

61A Lecture 37

Friday, December 2

What is Computer Science?

What is Computer Science?

Systems

What is Computer Science?

Systems

Artificial Intelligence

What is Computer Science?

Systems

Artificial Intelligence

Graphics

What is Computer Science?

Systems

Artificial Intelligence

Graphics

Security

What is Computer Science?

Systems

Artificial Intelligence

Graphics

Security

Networking

What is Computer Science?

Systems

Artificial Intelligence

Graphics

Security

Networking

Programming Languages

What is Computer Science?

Systems

Artificial Intelligence

Graphics

Security

Networking

Programming Languages

...

What is Computer Science?

Systems

Artificial Intelligence

Graphics

Security

Networking

Programming Languages

...



What is Computer Science?

Systems

Artificial Intelligence

Graphics

Security

Networking

Programming Languages

...



Computer Vision

What is Computer Science?

Systems

Artificial Intelligence

Graphics

Security

Networking

Programming Languages

...

Computer Vision

Planning

What is Computer Science?

Systems

Artificial Intelligence

Graphics

Security

Networking

Programming Languages

...

Computer Vision

Planning

Robotics

What is Computer Science?

Systems

Artificial Intelligence

Graphics

Security

Networking

Programming Languages

...

Computer Vision

Planning

Robotics

Natural Language Processing

What is Computer Science?

Systems

Artificial Intelligence

Graphics

Security

Networking

Programming Languages

...

Computer Vision

Planning

Robotics

Natural Language Processing

...

What is Computer Science?

Systems

Artificial Intelligence

Graphics

Security

Networking

Programming Languages

...

Computer Vision

Planning

Robotics

Natural Language Processing

...



Machine Translation

Machine Translation

Target language corpus gives examples of well-formed sentences

I will get to it later

See you later

He will do it

Machine Translation

Target language corpus gives examples of well-formed sentences

I will get to it later

See you later

He will do it

Parallel corpus gives translation examples

I will do it gladly

Yo lo haré de muy buen grado

You will see later

Después lo veras

Machine Translation

Target language corpus gives examples of well-formed sentences

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Después lo veras

Machine translation system:

Machine Translation

Target language corpus gives examples of well-formed sentences

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Después lo veras

Machine translation system:

Model of
translation

Machine Translation

Target language corpus gives examples of well-formed sentences

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Parallel corpus gives translation examples

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Yo lo haré de muy buen grado

You will see later

Después lo veras

Machine translation system:

Source language

Yo lo haré después

NOVEL SENTENCE

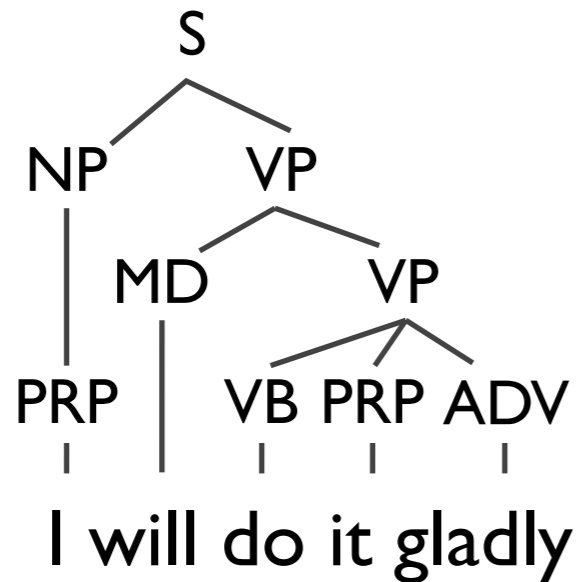
Model of translation

Target language

I will do it later

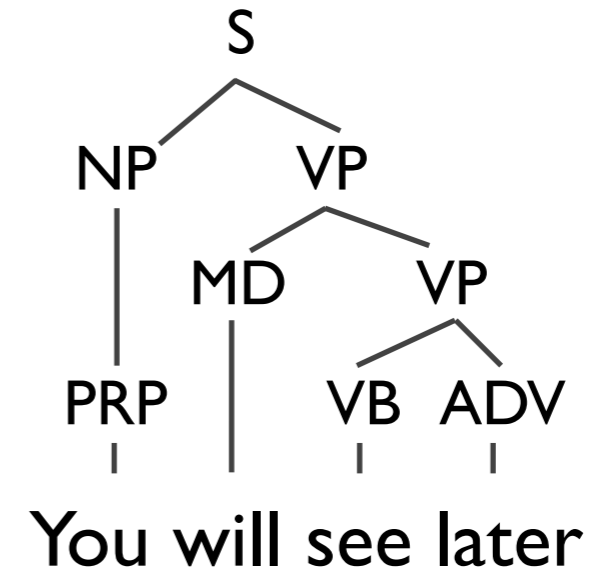
The Syntactic Structure of Natural Language

Parallel corpus gives translation examples



I will do it gladly

Yo lo haré de muy buen grado



You will see later

Después lo veras

Machine translation system:

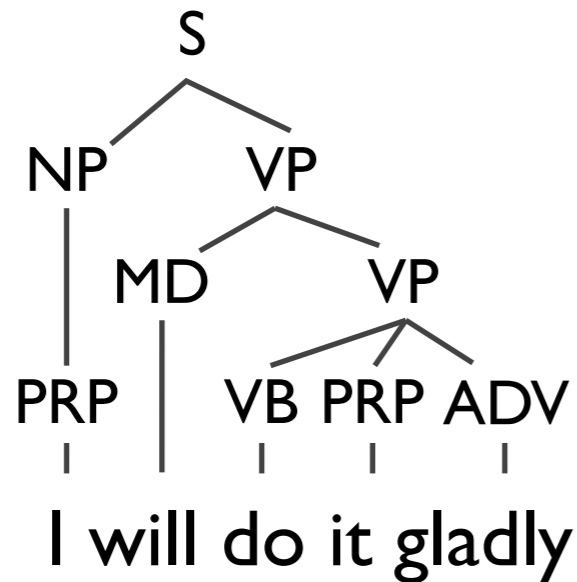
Yo lo haré después

Model of translation

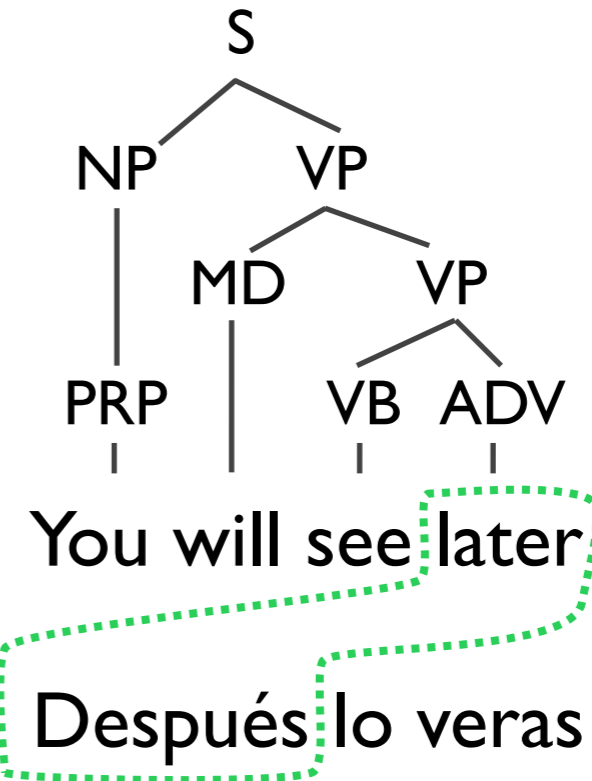
I will do it later

The Syntactic Structure of Natural Language

Parallel corpus gives translation examples



Yo lo haré de muy buen grado

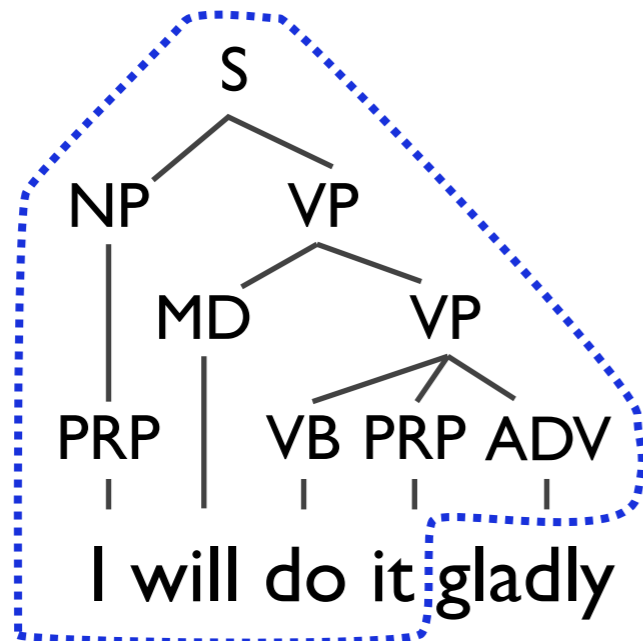


Machine translation system:

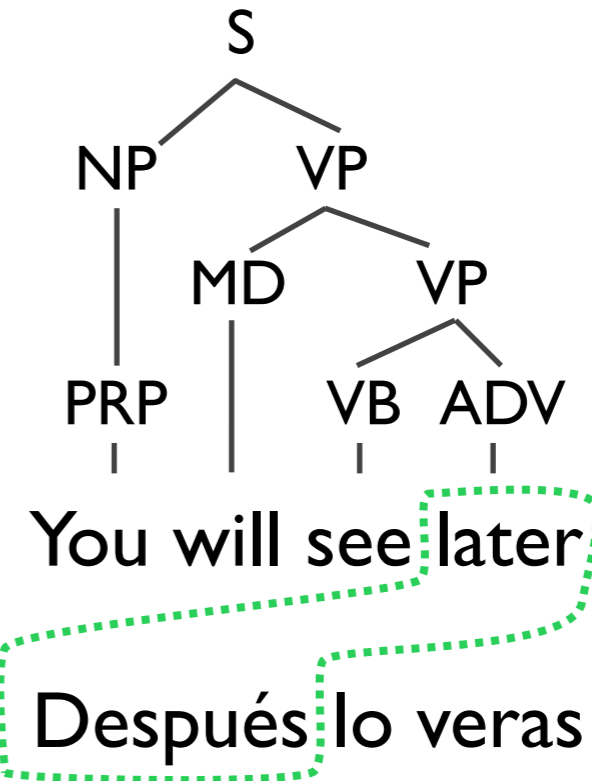


The Syntactic Structure of Natural Language

Parallel corpus gives translation examples

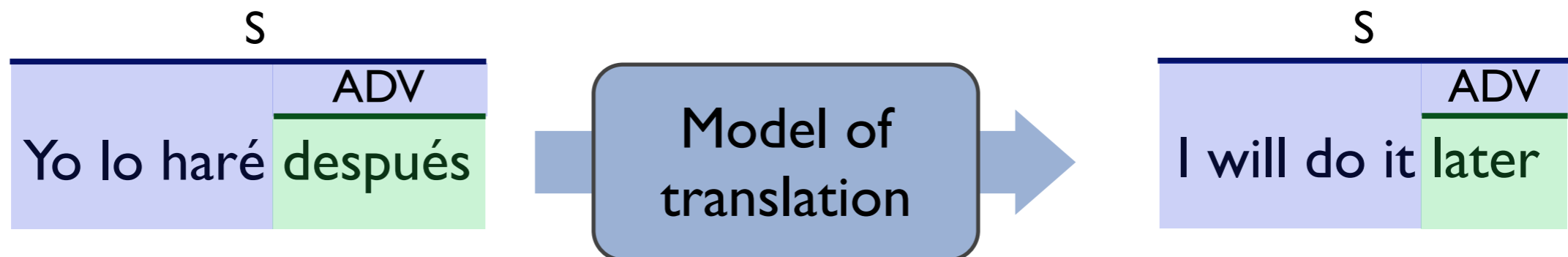


Yo lo haré de muy buen grado



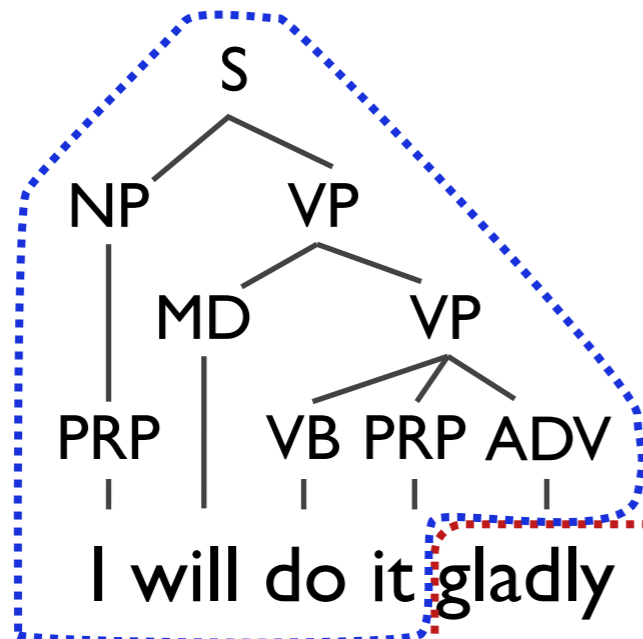
Después lo veras

Machine translation system:



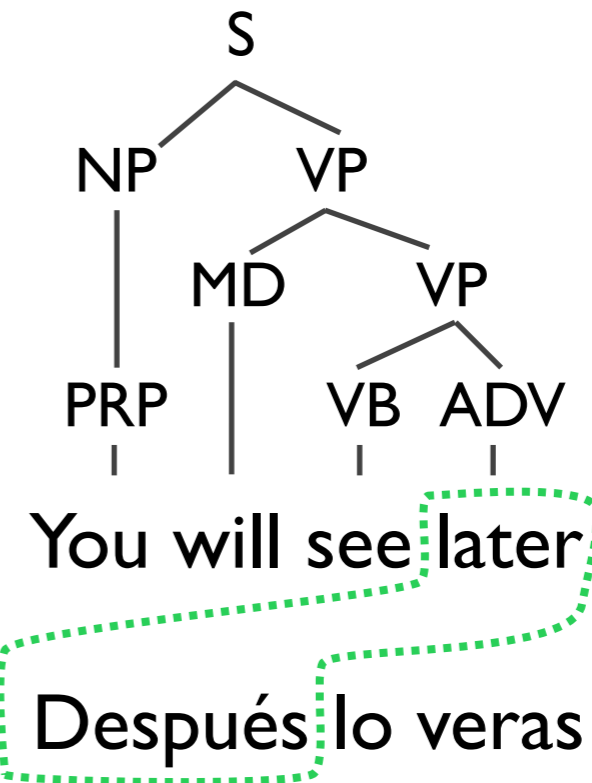
The Syntactic Structure of Natural Language

Parallel corpus gives translation examples



I will do it gladly

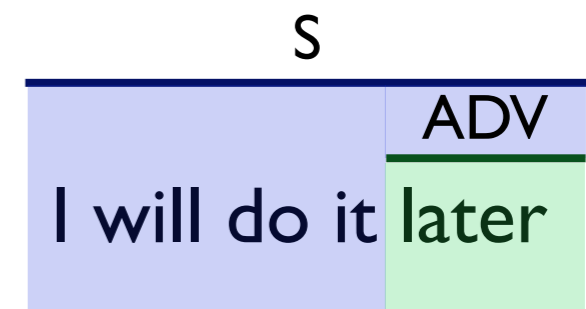
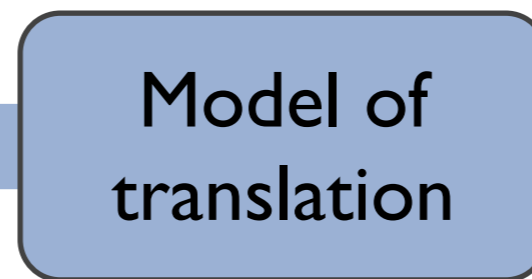
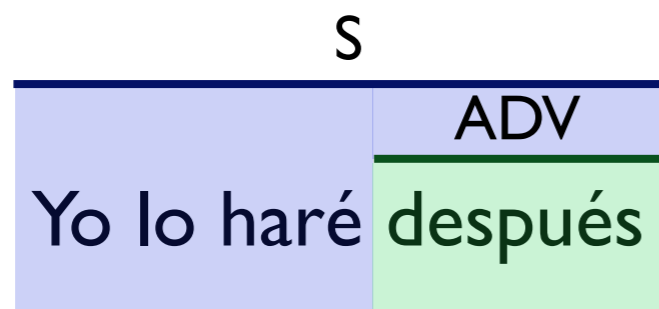
Yo lo haré de muy buen grado



You will see later

Después lo veras

Machine translation system:



A Translation System in 20 Minutes

A Translation System in 20 Minutes

Context-free grammars as a model of language generation

A Translation System in 20 Minutes

Context-free grammars as a model of language generation

Large-scale linguistic annotations

A Translation System in 20 Minutes

Context-free grammars as a model of language generation

Large-scale linguistic annotations

Tree transformations

A Translation System in 20 Minutes

Context-free grammars as a model of language generation

Large-scale linguistic annotations

Tree transformations

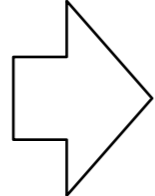
English

A Translation System in 20 Minutes

Context-free grammars as a model of language generation

Large-scale linguistic annotations

Tree transformations

English  **Yoda-speak**



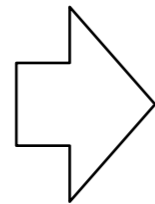
A Translation System in 20 Minutes

Context-free grammars as a model of language generation

Large-scale linguistic annotations

Tree transformations

English



Yoda-speak

Help you, I can!
Yes! Mm!



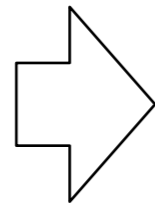
A Translation System in 20 Minutes

Context-free grammars as a model of language generation

Large-scale linguistic annotations

Tree transformations

English



Yoda-speak

Help you, I can!
Yes! Mm!

When 900 years old you reach,
look as good, you will not. Hm.



A Context-Free Grammar Describes Generation

"Grammar"

A Context-Free Grammar Describes Generation

"Grammar"

$S \rightarrow NP VP$

A Context-Free Grammar Describes Generation

"Grammar"

$S \rightarrow NP VP$

$NP \rightarrow PRP$

A Context-Free Grammar Describes Generation

"Grammar"

S \rightarrow NP VP

NP \rightarrow PRP

VP \rightarrow VB

A Context-Free Grammar Describes Generation

"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP

A Context-Free Grammar Describes Generation

S

"Grammar"

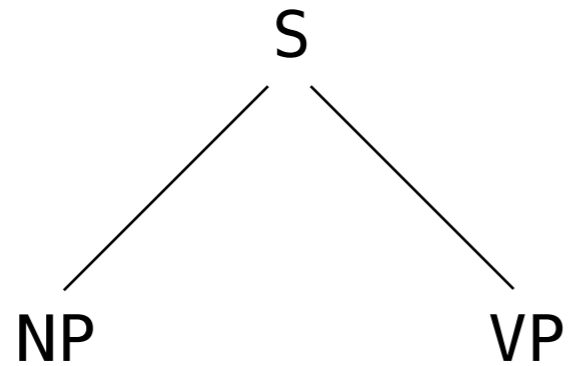
S \rightarrow NP VP

NP \rightarrow PRP

VP \rightarrow VB

VP \rightarrow VB PRP

A Context-Free Grammar Describes Generation



"Grammar"

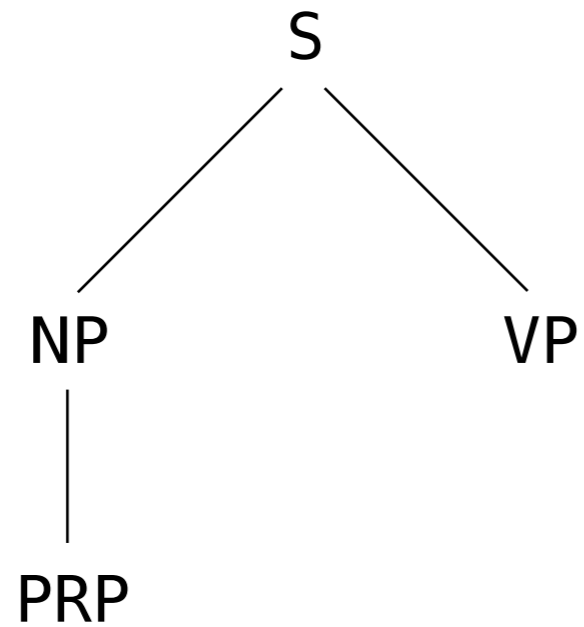
$S \rightarrow NP VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB PRP$

A Context-Free Grammar Describes Generation



"Grammar"

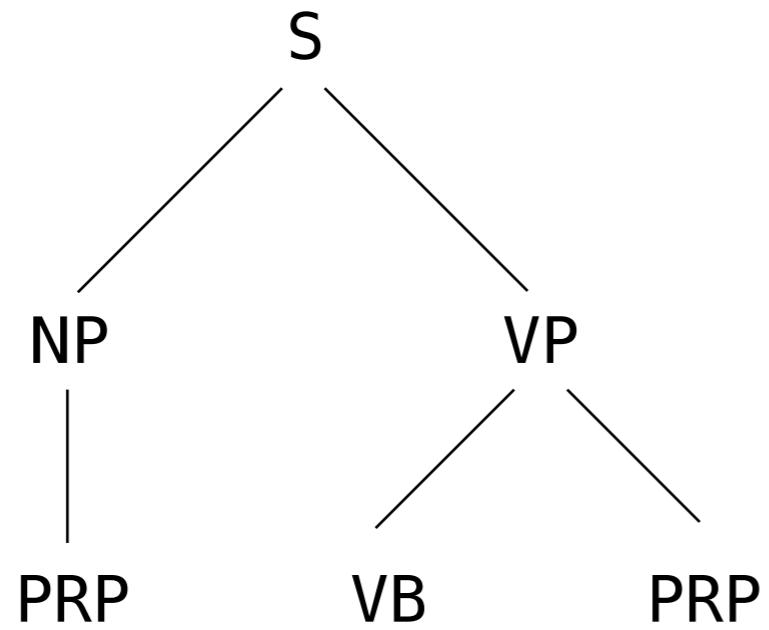
$S \rightarrow NP VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB PRP$

A Context-Free Grammar Describes Generation



"Grammar"

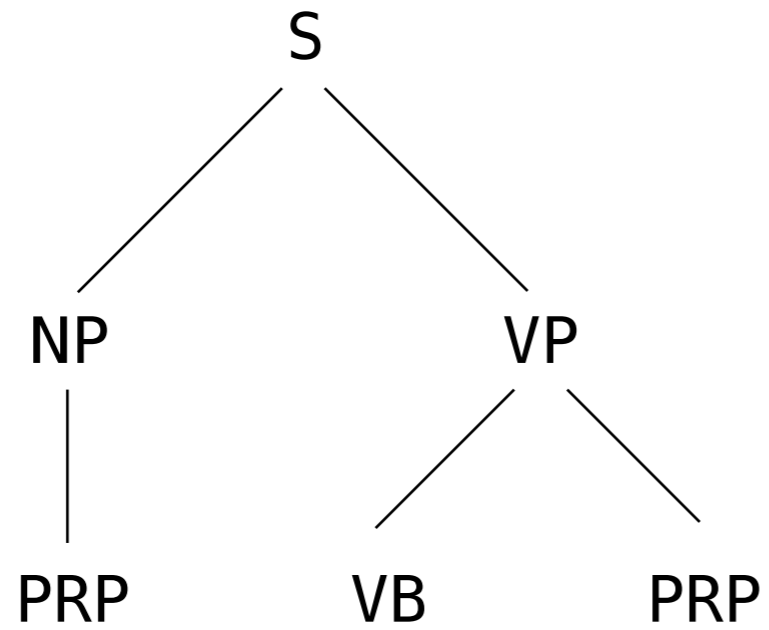
$S \rightarrow NP VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB PRP$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP VP$

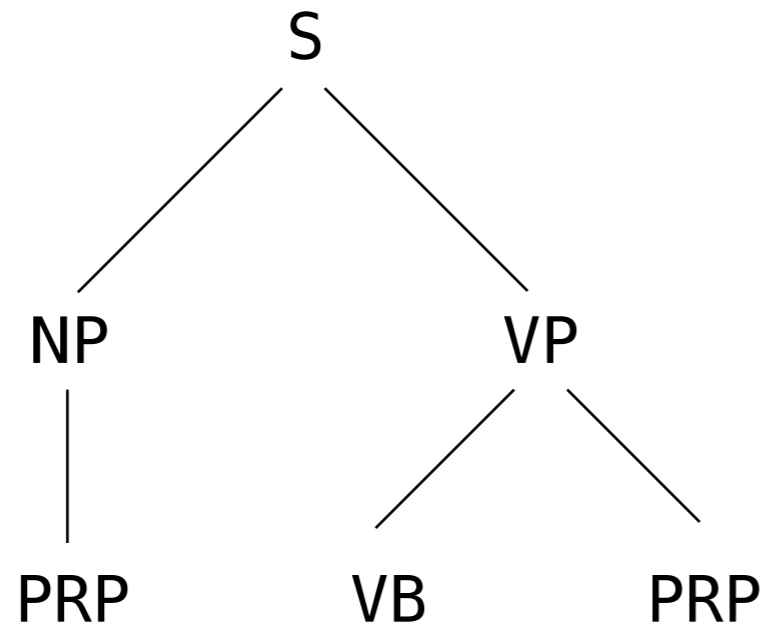
$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB PRP$

"Lexicon"

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP VP$

$NP \rightarrow PRP$

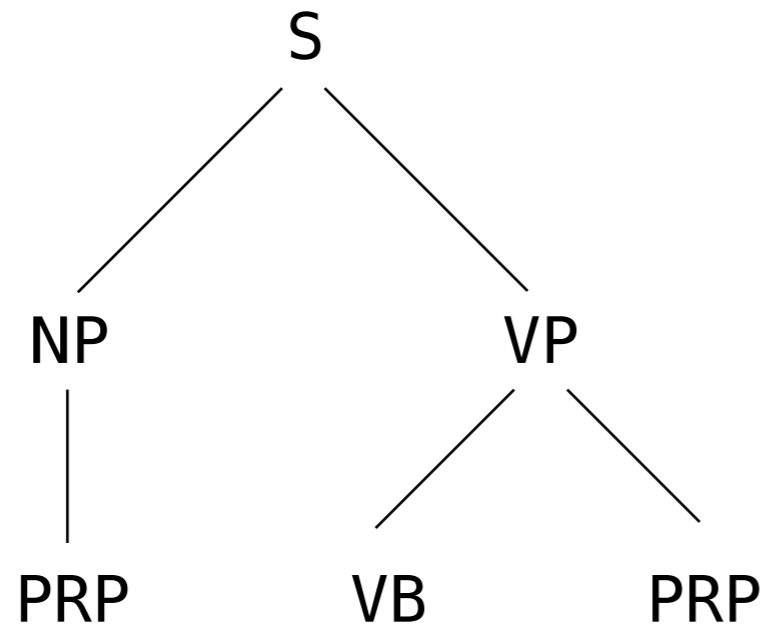
$VP \rightarrow VB$

$VP \rightarrow VB PRP$

"Lexicon"

$PRP \rightarrow I$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

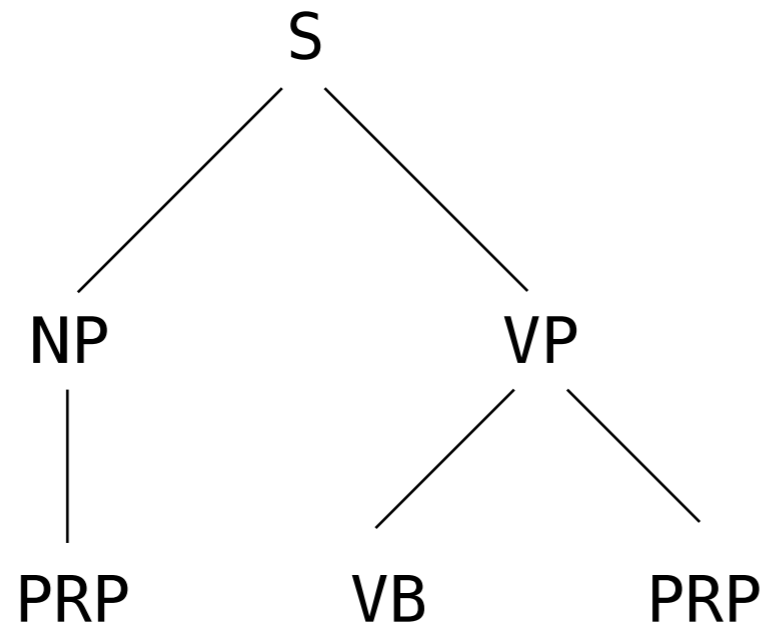
$VP \rightarrow VB PRP$

"Lexicon"

$PRP \rightarrow I$

$PRP \rightarrow you$

A Context-Free Grammar Describes Generation



"Grammar"

S \rightarrow NP VP

NP \rightarrow PRP

VP \rightarrow VB

VP \rightarrow VB PRP

"Lexicon"

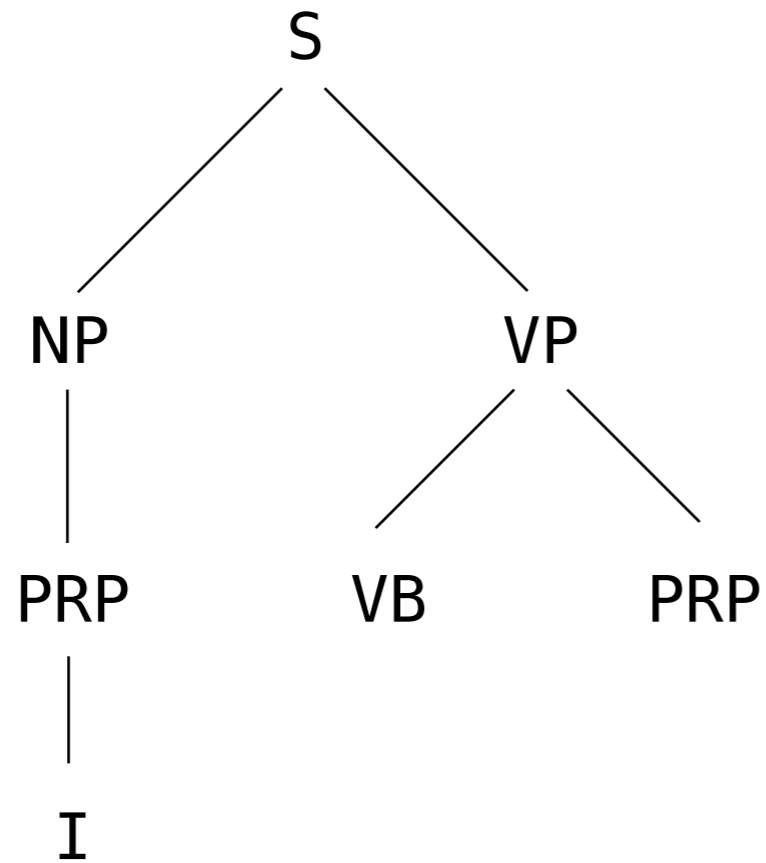
PRP \rightarrow I

PRP \rightarrow you

VB \rightarrow know

VB \rightarrow help

A Context-Free Grammar Describes Generation



"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP

"Lexicon"

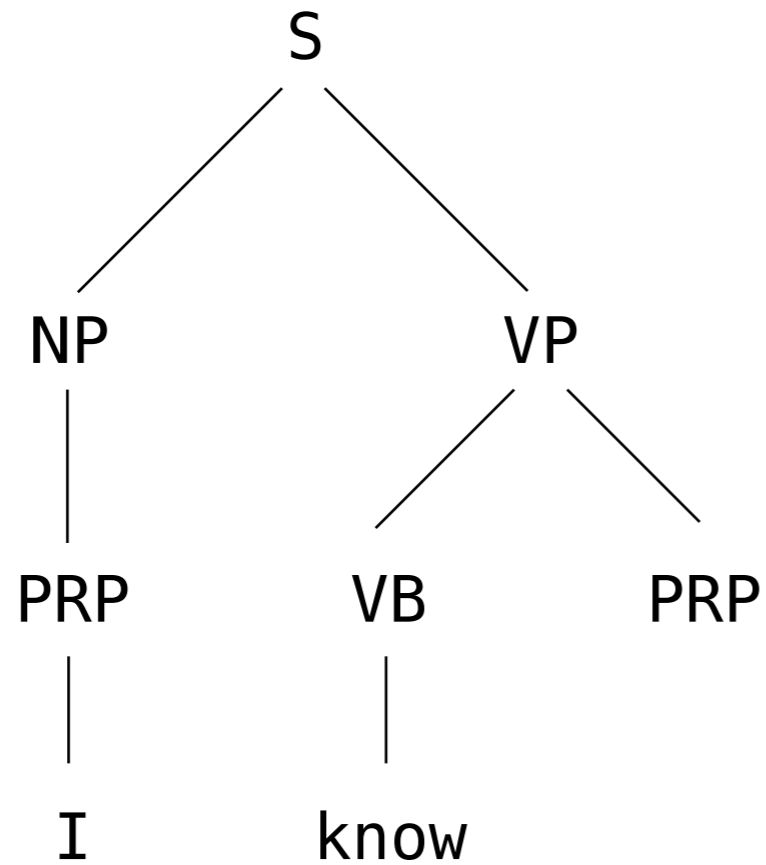
PRP → I

PRP → you

VB → know

VB → help

A Context-Free Grammar Describes Generation



"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP

"Lexicon"

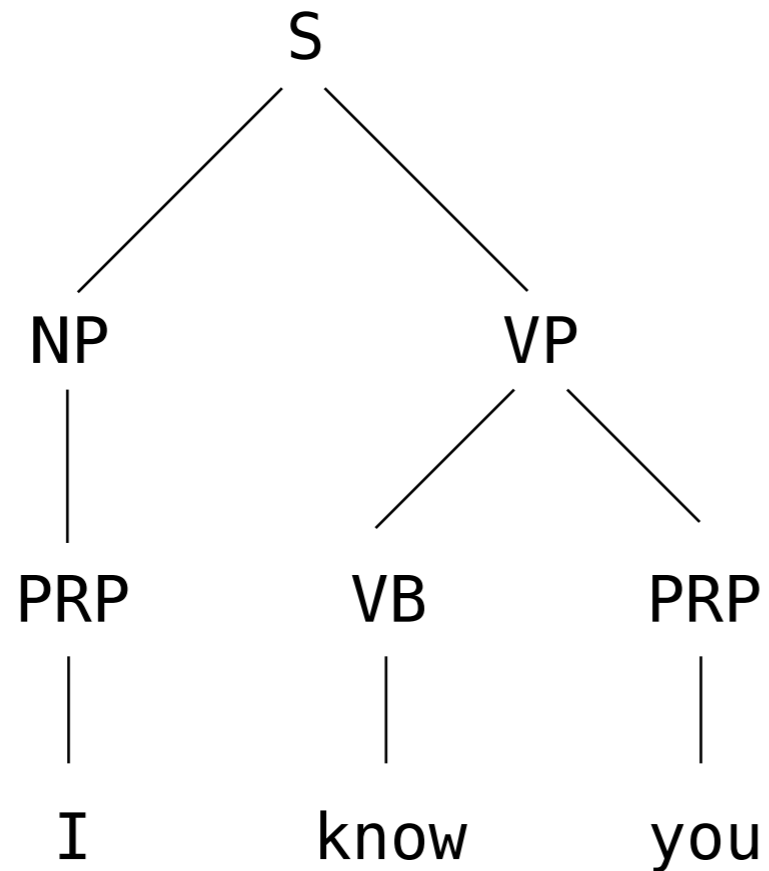
PRP → I

PRP → you

VB → know

VB → help

A Context-Free Grammar Describes Generation



"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP

"Lexicon"

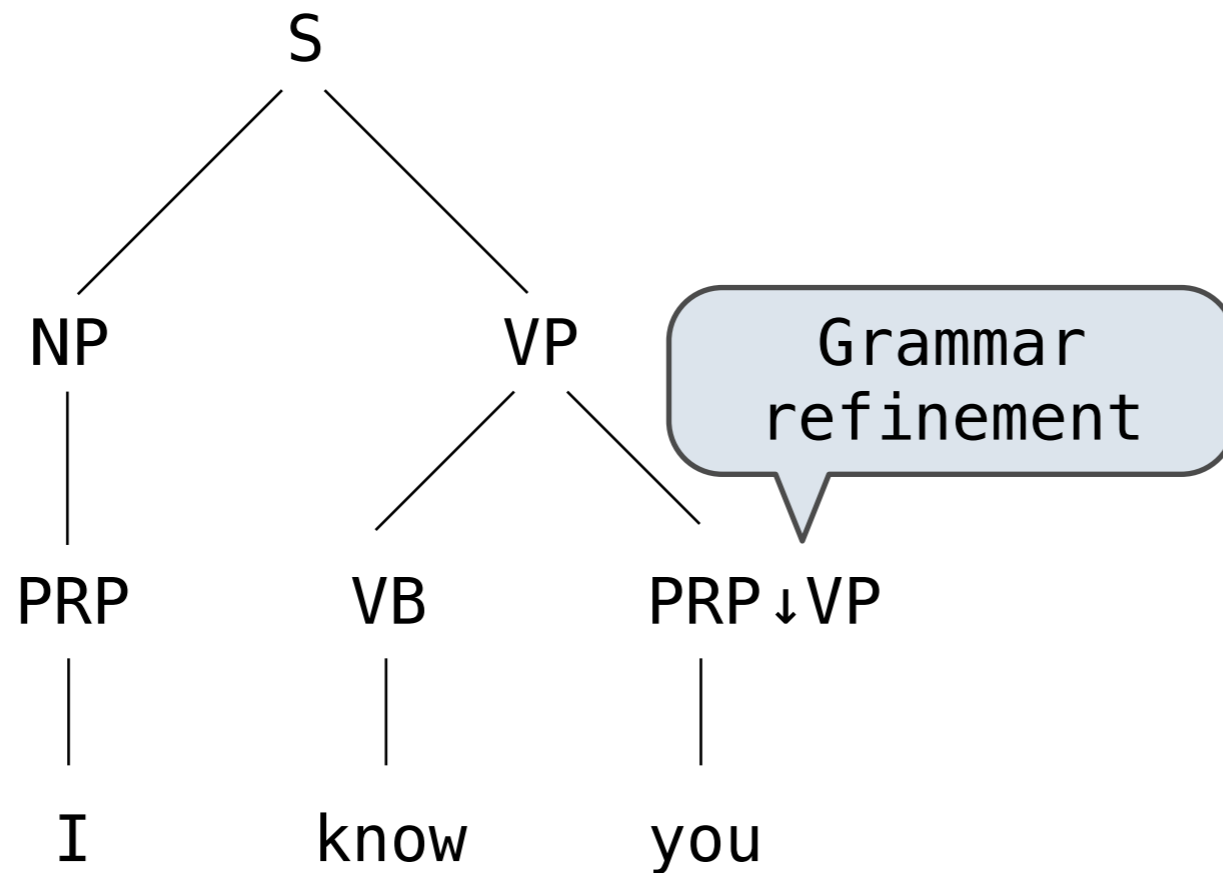
PRP → I

PRP → you

VB → know

VB → help

A Context-Free Grammar Describes Generation



"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP

"Lexicon"

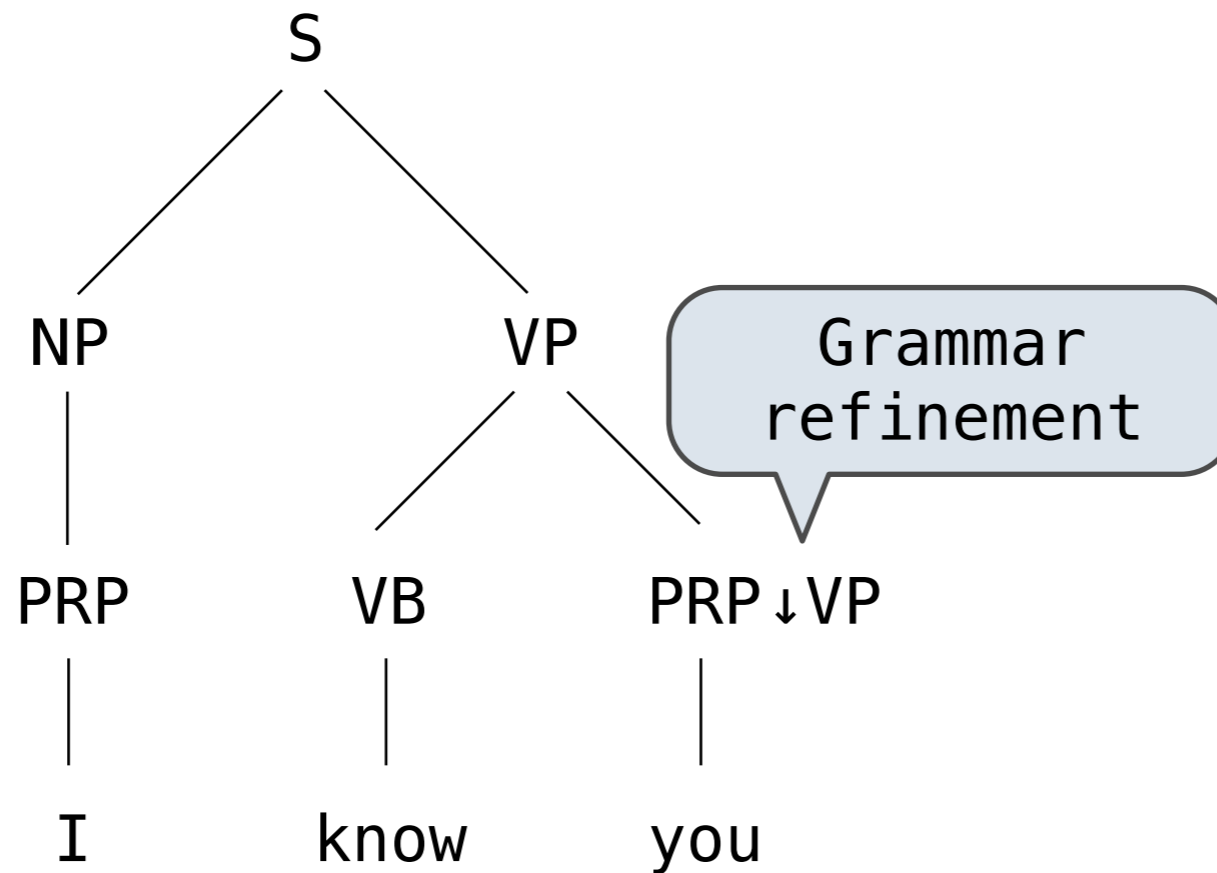
PRP → I

PRP → you

VB → know

VB → help

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP VP$

$NP \rightarrow PRP \downarrow NP$

$VP \rightarrow VB$

$VP \rightarrow VB PRP$

"Lexicon"

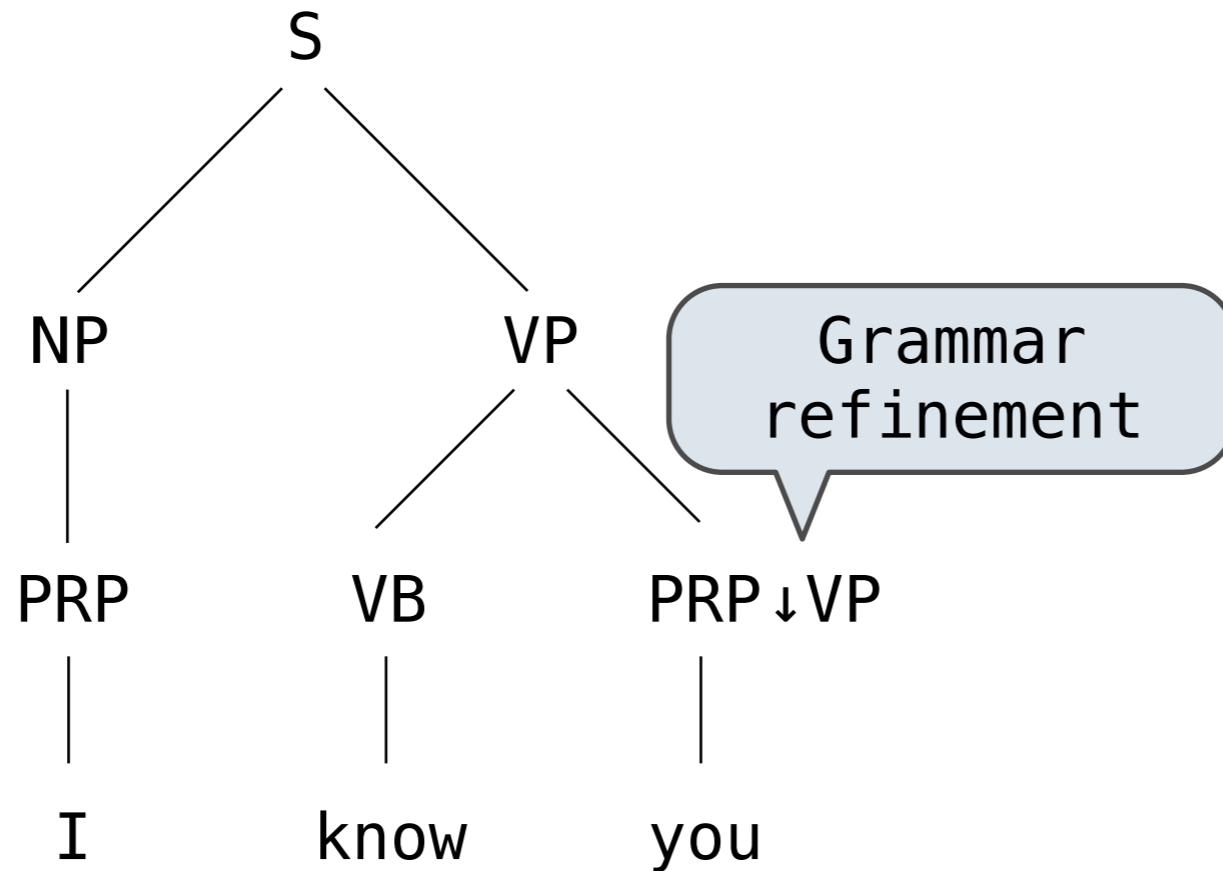
$PRP \rightarrow I$

$PRP \rightarrow you$

$VB \rightarrow know$

$VB \rightarrow help$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP VP$

$NP \rightarrow PRP \downarrow NP$

$VP \rightarrow VB$

$VP \rightarrow VB PRP \downarrow VP$

"Lexicon"

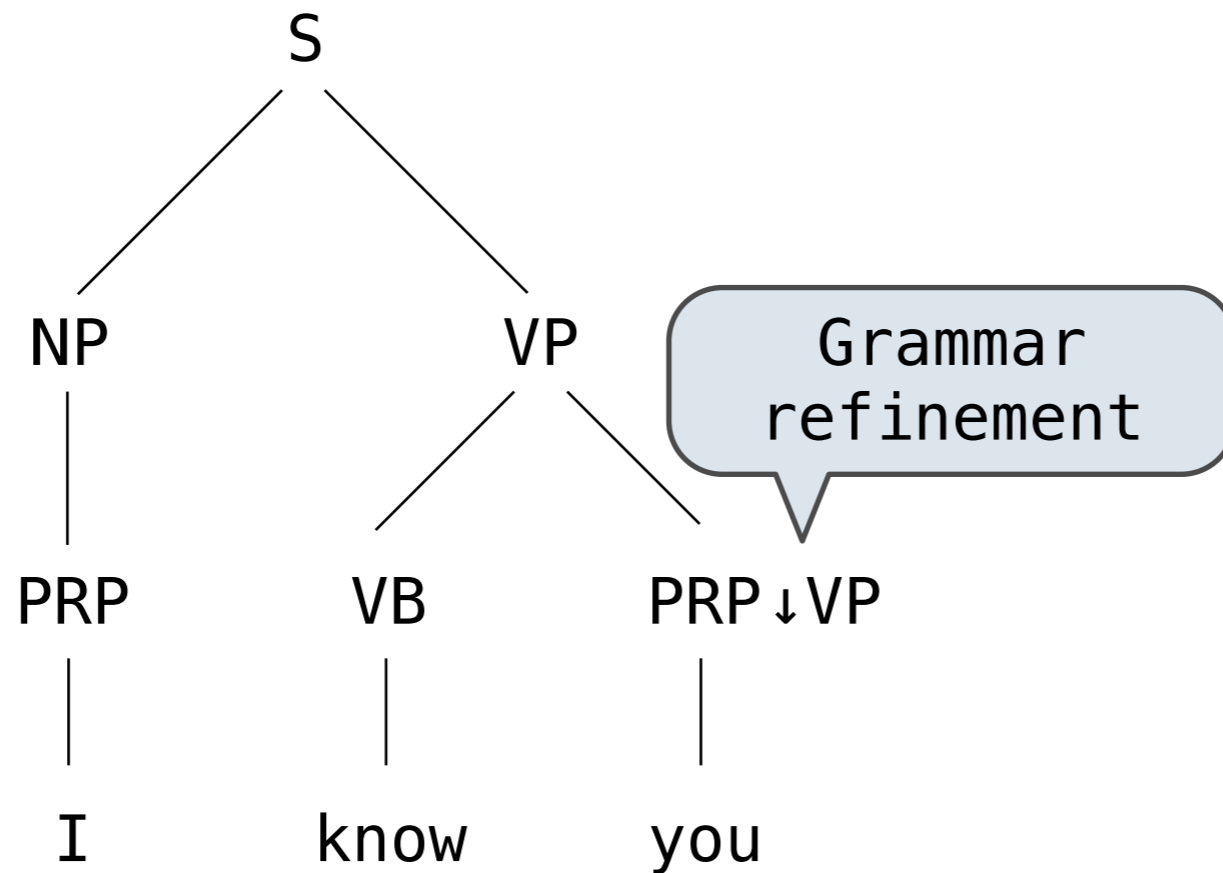
$PRP \rightarrow I$

$PRP \rightarrow you$

$VB \rightarrow know$

$VB \rightarrow help$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP VP$

$NP \rightarrow PRP \downarrow NP$

$VP \rightarrow VB$

$VP \rightarrow VB PRP \downarrow VP$

"Lexicon"

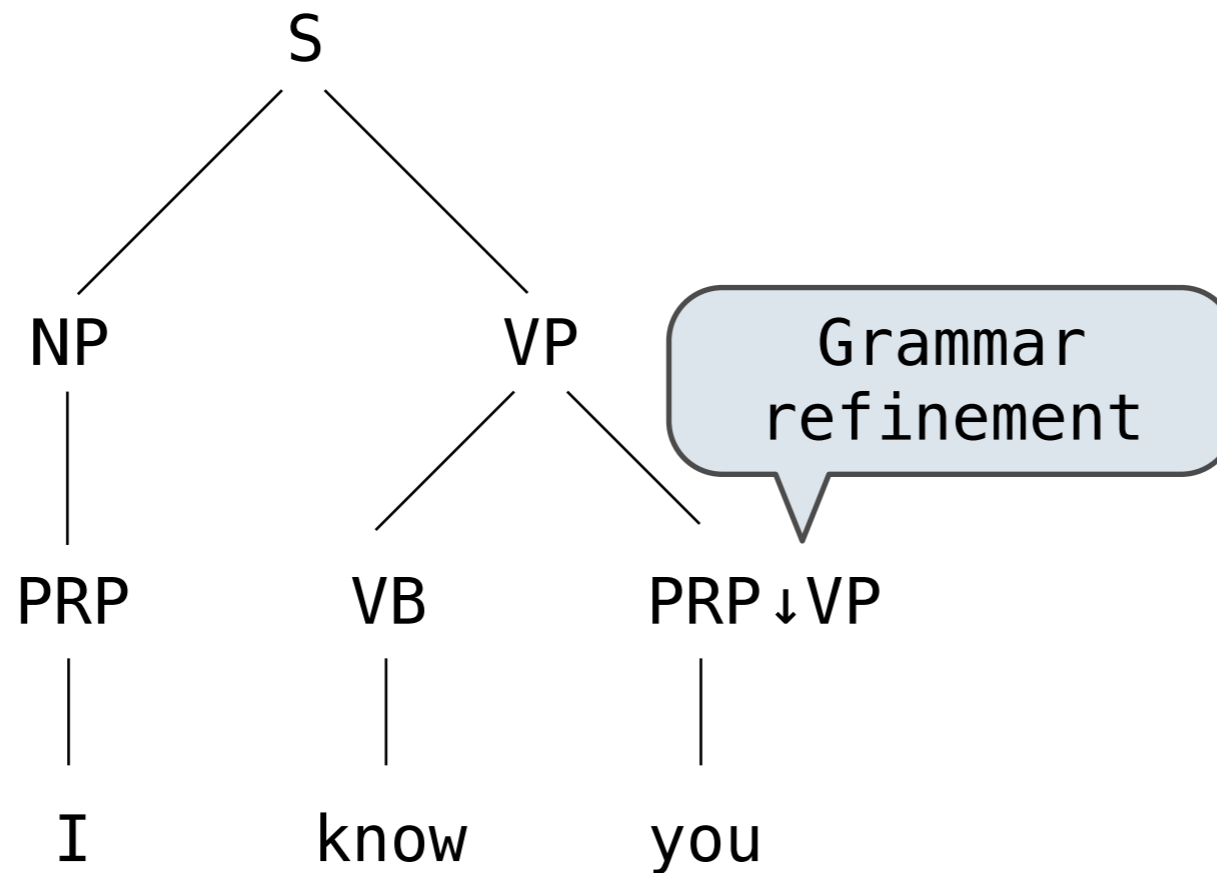
$PRP \downarrow NP \rightarrow I$

$PRP \rightarrow you$

$VB \rightarrow know$

$VB \rightarrow help$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP VP$

$NP \rightarrow PRP \downarrow NP$

$VP \rightarrow VB$

$VP \rightarrow VB PRP \downarrow VP$

"Lexicon"

$PRP \downarrow NP \rightarrow I$

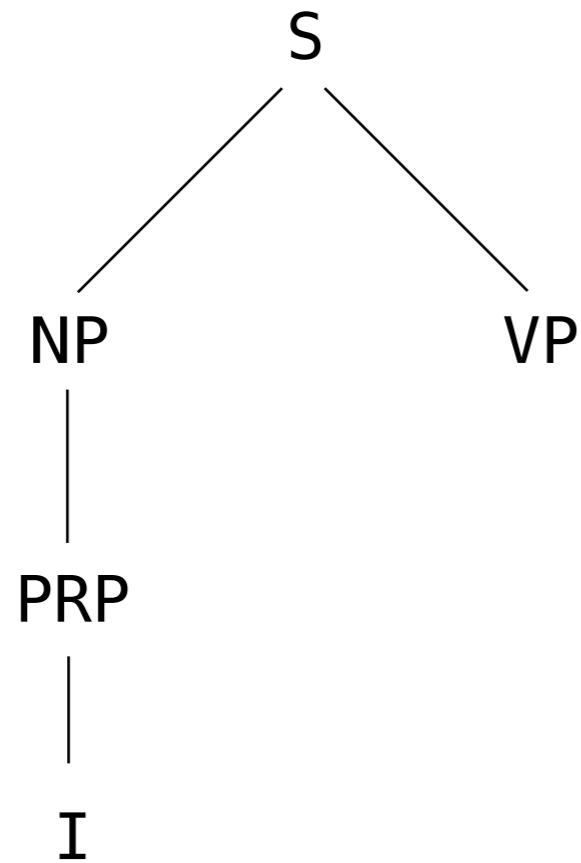
$PRP \rightarrow you$

$VB \rightarrow know$

$VB \rightarrow help$

$PRP \downarrow VP \rightarrow me$

A Context-Free Grammar Describes Generation



"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP

"Lexicon"

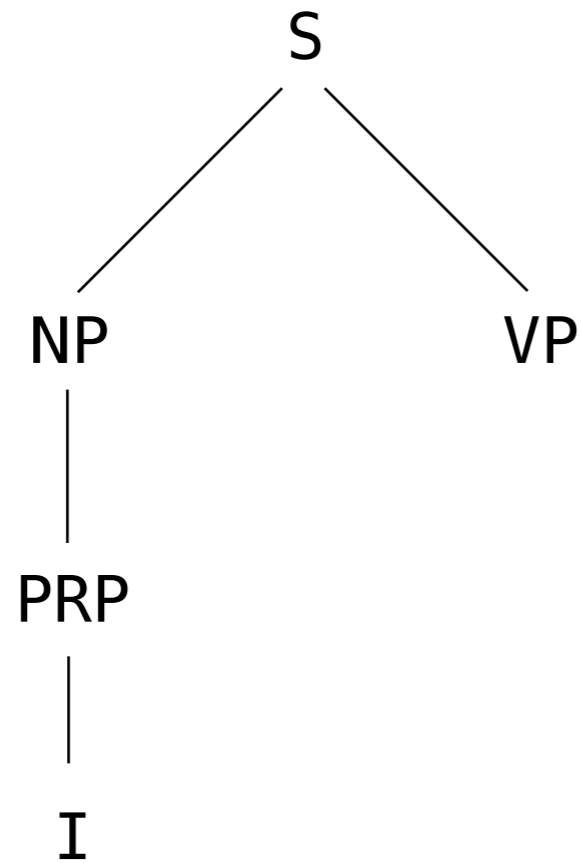
PRP → I

PRP → you

VB → know

VB → help

A Context-Free Grammar Describes Generation



"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP

VP → MD VP

"Lexicon"

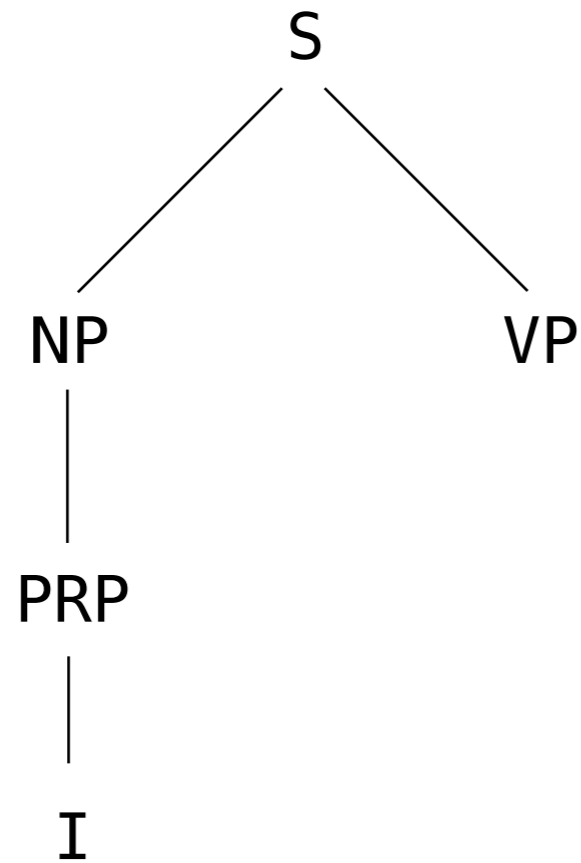
PRP → I

PRP → you

VB → know

VB → help

A Context-Free Grammar Describes Generation



"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP

VP → MD VP

"Lexicon"

PRP → I

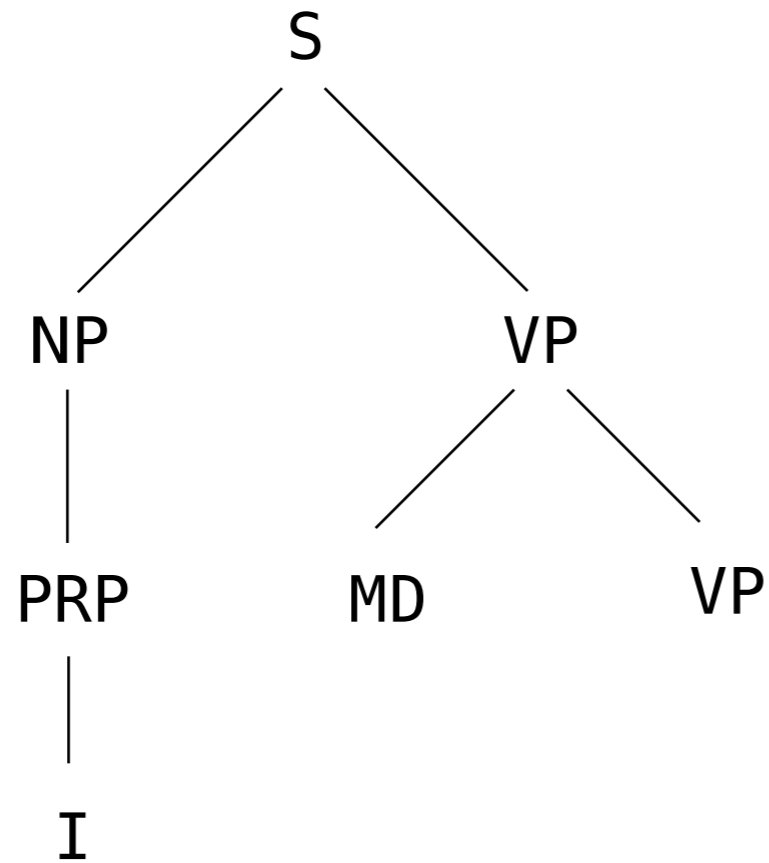
PRP → you

VB → know

VB → help

MD → can

A Context-Free Grammar Describes Generation



"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP

VP → MD VP

"Lexicon"

PRP → I

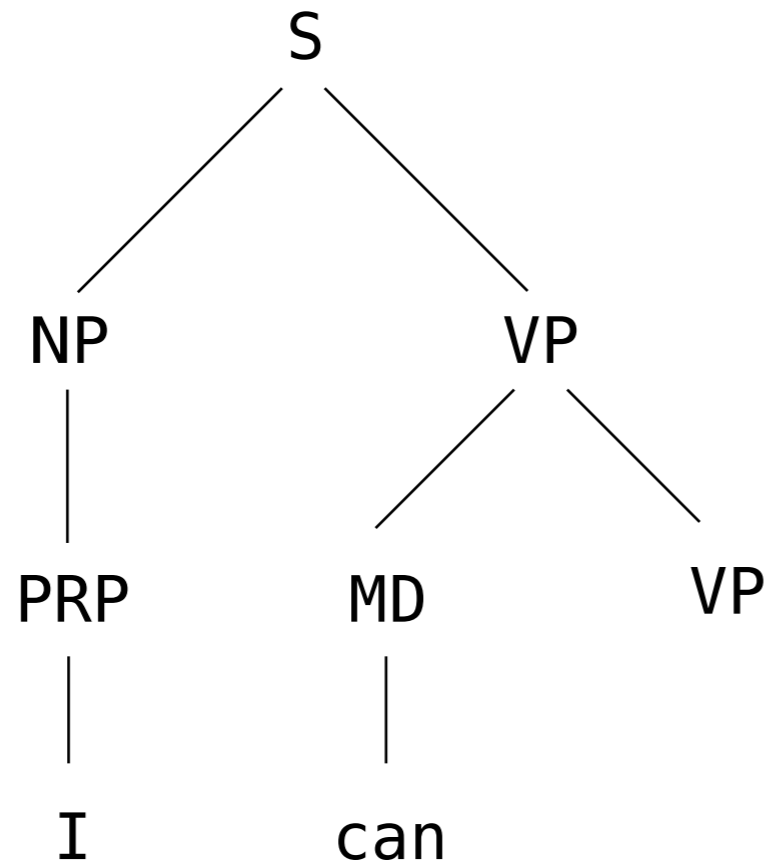
PRP → you

VB → know

VB → help

MD → can

A Context-Free Grammar Describes Generation



"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP

VP → MD VP

"Lexicon"

PRP → I

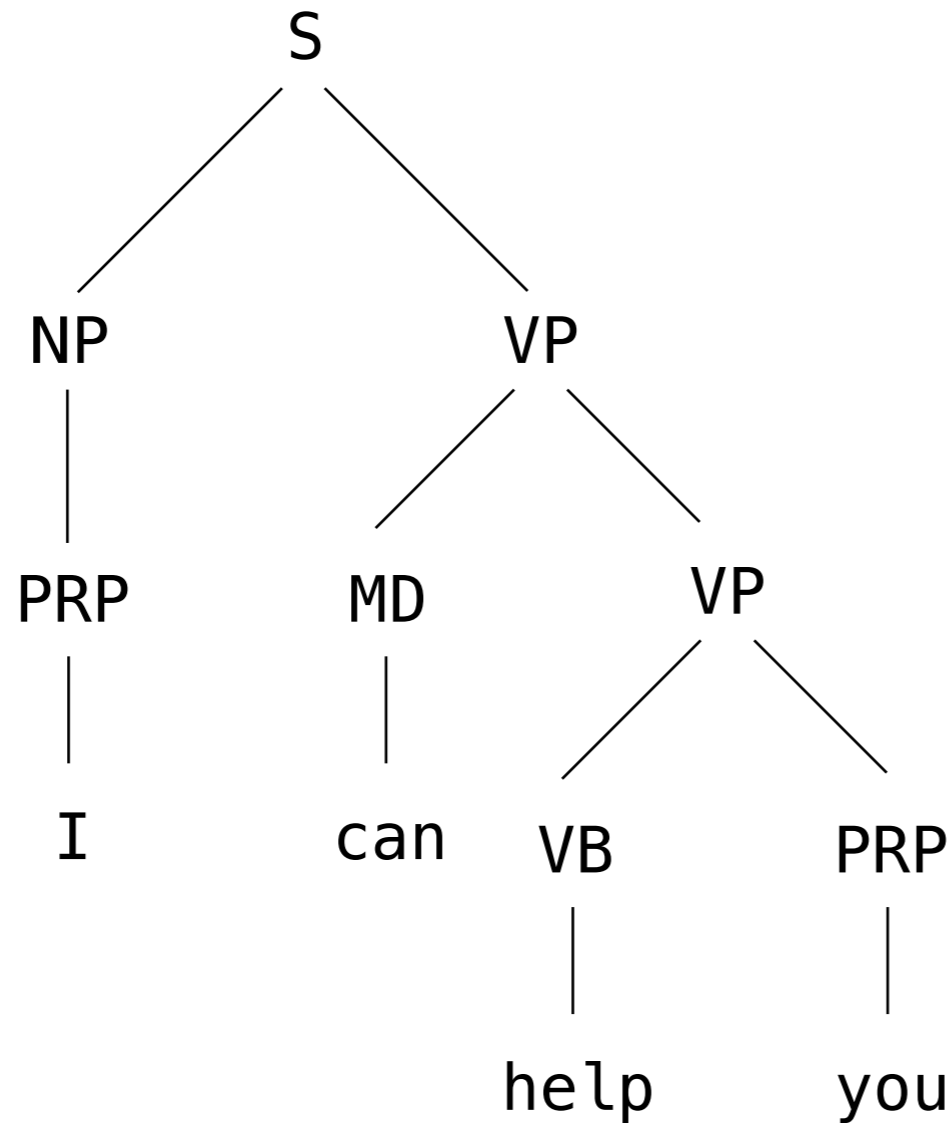
PRP → you

VB → know

VB → help

MD → can

A Context-Free Grammar Describes Generation



"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP

VP → MD VP

"Lexicon"

PRP → I

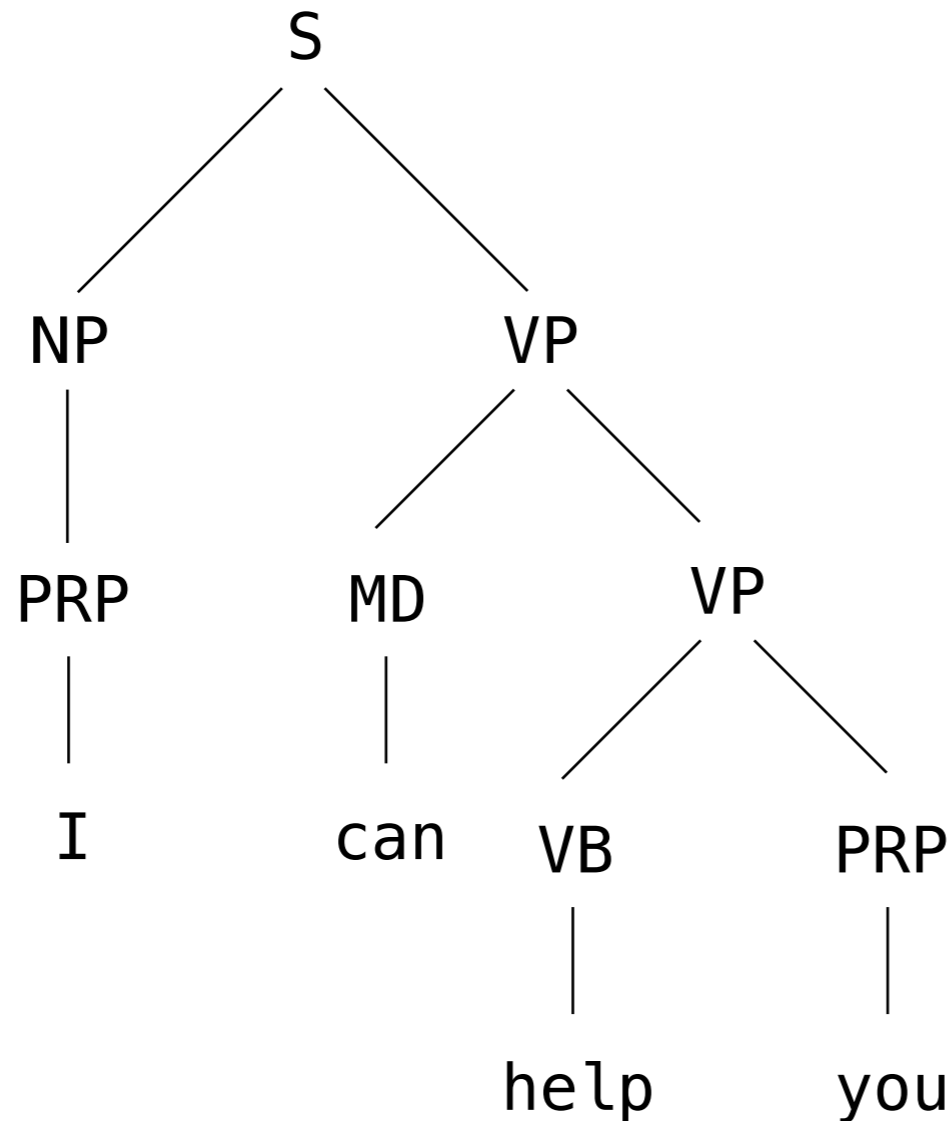
PRP → you

VB → know

VB → help

MD → can

A Context-Free Grammar Describes Generation



"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP

VP → MD VP

"Lexicon"

PRP → I

PRP → you

VB → know

VB → help

MD → can

A grammar can be *learned* from data (demo)

Left-Corner Parsing Builds Trees For Sentences

"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP

"Lexicon"

PRP → I

PRP → you

VB → know

VB → help

Left-Corner Parsing Builds Trees For Sentences

"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP

"Lexicon"

PRP → I

PRP → you

VB → know

VB → help

i know you

Left-Corner Parsing Builds Trees For Sentences

"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP


"Lexicon"

PRP → I

PRP → you

VB → know

VB → help

 i know you 

Left-Corner Parsing Builds Trees For Sentences

"Grammar"

S → NP VP
NP → PRP
VP → VB
VP → VB PRP

Left corners

"Lexicon"

PRP → I

PRP → you

VB → know

VB → help

▶ i know you ■

Left-Corner Parsing Builds Trees For Sentences

parse_next(S, 1)

"Grammar"

S → NP VP
NP → PRP
VP → VB
VP → VB PRP

Left corners

"Lexicon"

PRP → I

PRP → you

VB → know

VB → help

▶ i know you ■

Left-Corner Parsing Builds Trees For Sentences

parse_next(S, 1)

"Grammar"

S → NP VP
NP → PRP
VP → VB
VP → VB PRP

Left corners

S

"Lexicon"

PRP → I
PRP → you
VB → know
VB → help

▶ i know you ■

Left-Corner Parsing Builds Trees For Sentences

parse_next(S, 1)

"Grammar"

S → NP VP
NP → PRP
VP → VB
VP → VB PRP

Left corners

S

"Lexicon"

PRP → I
PRP → you
VB → know
VB → help

PRP
|
▶ i know you ■

Left-Corner Parsing Builds Trees For Sentences

parse_next(S, 1)

complete(S, (PRP i), 1)

"Grammar"

S → NP VP

NP → PRP

VP → VB

VP → VB PRP

Left corners

S

"Lexicon"

PRP → I

PRP → you

VB → know

VB → help



Left-Corner Parsing Builds Trees For Sentences

parse_next(S, 1)

complete(S, (PRP i), 1)

"Grammar"

S → NP VP

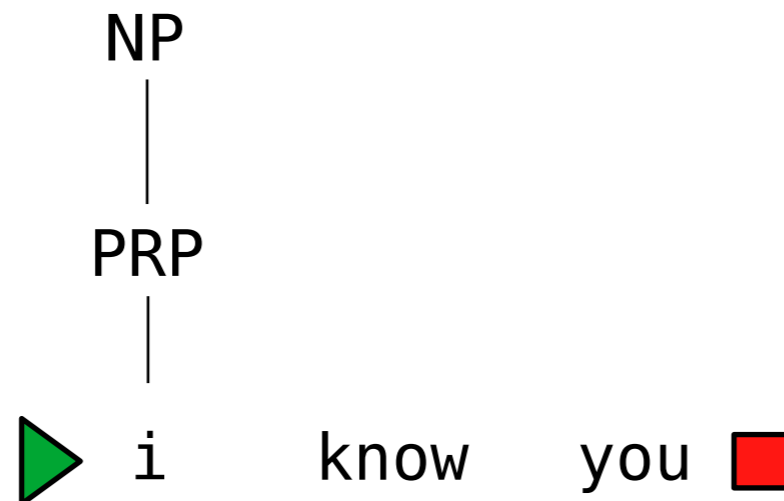
NP → PRP

VP → VB

VP → VB PRP

Left corners

S



"Lexicon"

PRP → I

PRP → you

VB → know

VB → help

Left-Corner Parsing Builds Trees For Sentences

```
parse_next(S, 1)
```

```
complete(S, (PRP i), 1)
```

```
complete(S, (NP (PRP i)), 1)
```

"Grammar"

S → NP VP

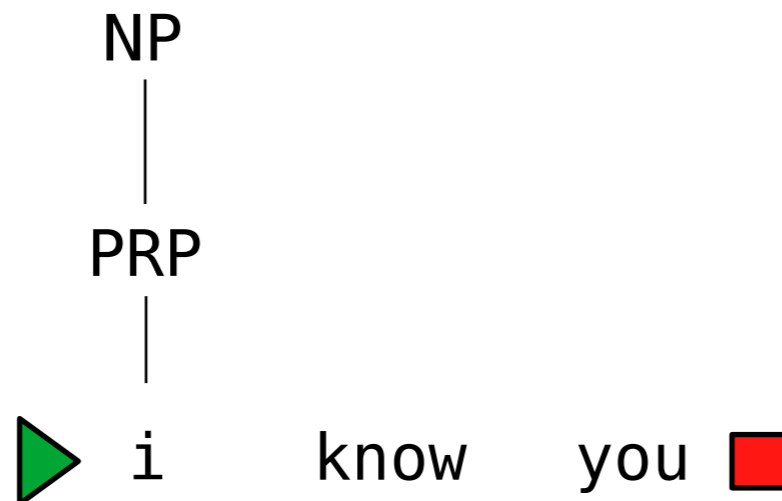
NP → PRP

VP → VB

VP → VB PRP

Left corners

S



"Lexicon"

PRP → I

PRP → you

VB → know

VB → help

Left-Corner Parsing Builds Trees For Sentences

```
parse_next(S, 1)
```

```
complete(S, (PRP i), 1)
```

```
complete(S, (NP (PRP i)), 1)
```

```
parse_next(VP, 2)
```

"Grammar"

S → NP VP

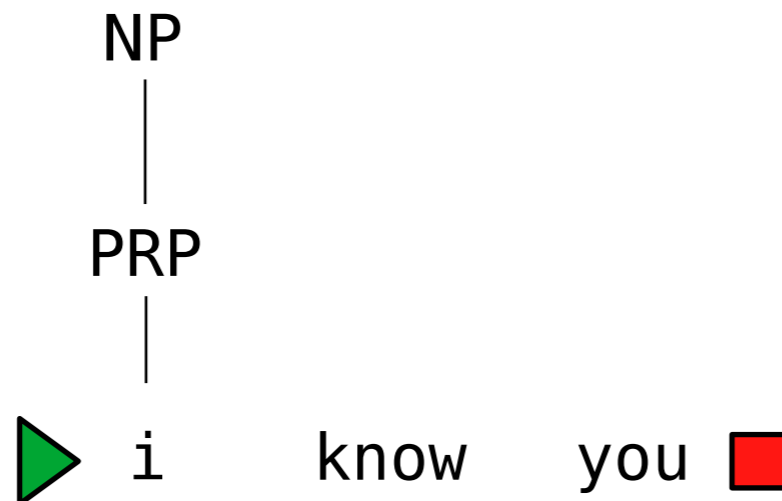
NP → PRP

VP → VB

VP → VB PRP

Left corners

S



"Lexicon"

PRP → I

PRP → you

VB → know

VB → help

Left-Corner Parsing Builds Trees For Sentences

parse_next(S, 1)

complete(S, (PRP i), 1)

complete(S, (NP (PRP i)), 1)

parse_next(VP, 2)

"Grammar"

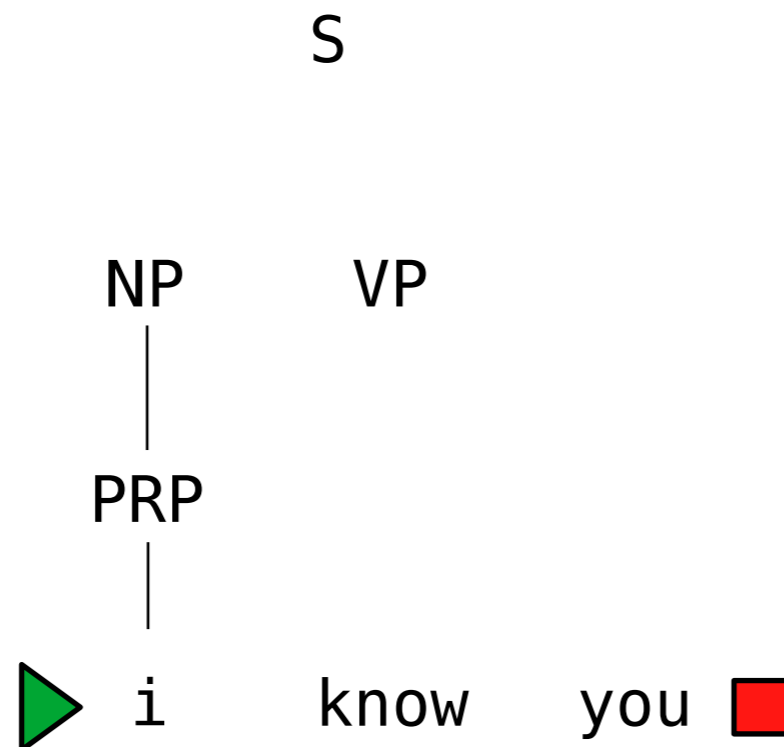
S → NP VP

NP → PRP

VP → VB

VP → VB PRP

Left corners



"Lexicon"

PRP → I

PRP → you

VB → know

VB → help

Left-Corner Parsing Builds Trees For Sentences

```
parse_next(S, 1)
```

```
complete(S, (PRP i), 1)
```

```
complete(S, (NP (PRP i)), 1)
```

```
parse_next(VP, 2)
```

"Grammar"

S → NP VP

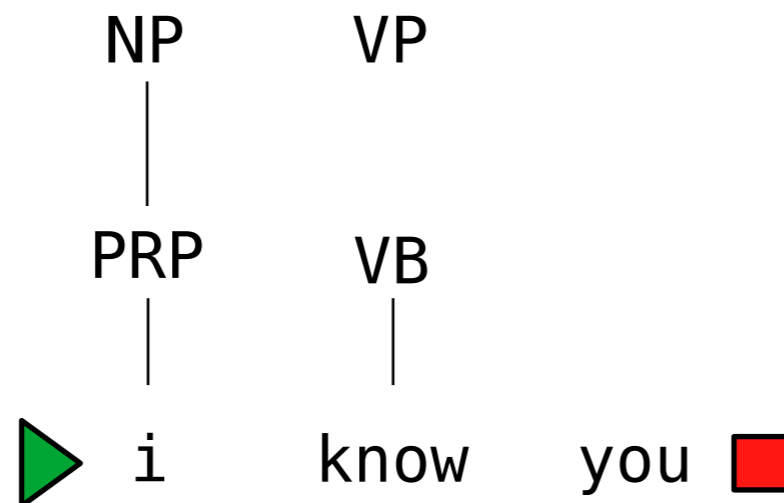
NP → PRP

VP → VB

VP → VB PRP

Left corners

S



"Lexicon"

PRP → I

PRP → you

VB → know

VB → help

Left-Corner Parsing Builds Trees For Sentences

```
parse_next(S, 1)
```

```
complete(S, (PRP i), 1)
```

```
complete(S, (NP (PRP i)), 1)
```

```
parse_next(VP, 2)
```

```
complete(VP, (VB know), 2)
```

"Grammar"

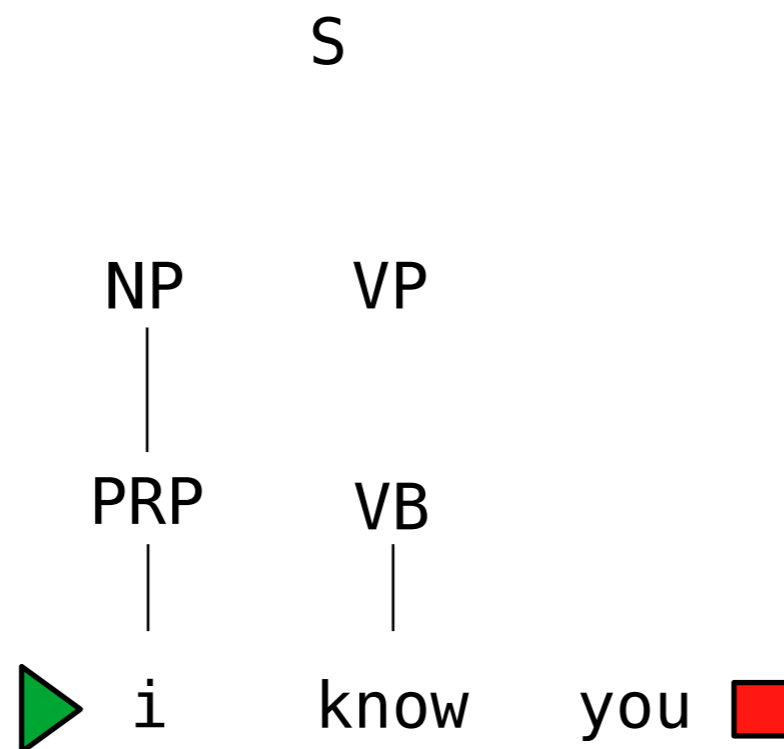
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Left-Corner Parsing Builds Trees For Sentences

parse_next(S, 1)

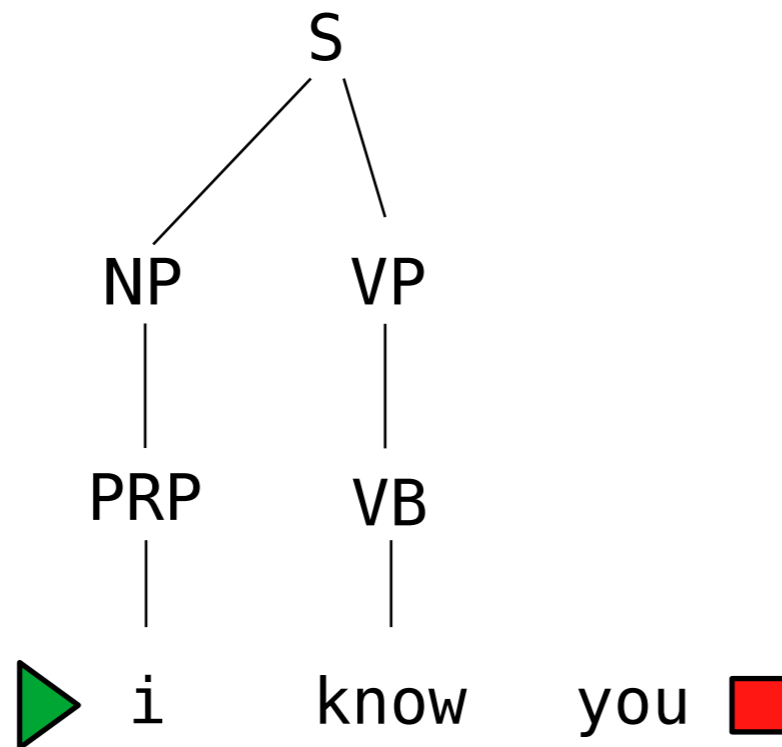
complete(S, (PRP i), 1)

complete(S, (NP (PRP i)), 1)

parse_next(VP, 2)

complete(VP, (VB know), 2)

complete(VP, (VP (VB know)), 2)



"Grammar"

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Left-Corner Parsing Builds Trees For Sentences

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parse_next(S, 1)
```

```
complete(S, (PRP i), 1)
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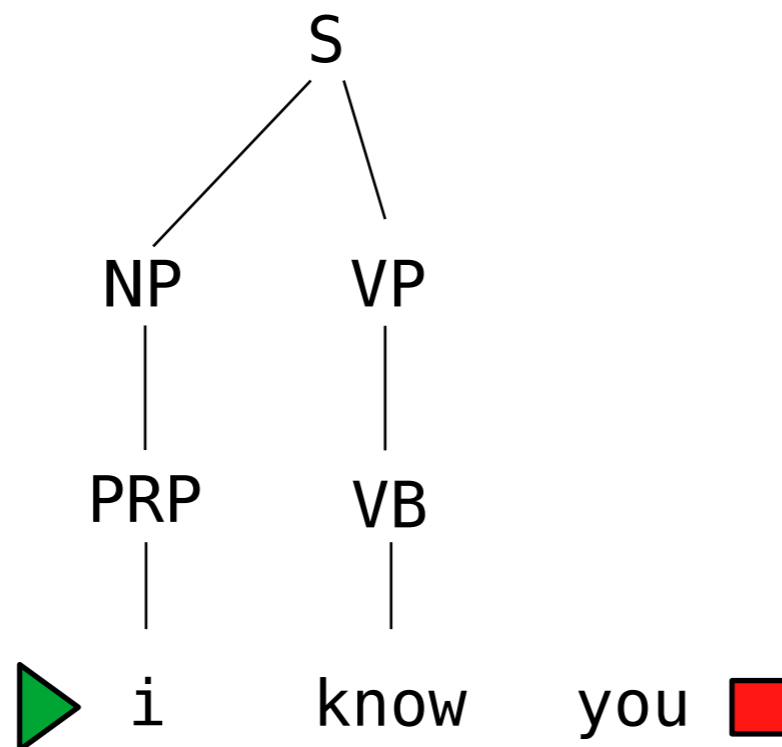
```
complete(S, (NP (PRP i)), 1)
```

```
parse_next(VP, 2)
```

```
complete(VP, (VB know), 2)
```

```
complete(VP, (VP (VB know)), 2)
```

```
complete(S, (S ...), 1)
```



"Grammar"

S → NP VP

NP → PRP

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```

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```

```
complete(VP, (VB know), 2)
```

"Grammar"

S → NP VP

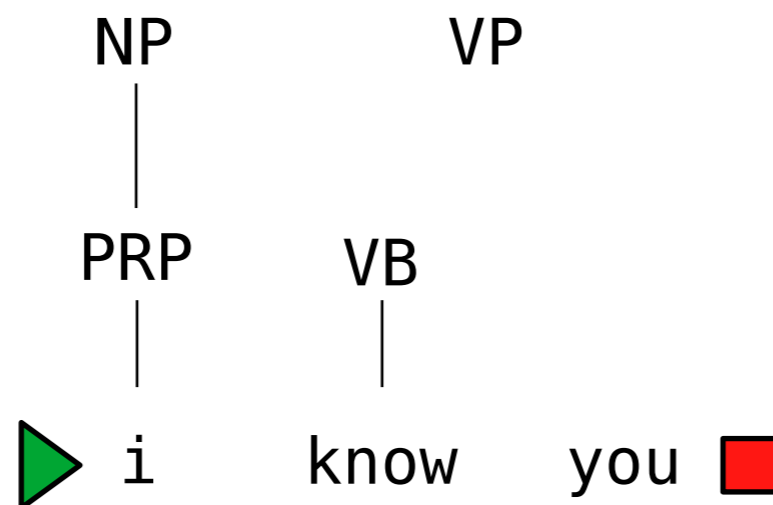
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Left-Corner Parsing Builds Trees For Sentences

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complete(S, (NP (PRP i)), 1)
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```
parse_next(VP, 2)
```

```
complete(VP, (VB know), 2)
```

"Grammar"

S → NP VP

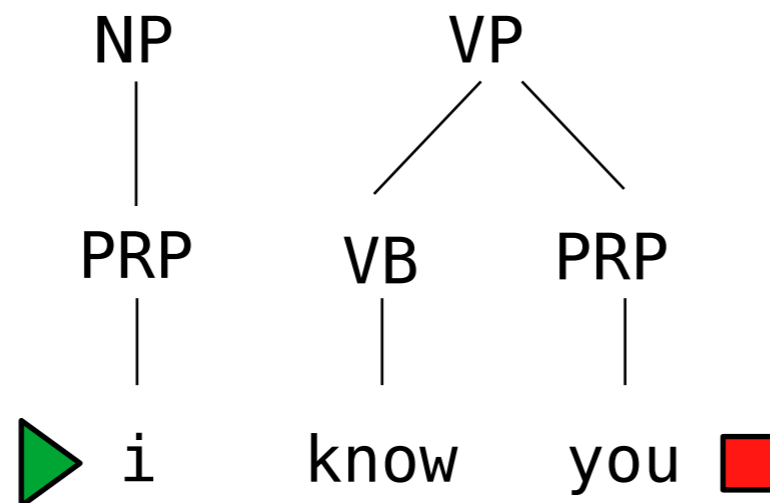
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complete(S, (NP (PRP i)), 1)
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```
parse_next(VP, 2)
```

```
complete(VP, (VB know), 2)
```

```
complete(VP, (VP (VB know) (PRP you)), 2)
```

"Grammar"

S → NP VP

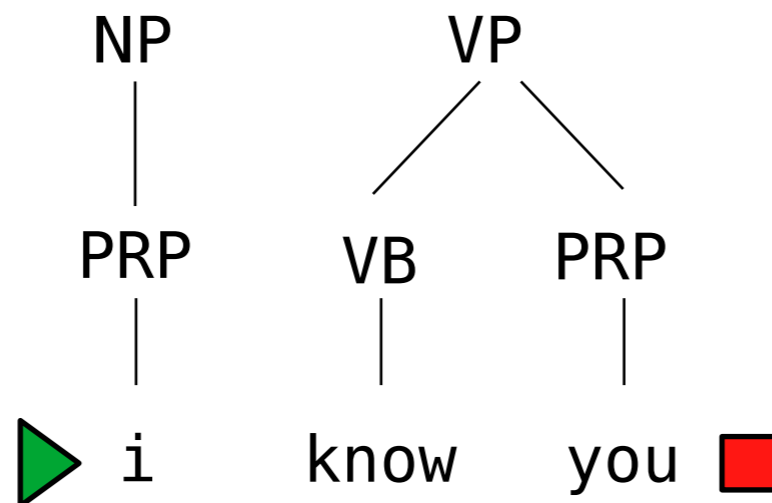
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Left-Corner Parsing Builds Trees For Sentences

parse_next(S, 1)

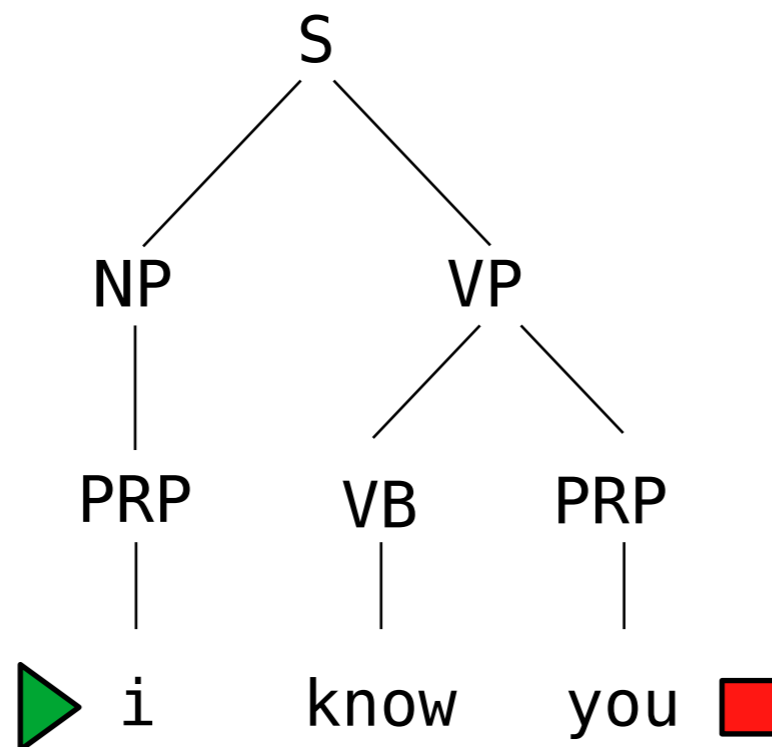
complete(S, (PRP i), 1)

complete(S, (NP (PRP i)), 1)

parse_next(VP, 2)

complete(VP, (VB know), 2)

complete(VP, (VP (VB know) (PRP you)), 2)



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parse_next(S, 1)

complete(S, (PRP i), 1)

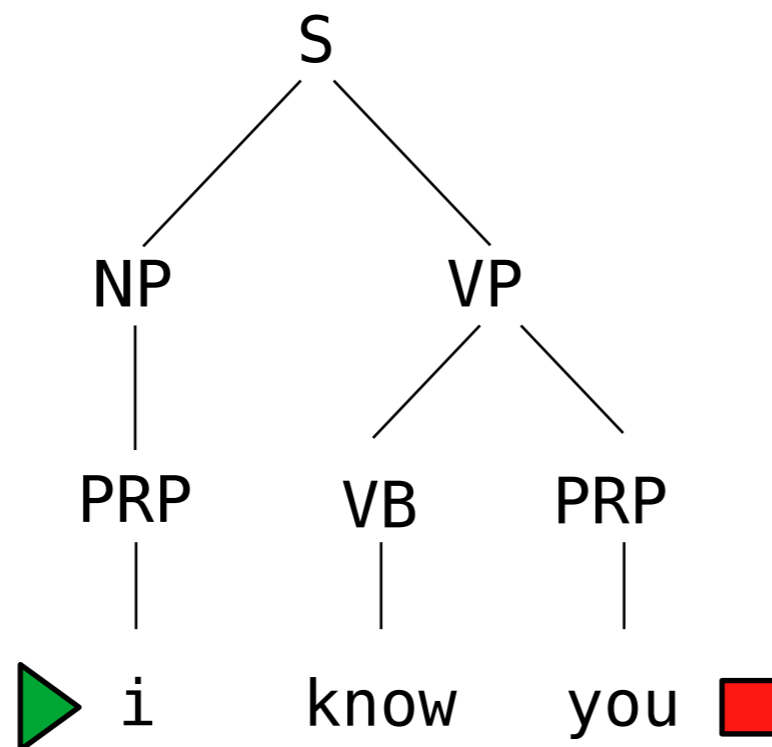
complete(S, (NP (PRP i)), 1)

parse_next(VP, 2)

complete(VP, (VB know), 2)

complete(VP, (VP (VB know) (PRP you)), 2)

complete(S, (S ...), 1)



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