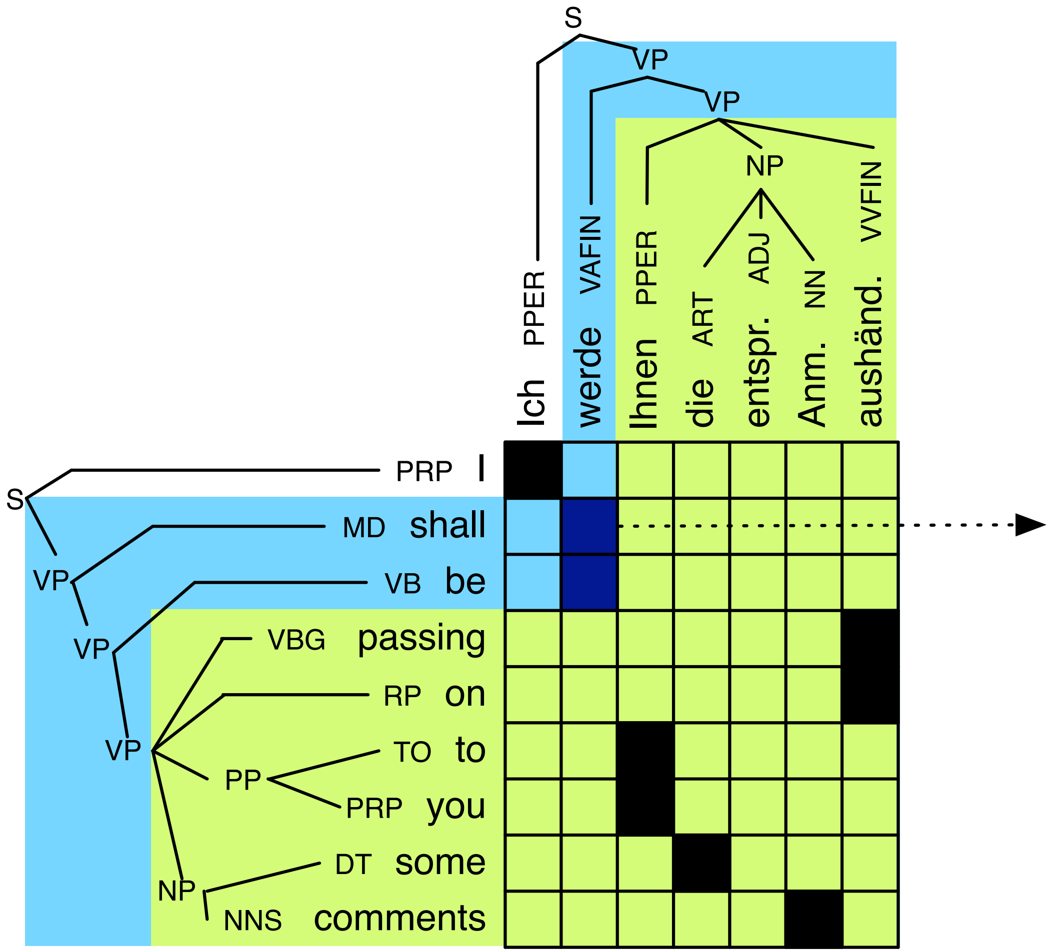
- Same word alignment constraints as hierarchical models
- Hierarchical: rule can cover any span
  $\Leftrightarrow$ syntactic rules must cover constituents in the tree
- Hierarchical: gaps may cover any span
  $\Leftrightarrow$ gaps must cover constituents in the tree
- Many less rules are extracted (all things being equal)

Impossible Rules

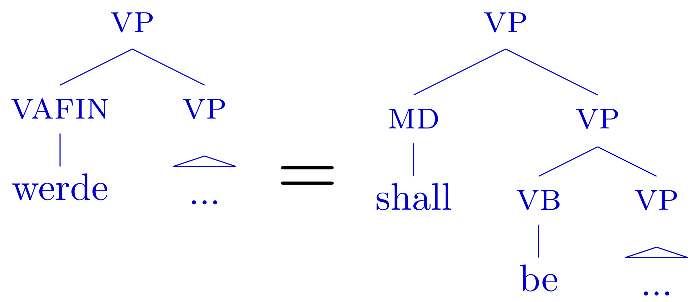


English span not a constituent
no rule extracted

Rules with Context



Rule with this phrase pair requires syntactic context



Too Many Rules Extractable

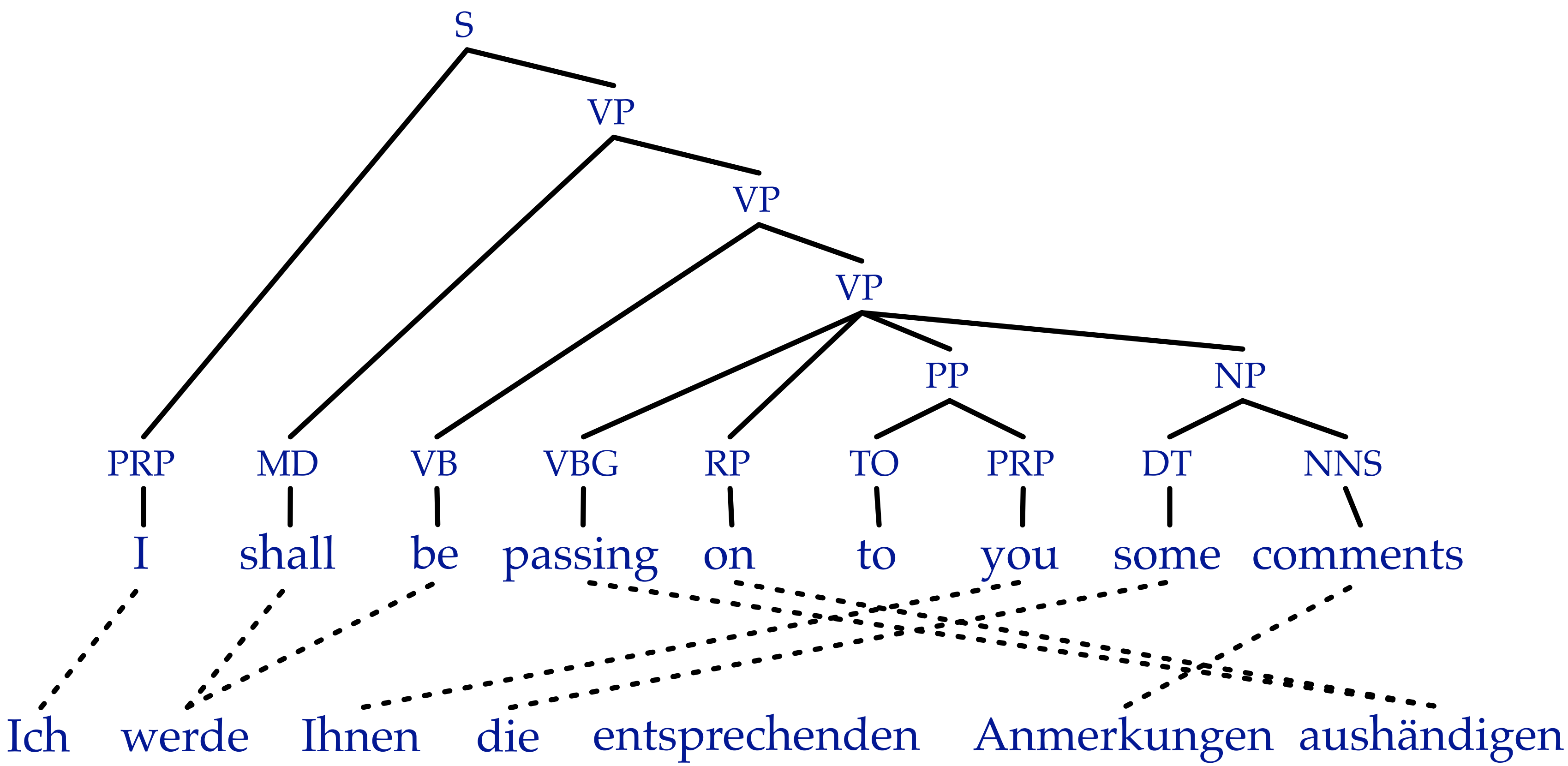
- Huge number of rules can be extracted
  (every alignable node may or may not be part of a rule $\rightarrow$ exponential number of rules)

- Need to limit which rules to extract

- Option 1: similar restriction as for hierarchical model
  (maximum span size, maximum number of terminals and non-terminals, etc.)

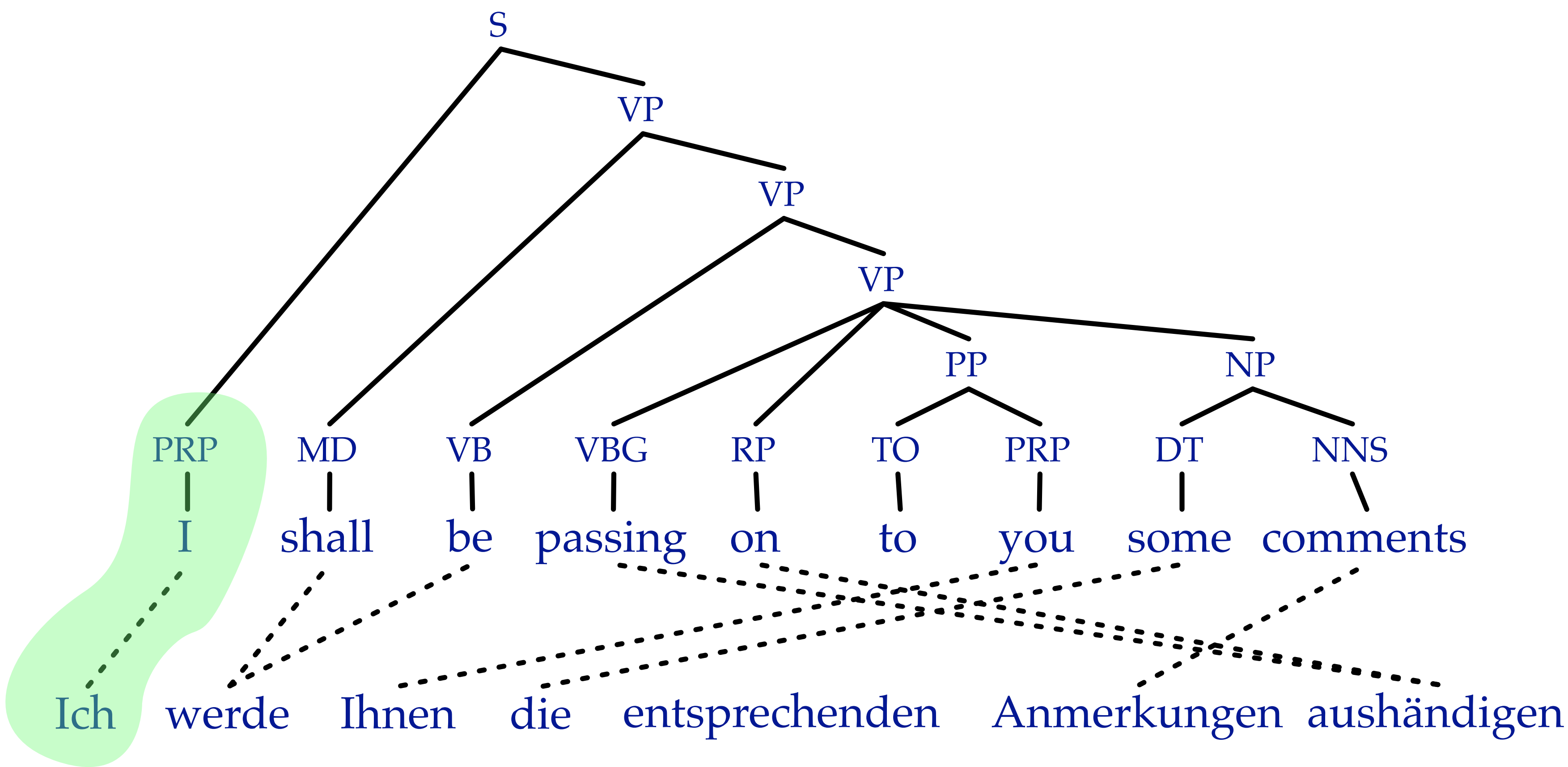
- Option 2: only extract minimal rules ("GHKM" rules)

Minimal Rules



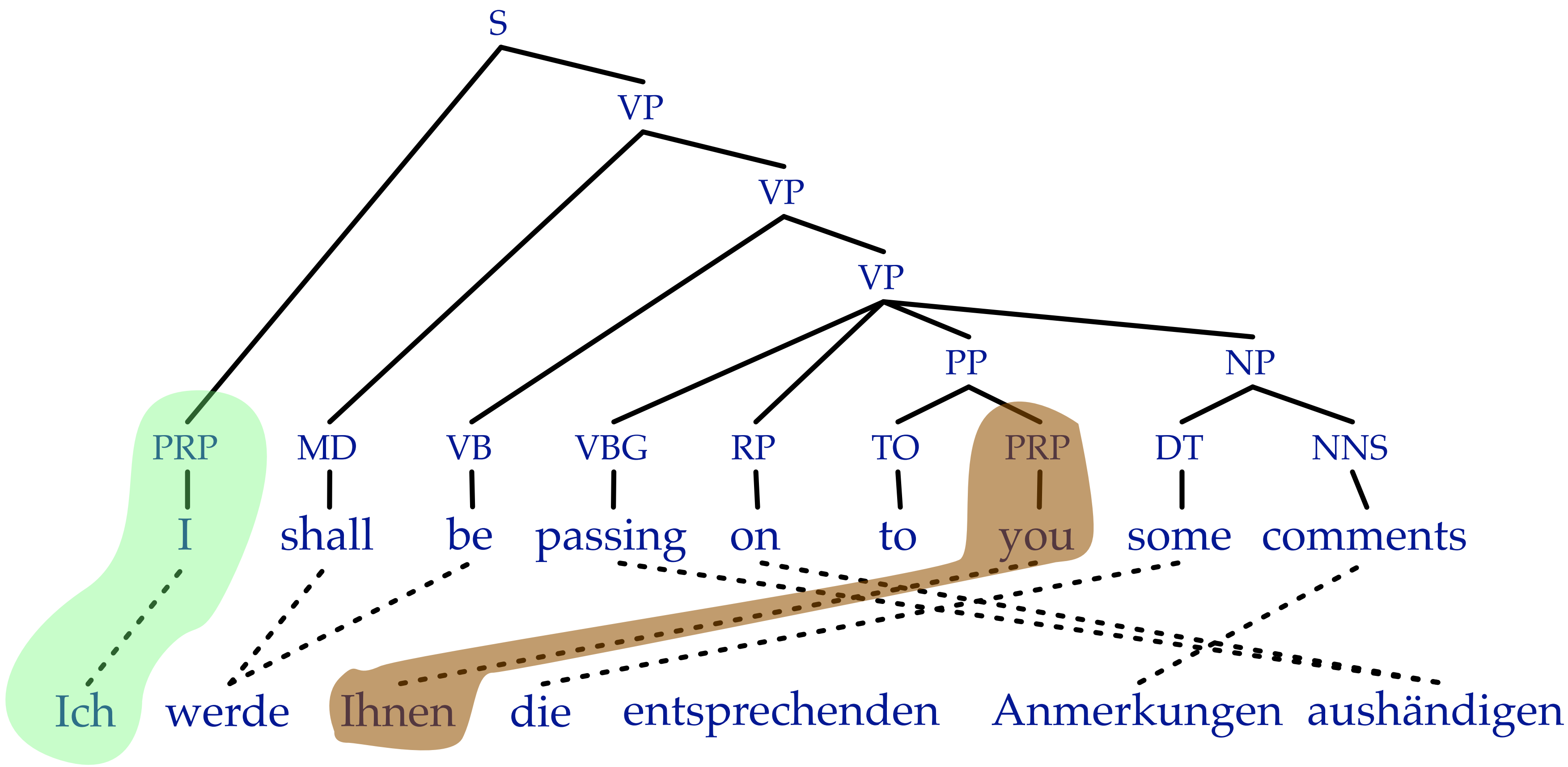
Extract: set of smallest rules required to explain the sentence pair

Lexical Rule



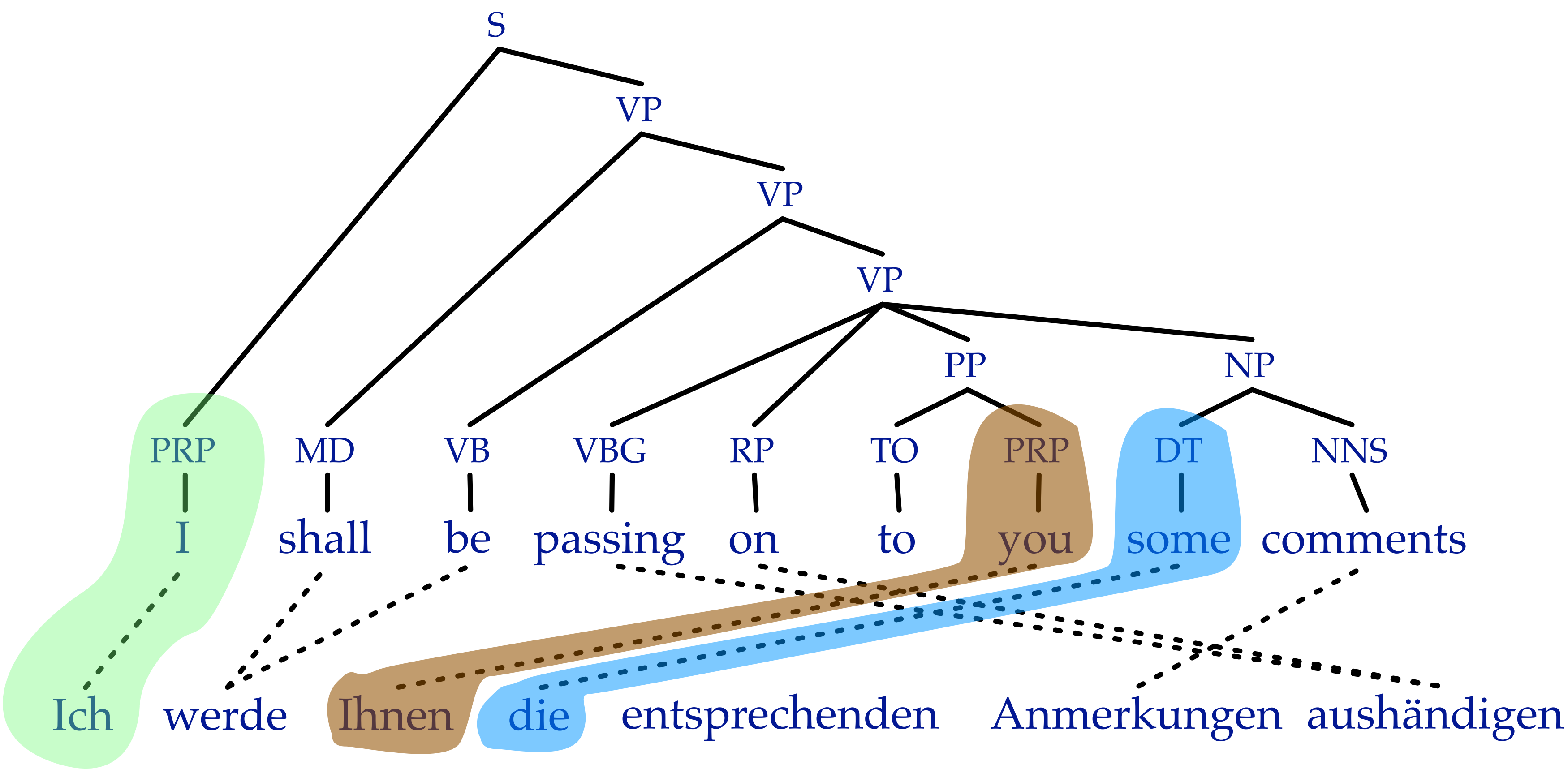
Extracted rule: PRP → Ich | I

Lexical Rule



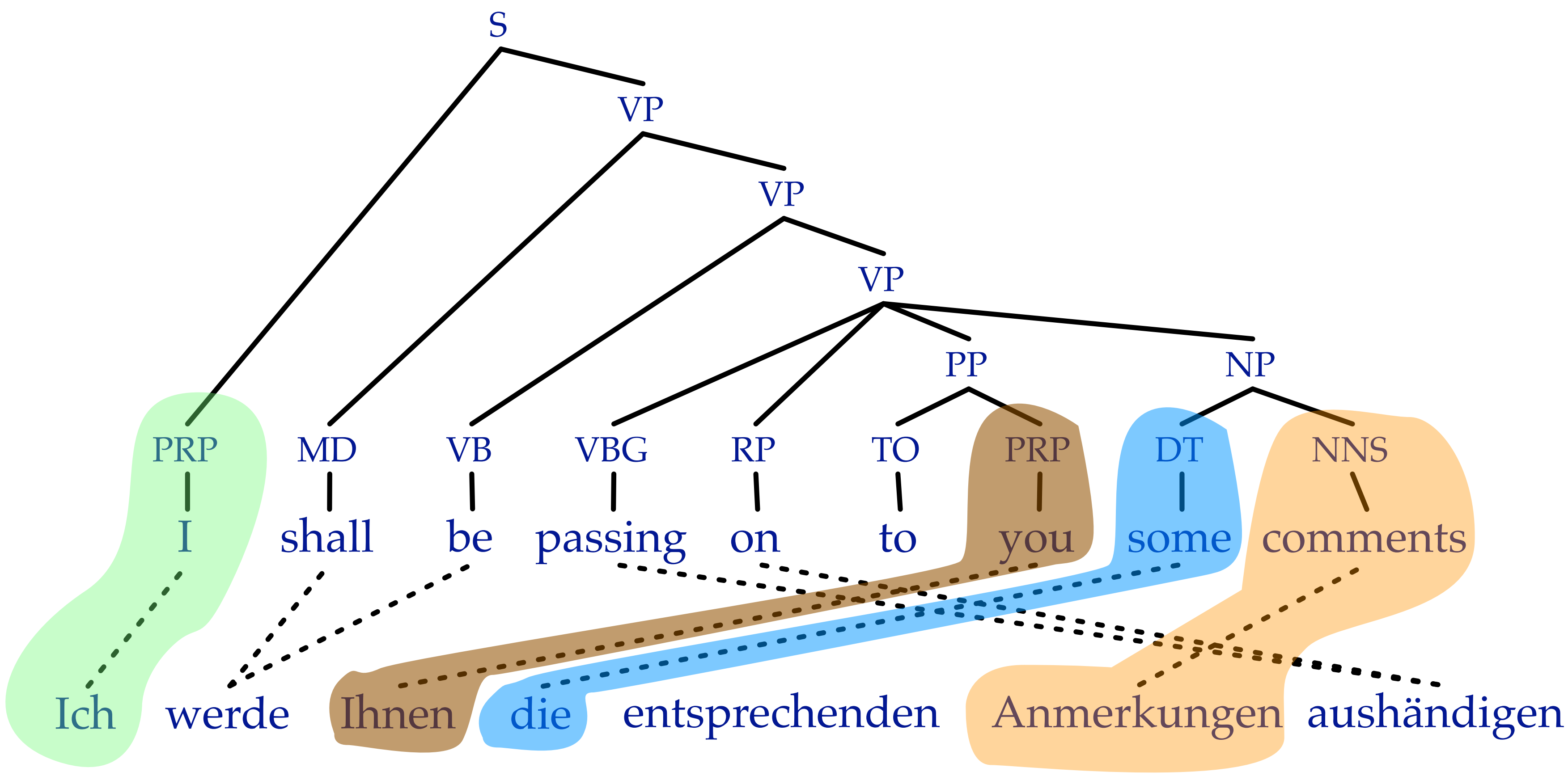
Extracted rule: PRP $\rightarrow$ Ihnen | you

Lexical Rule



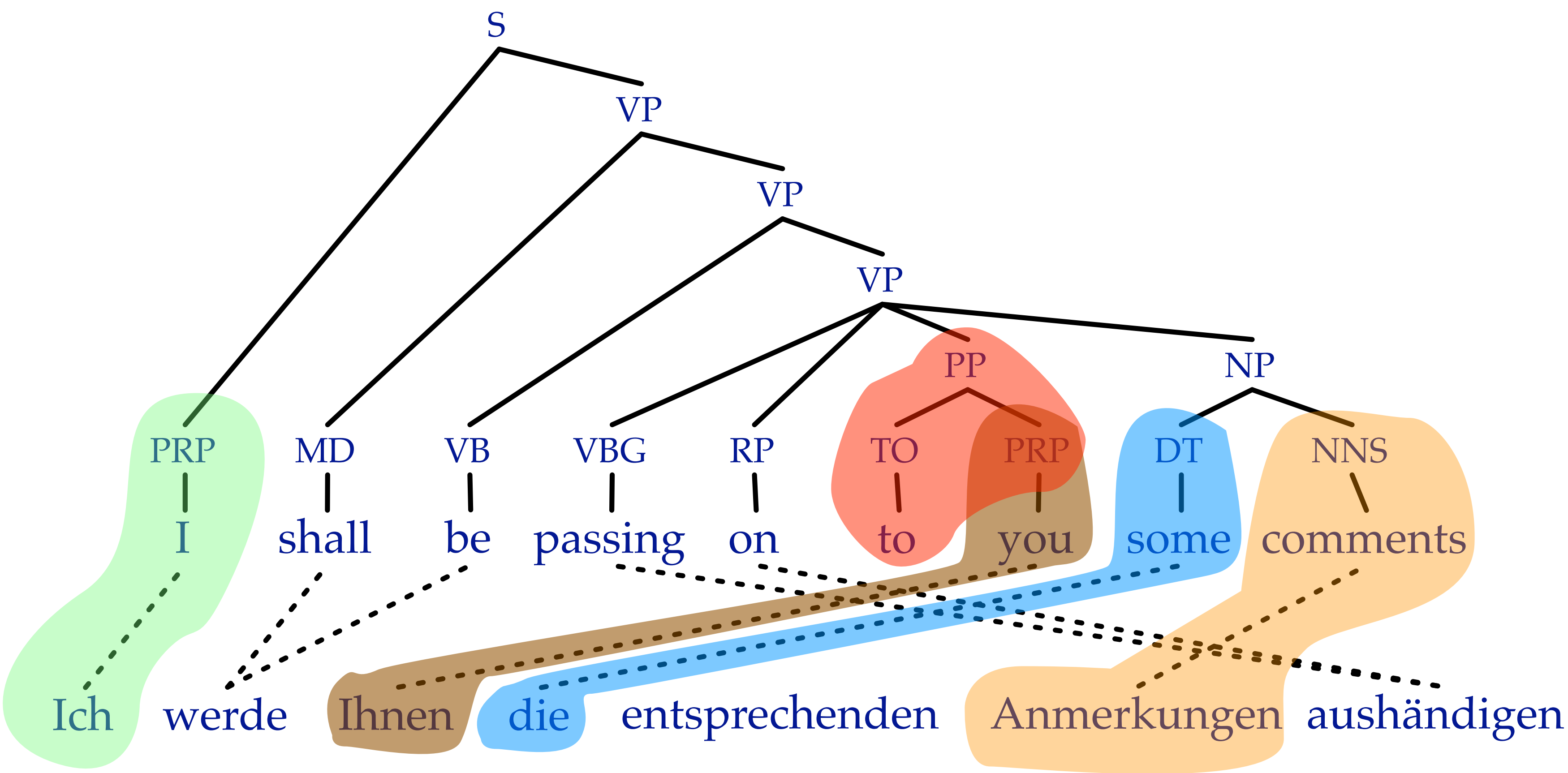
Extracted rule: DT $\rightarrow$ die | some

Lexical Rule



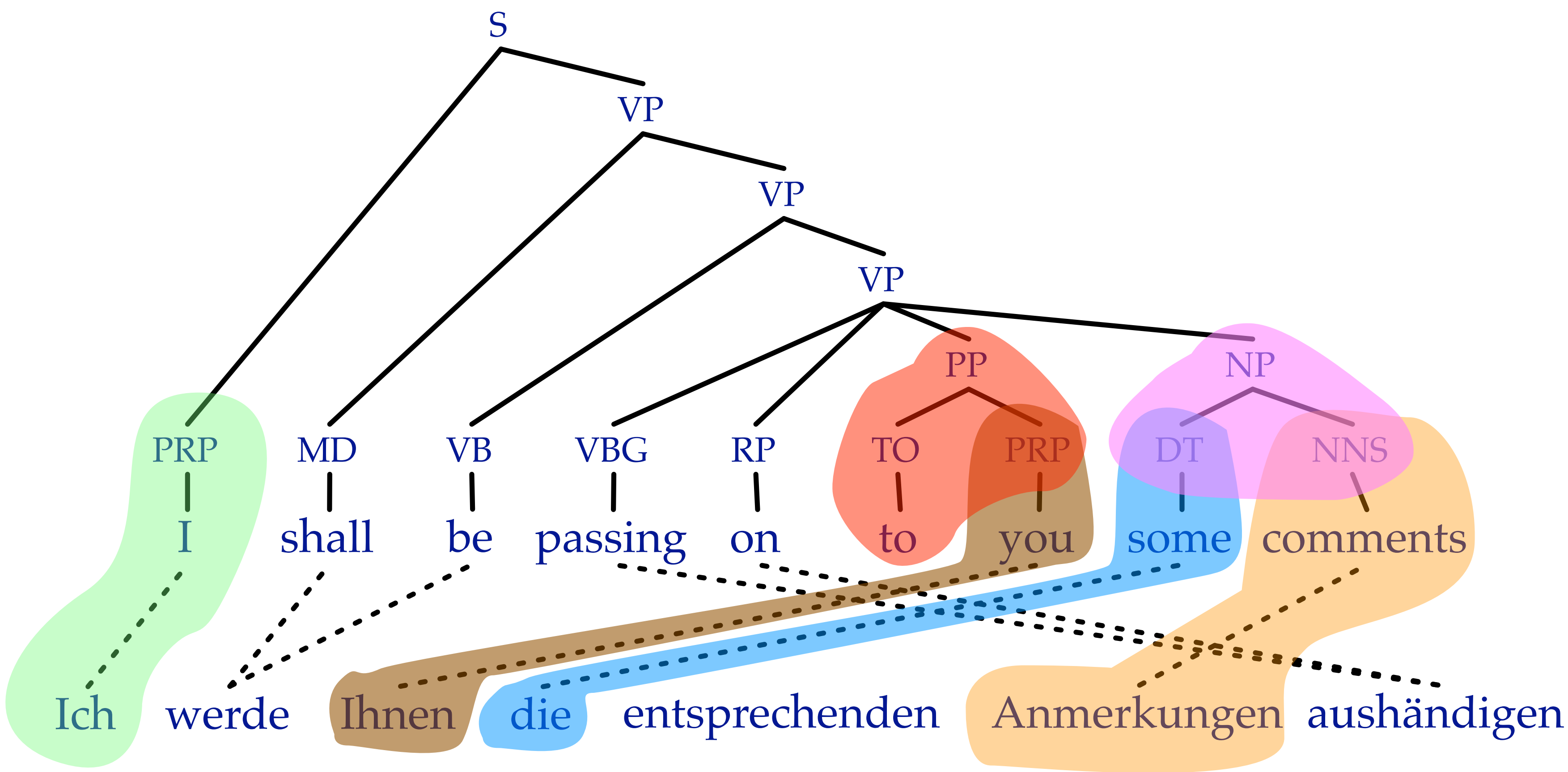
Extracted rule: NNS → Anmerkungen | comments

Insertion Rule



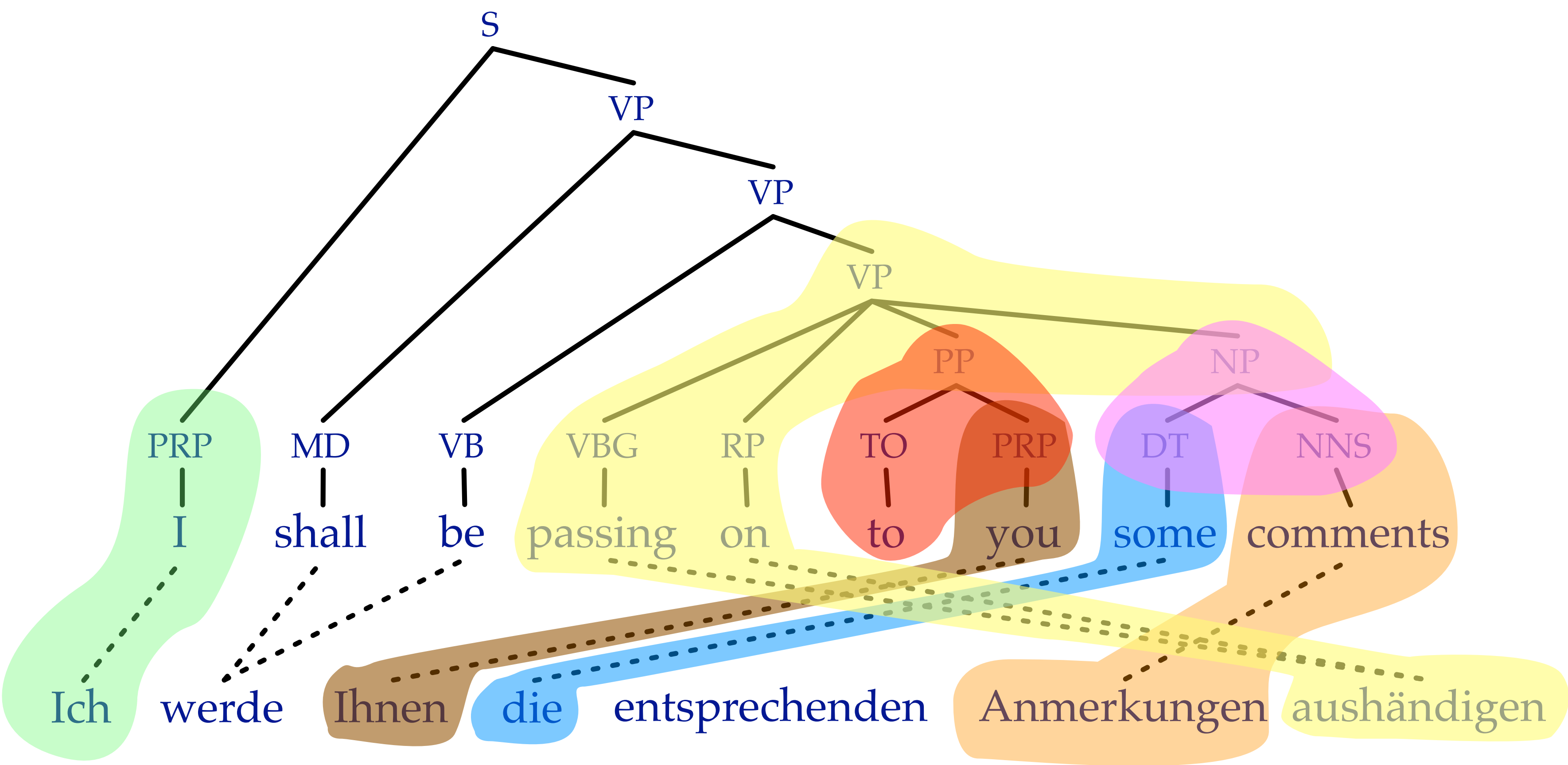
Extracted rule: PP → X | to PRP

Non-Lexical Rule



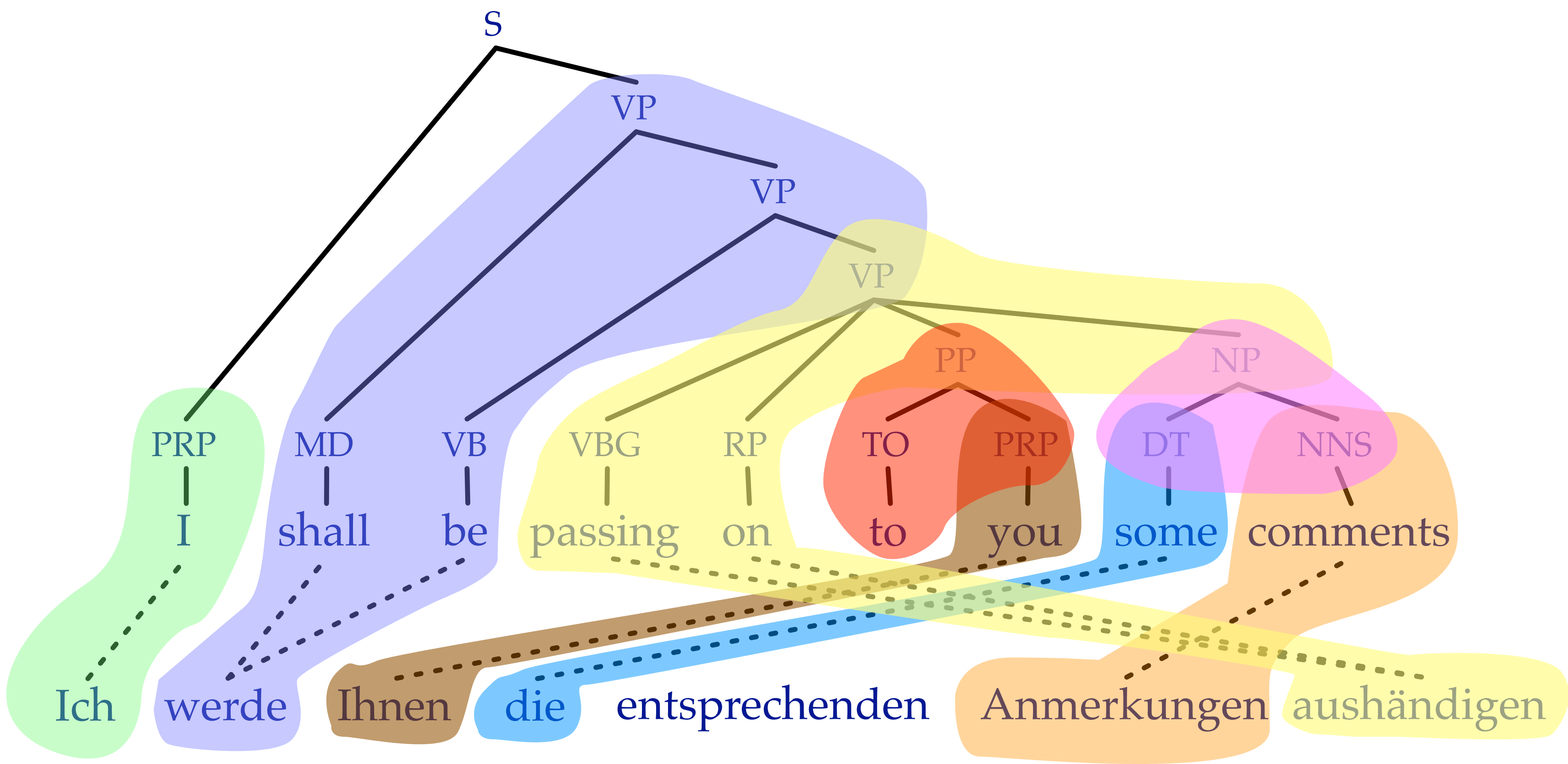
Extracted rule: $\mathrm{NP} \rightarrow \mathrm{X}_1\ \mathrm{X}_2 \mid \mathrm{DT}_1\ \mathrm{NNS}_2$

Lexical Rule with Syntactic Context



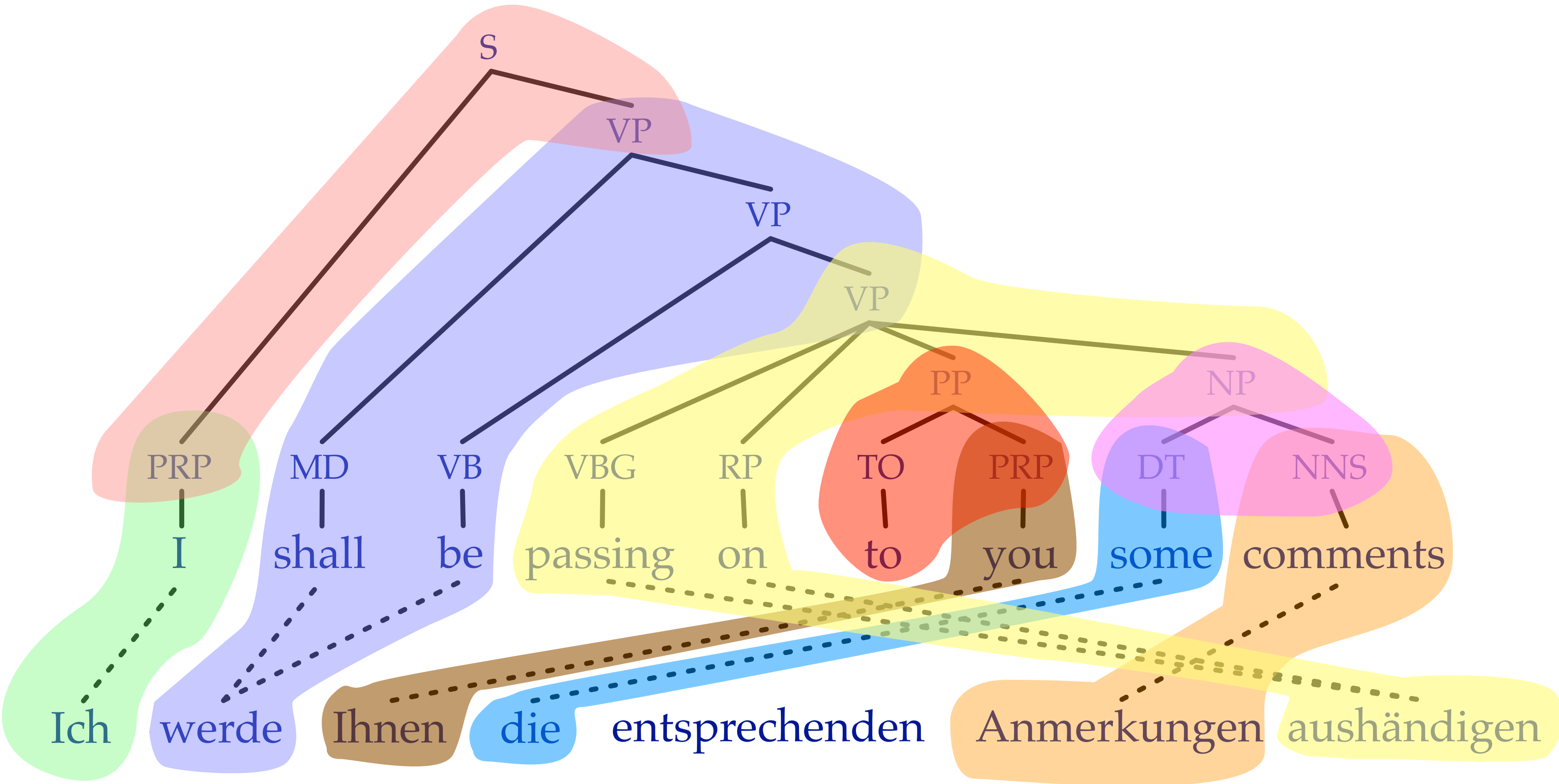
Extracted rule: VP → X_1 X_2 aushändigen | passing on PP_1 NP_2

Lexical Rule with Syntactic Context



Extracted rule: VP → werde X | shall be VP (ignoring internal structure)

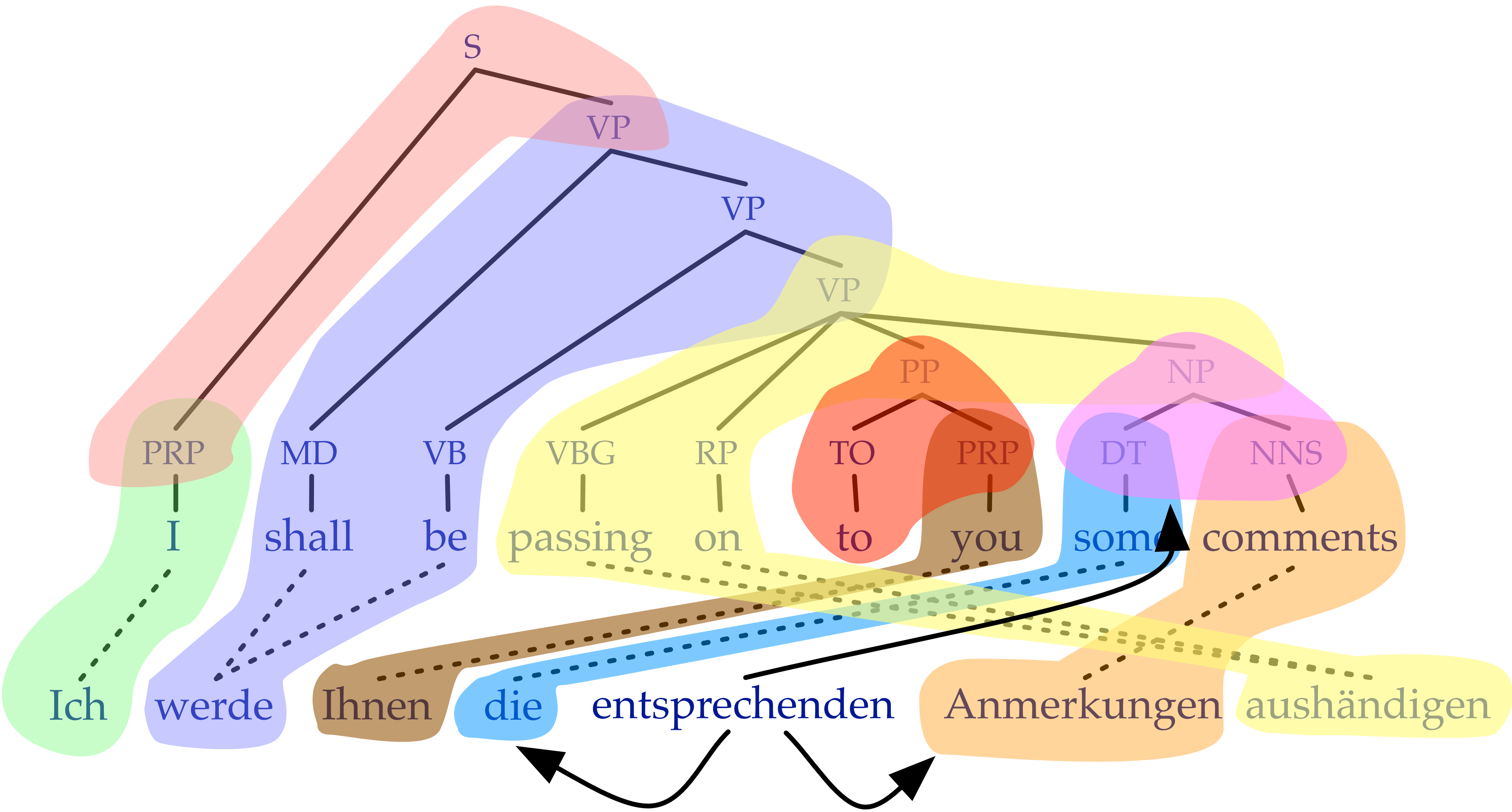
Non-Lexical Rule



Extracted rule: $\text{S} \rightarrow \text{X}_1\ \text{X}_2 \mid \text{PRP}_1\ \text{VP}_2$

DONE — note: one rule per alignable constituent

Unaligned Source Words



Attach to neighboring words or higher nodes → additional rules

Too Few Phrasal Rules?

- Lexical rules will be 1-to-1 mappings (unless word alignment requires otherwise)
- But: phrasal rules very beneficial in phrase-based models
- Solutions
  - combine rules that contain a maximum number of symbols
    (as in hierarchical models, recall: "Option 1")
  - compose minimal rules to cover a maximum number of non-leaf nodes

Composed Rules

- Current rules

$X_1\ X_2$ = NP → (DT_1 NNS_1)

die = DT → (some)

entsprechenden Anmerkungen = NNS → (comments)

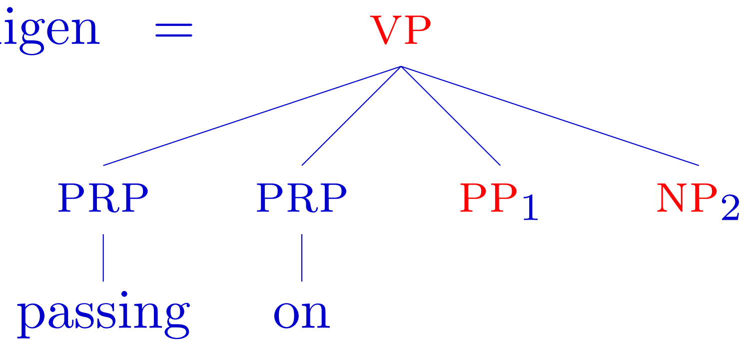
- Composed rule

die entsprechenden Anmerkungen = NP → (DT → (some) NNS → (comments))

(1 non-leaf node: NP)

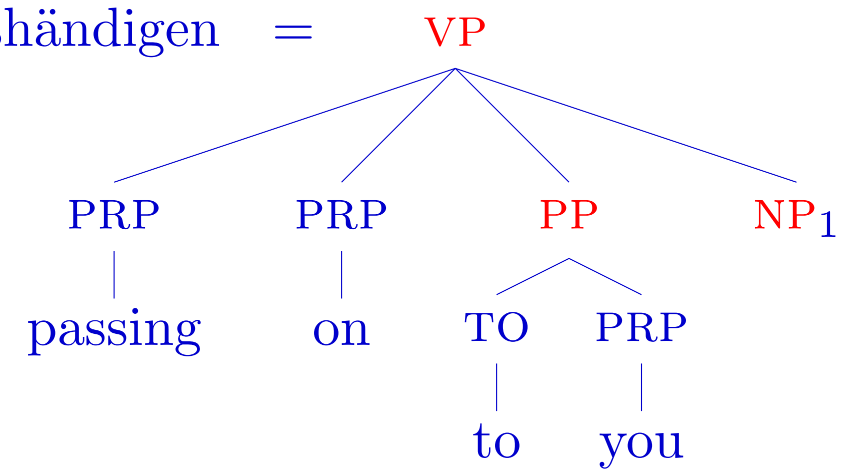
Composed Rules

- Minimal rule: x_1 x_2 aushändigen =



3 non-leaf nodes:
VP, PP, NP

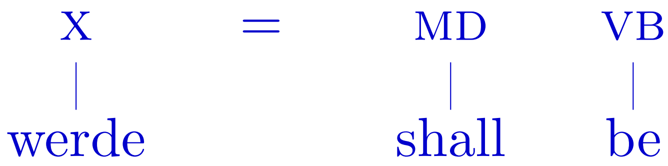
- Composed rule: Ihnen x_1 aushändigen =



3 non-leaf nodes:
VP, PP and NP

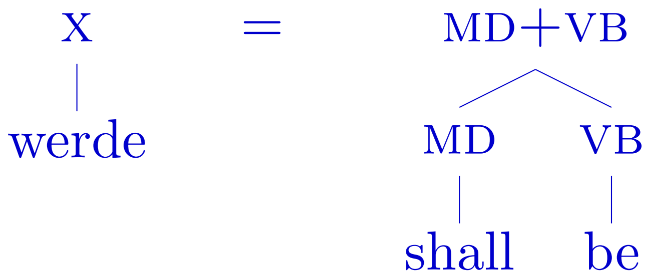
Relaxing Tree Constraints

- Impossible rule



- Create new non-terminal label: MD+VB

⇒ New rule



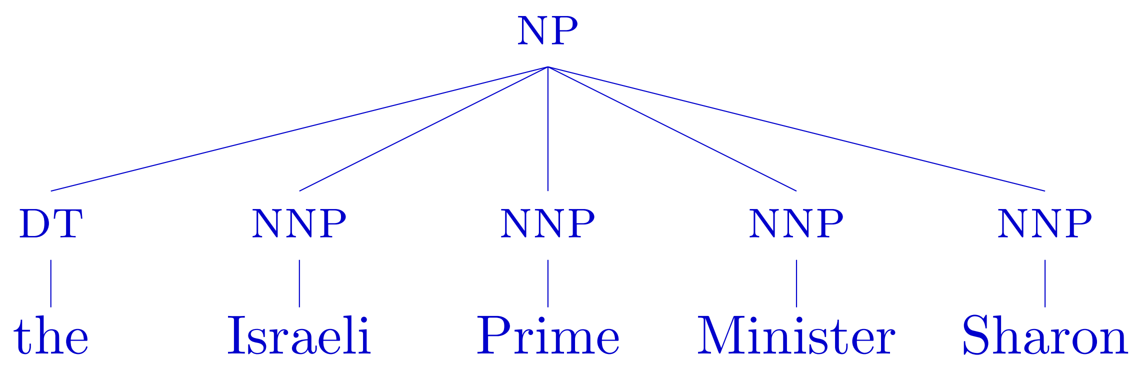
Zollmann–Venugopal Relaxation

- If span consists of two constituents , join them: X+Y
- If span conststs of three constituents, join them: X+Y+Z
- If span covers constituents with the same parent X and include
  - every but the first child Y, label as X\Y
  - every but the last child Y, label as X/Y
- For all other cases, label as FAIL

⇒ More rules can be extracted, but number of non-terminals blows up

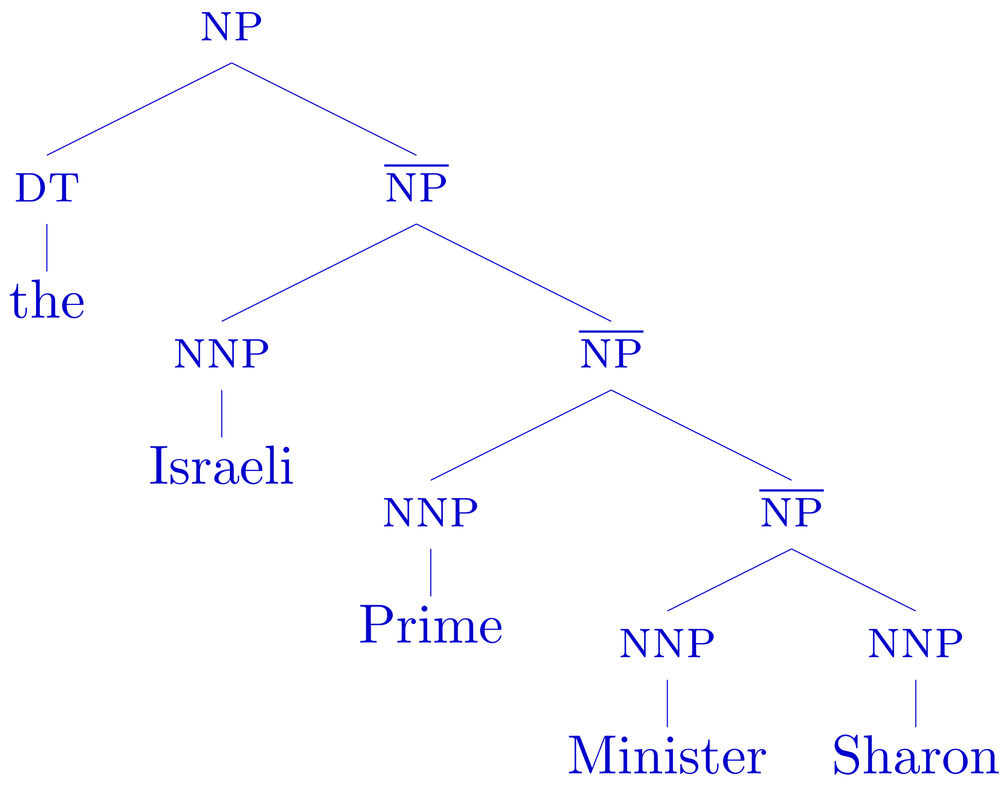
Special Problem: Flat Structures

- Flat structures severely limit rule extraction



- Can only extract rules for individual words or entire phrase

Relaxation by Tree Binarization



More rules can be extracted

Left-binarization or right-binarization?

Scoring Translation Rules

- Extract all rules from corpus
- Score based on counts
  - joint rule probability: $p(\text{LHS}, \text{RHS}_f, \text{RHS}_e)$
  - conditional rule probability: $p(\text{RHS}_f, \text{RHS}_e | \text{LHS})$
  - direct translation probability: $p(\text{RHS}_e | \text{RHS}_f, \text{LHS})$
  - noisy channel translation probability: $p(\text{RHS}_f | \text{RHS}_e, \text{LHS})$
  - lexical translation probability: $\prod_{e_i \in \text{RHS}_e} p(e_i | \text{RHS}_f, a)$

Summary

- Synchronous Grammars provide a natural analysis for many translation phenomena, but come at the cost of added complexity and restrictions.

- Syntactic information can be used to improve translation, but noisy parse trees and alignments can hurt translation performance.