

61A Lecture 37

Friday, November 30

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

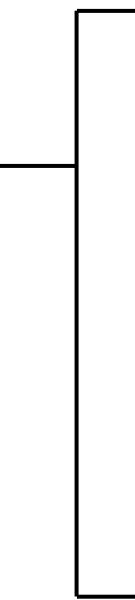
Graphics

Security

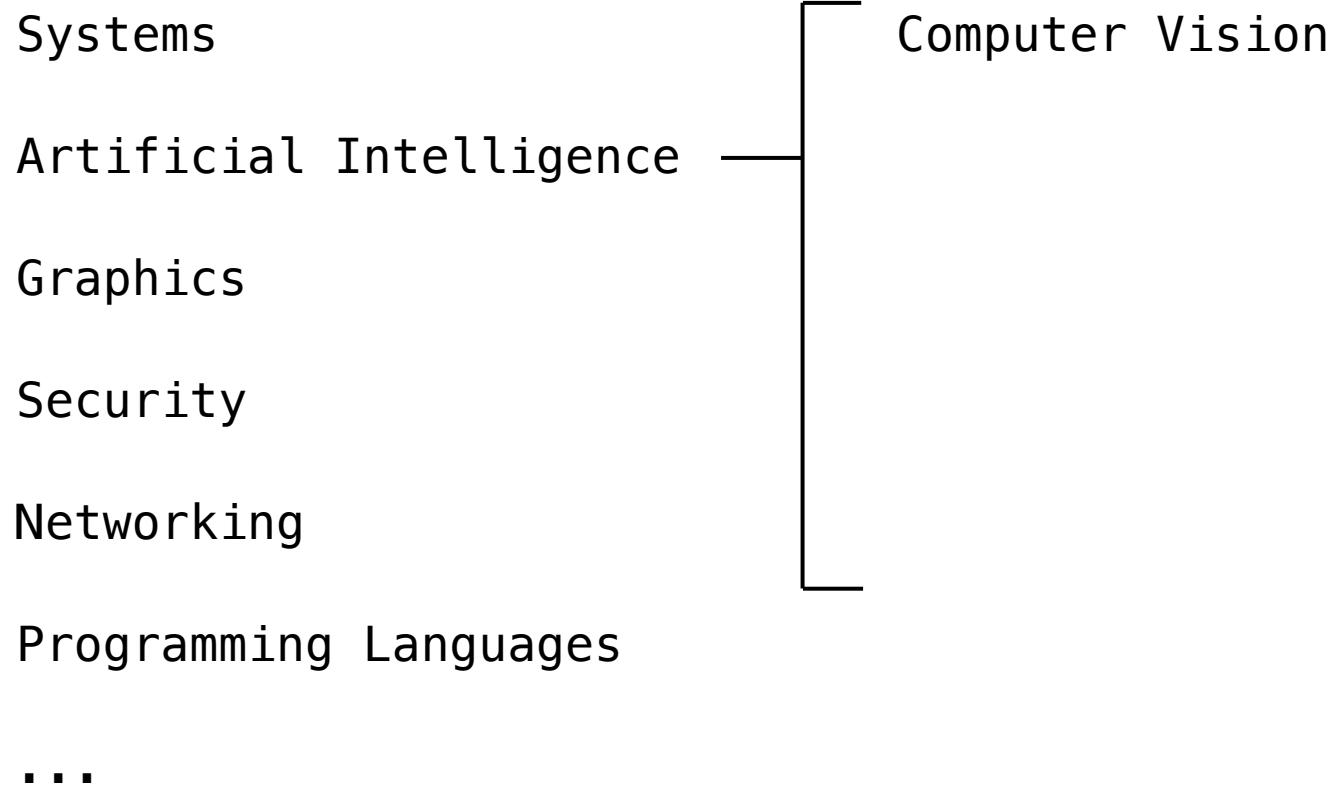
Networking

Programming Languages

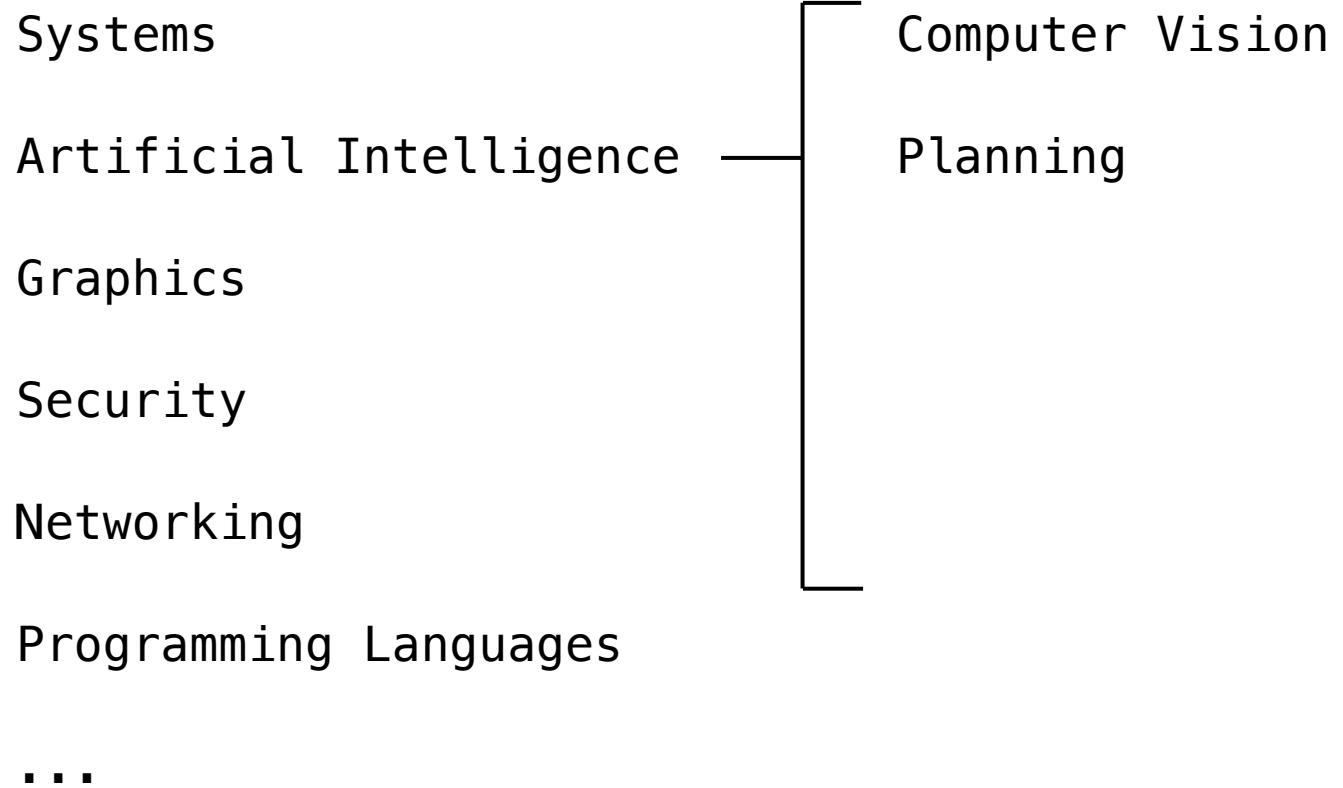
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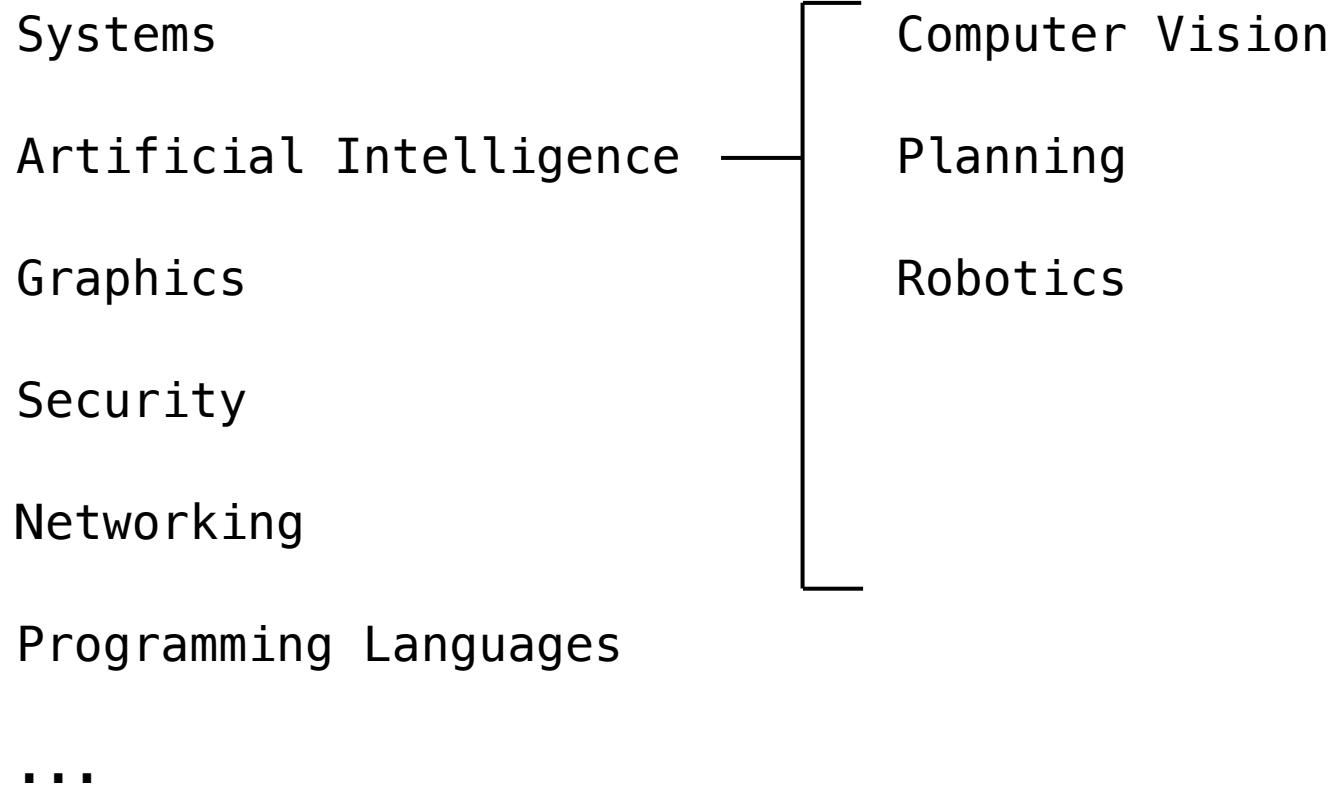
What is Computer Science?



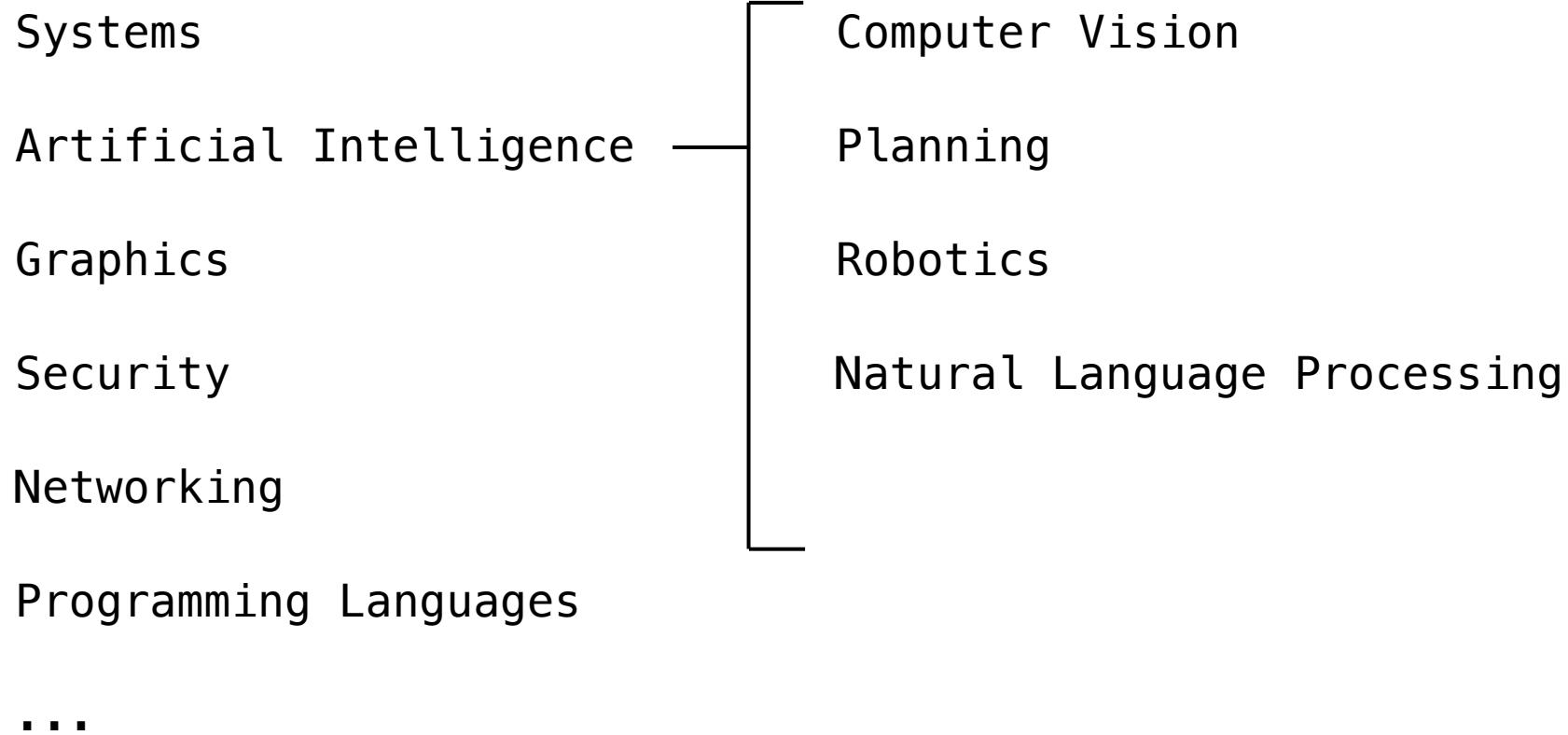
What is Computer Science?



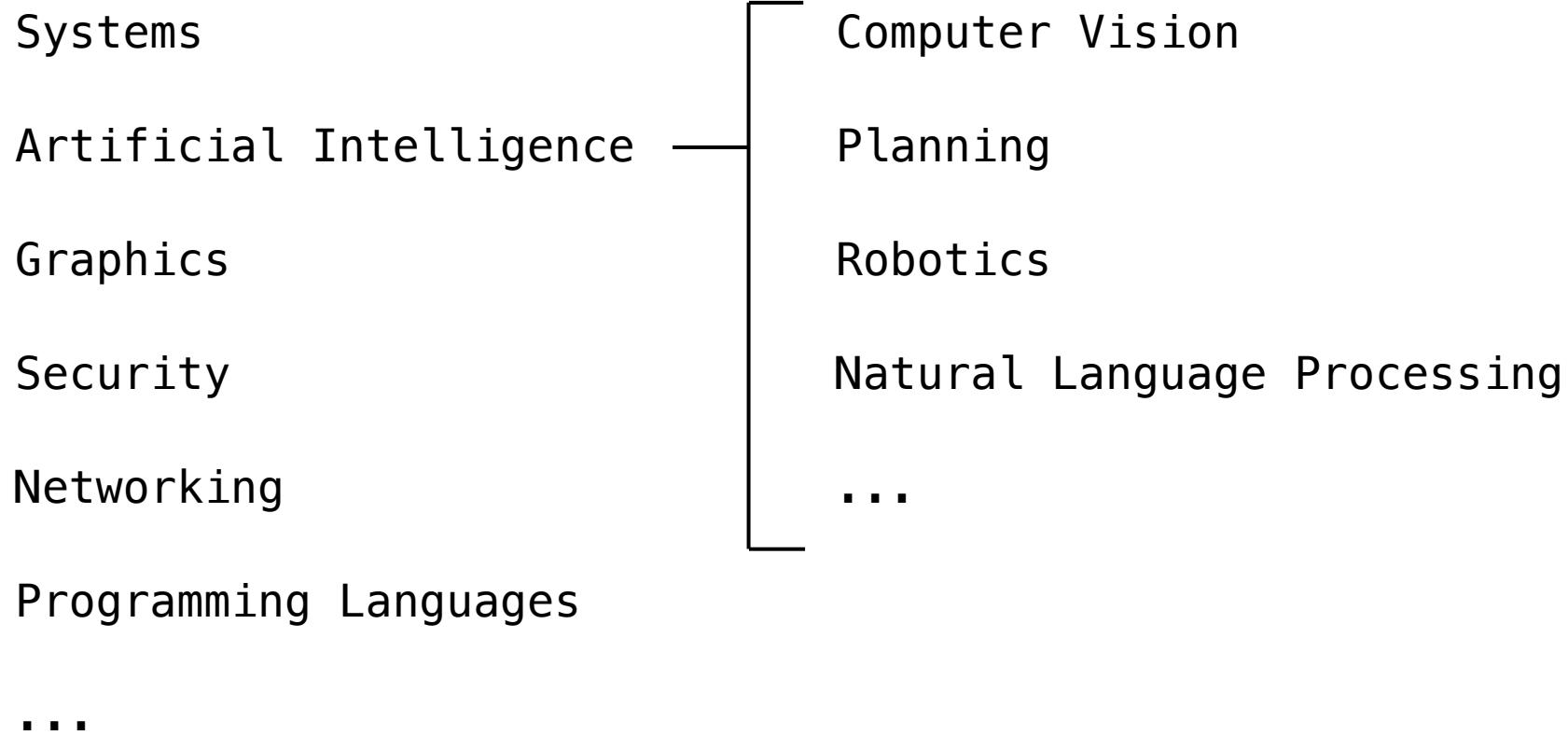
What is Computer Science?



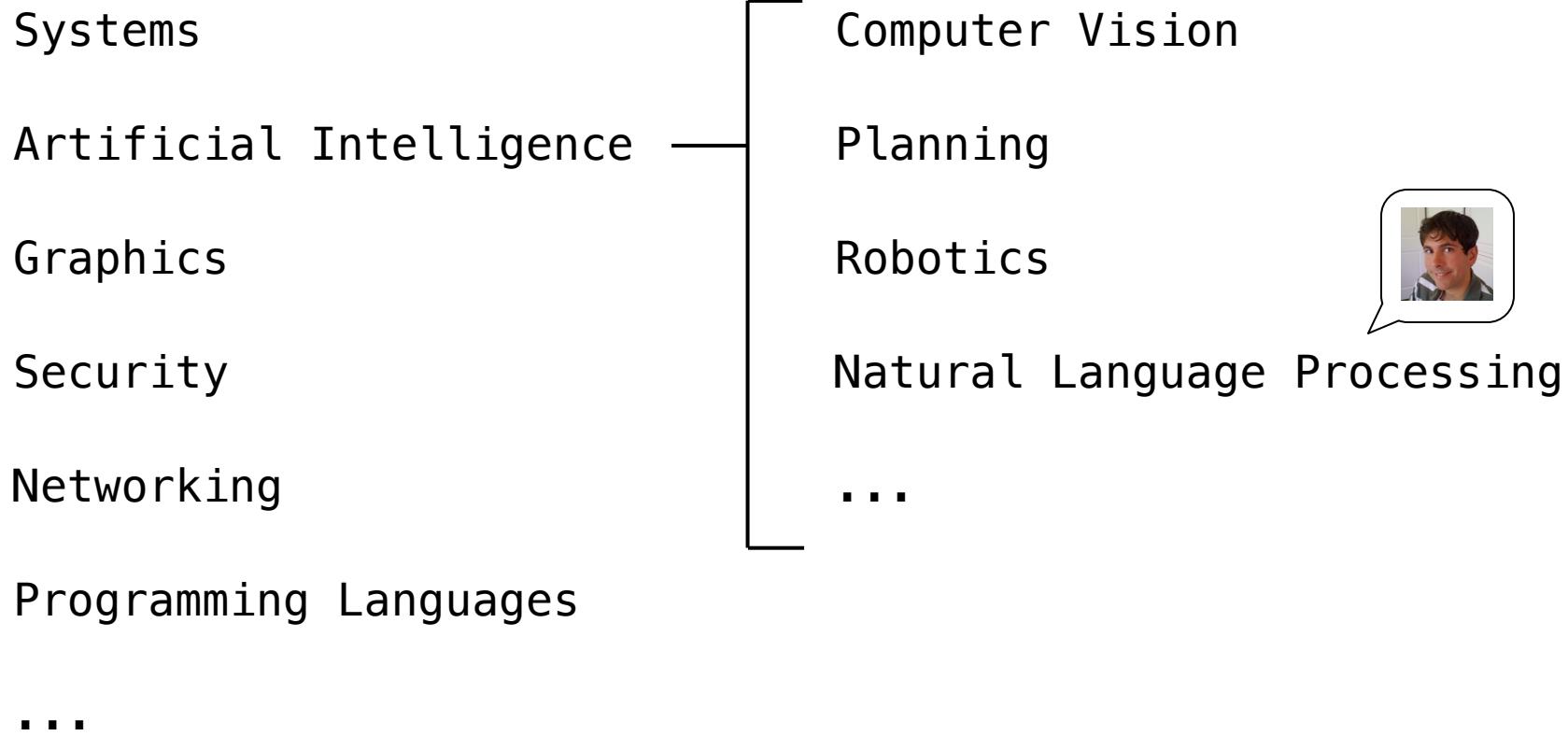
What is Computer Science?



What is Computer Science?



What is Computer Science?



Machine Translation

Bonus
Material

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 verás

Machine Translation

Target language corpus gives examples of well-formed sentences

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Machine translation system:

Machine Translation

Target language corpus gives examples of well-formed sentences

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Machine translation system:

Model of
translation

Machine Translation

Target language corpus gives examples of well-formed sentences

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Después lo veras

Machine translation system:

Source language

Yo lo haré después

NOVEL SENTENCE

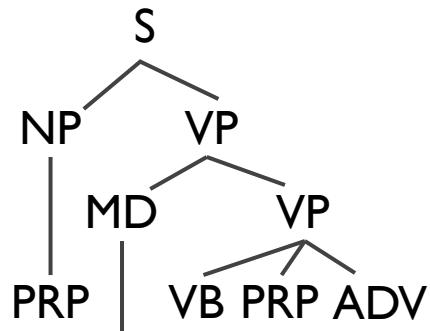
Model of
translation

Target language

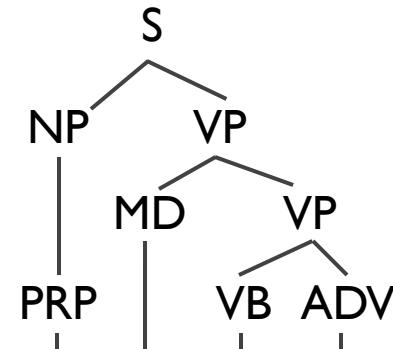
I will do it later

The Syntactic Structure of Natural Language

Parallel corpus gives translation examples



I will do it gladly



You will see later

Yo lo haré de muy buen grado

Después lo verás

Machine translation system:

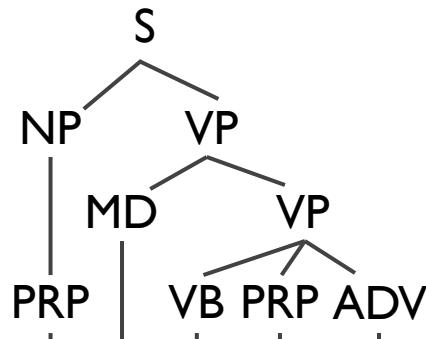
Yo lo haré después

Model of
translation

I will do it later

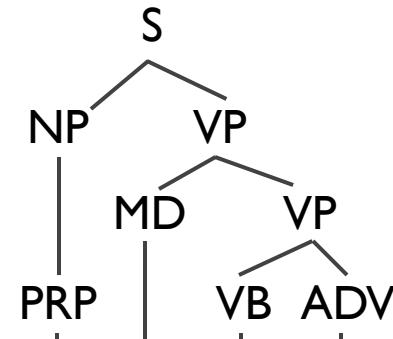
The Syntactic Structure of Natural Language

Parallel corpus gives translation examples



I will do it gladly

Yo lo haré de muy buen grado



You will see later

Después lo verás

Machine translation system:

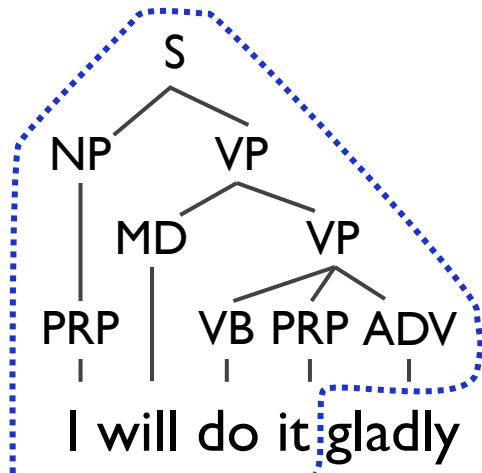
Yo lo haré después

Model of
translation

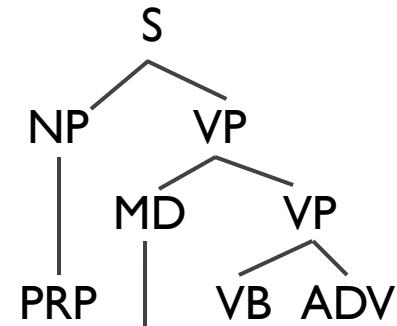
I will do it later

The Syntactic Structure of Natural Language

Parallel corpus gives translation examples



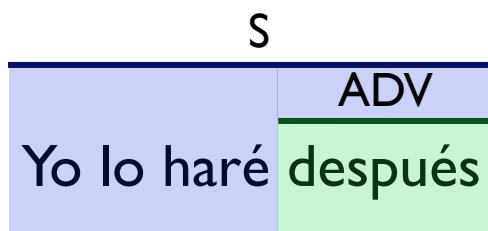
Yo lo haré de muy buen grado



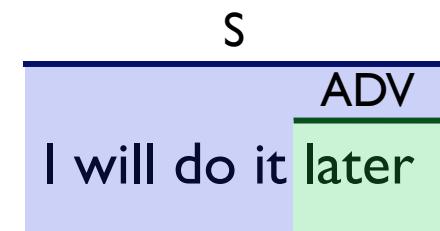
You will see later

Después lo verás

Machine translation system:

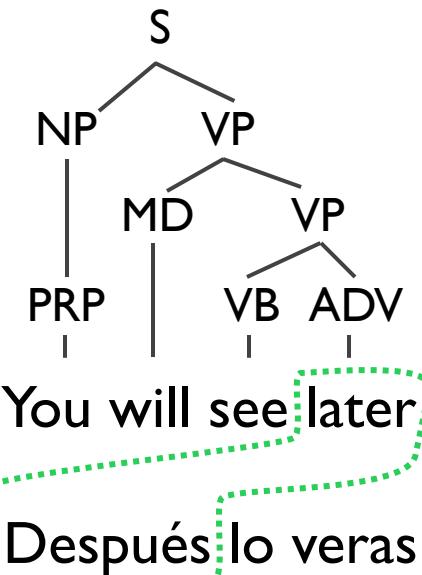
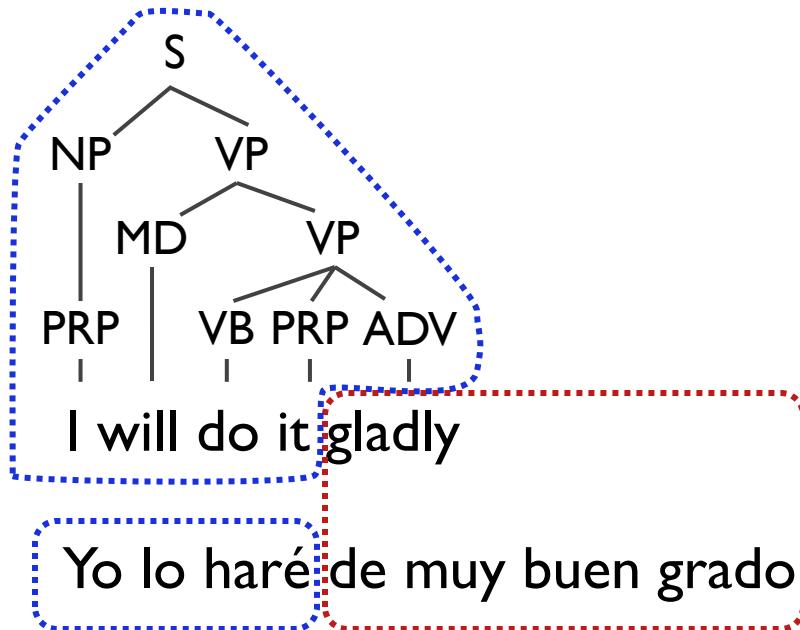


Model of
translation

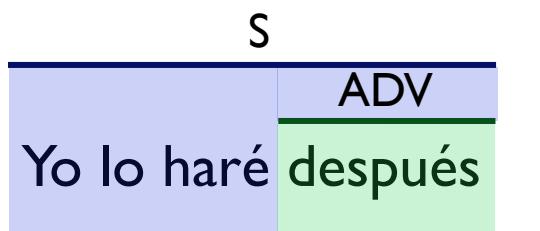


The Syntactic Structure of Natural Language

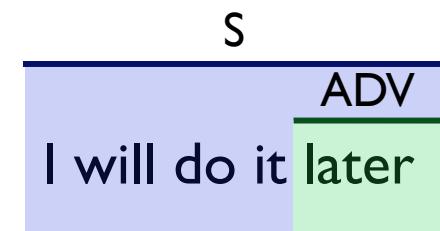
Parallel corpus gives translation examples



Machine translation system:



Model of
translation



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

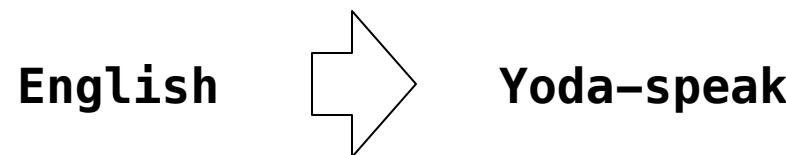
English

A Translation System in 20 Minutes

Context-free grammars as a model of language generation

Large-scale linguistic annotations

Tree transformations

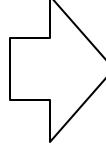


A Translation System in 20 Minutes

Context-free grammars as a model of language generation

Large-scale linguistic annotations

Tree transformations

English  Yoda-speak

Help you, I can!
Yes! Mm!



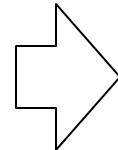
A Translation System in 20 Minutes

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"

$S \rightarrow NP\ VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB\ PRP$

A Context-Free Grammar Describes Generation

"Grammar"

S

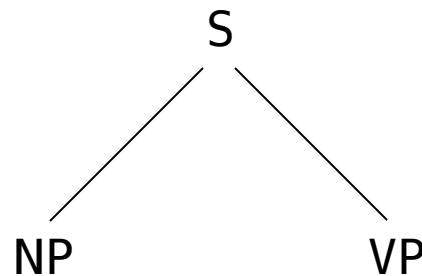
S → NP VP

NP → PRP

VP → VB

VP → VB PRP

A Context-Free Grammar Describes Generation



"Grammar"

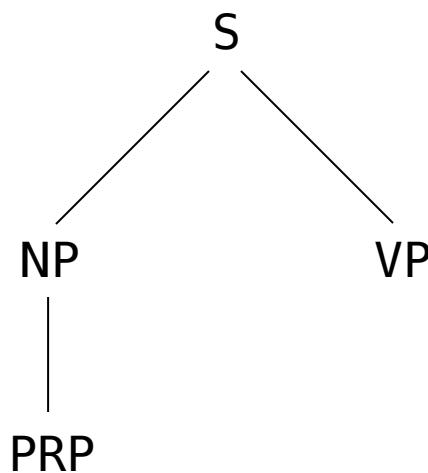
$S \rightarrow NP\ VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB\ PRP$

A Context-Free Grammar Describes Generation



"Grammar"

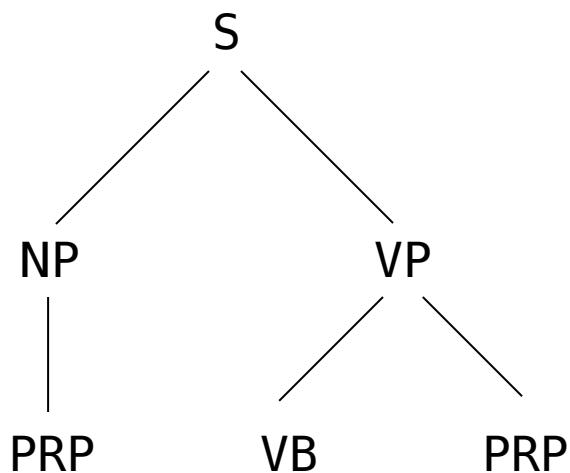
$S \rightarrow NP\ VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB\ PRP$

A Context-Free Grammar Describes Generation



"Grammar"

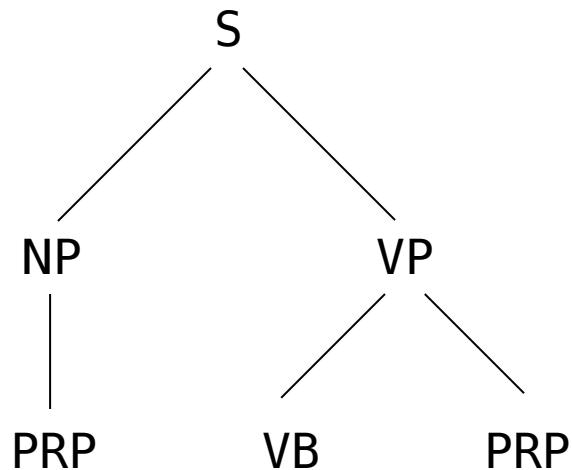
$S \rightarrow NP \ VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB \ PRP$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP\ VP$

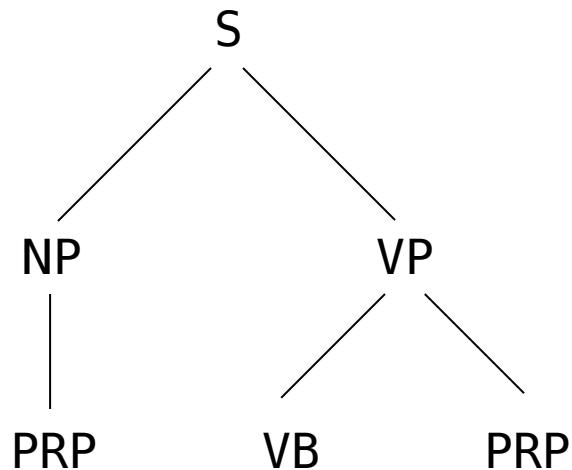
$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB\ PRP$

"Lexicon"

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP\ VP$

$NP \rightarrow PRP$

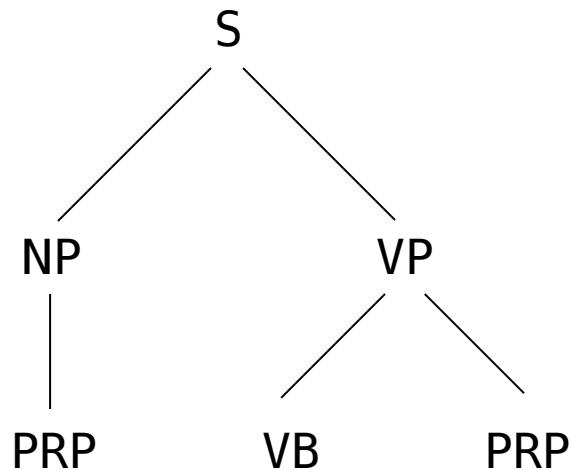
$VP \rightarrow VB$

$VP \rightarrow VB\ PRP$

"Lexicon"

$PRP \rightarrow I$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP\ VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

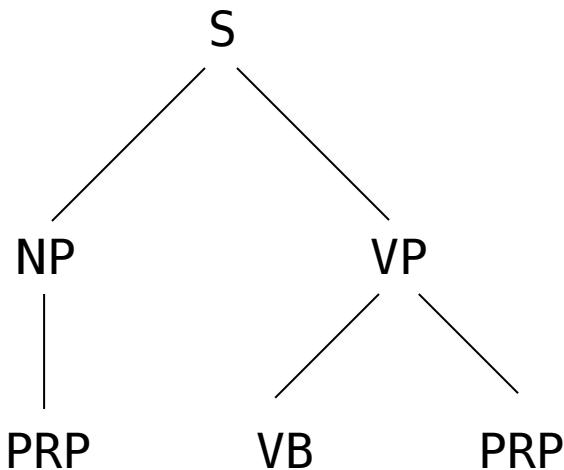
$VP \rightarrow VB\ PRP$

"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"

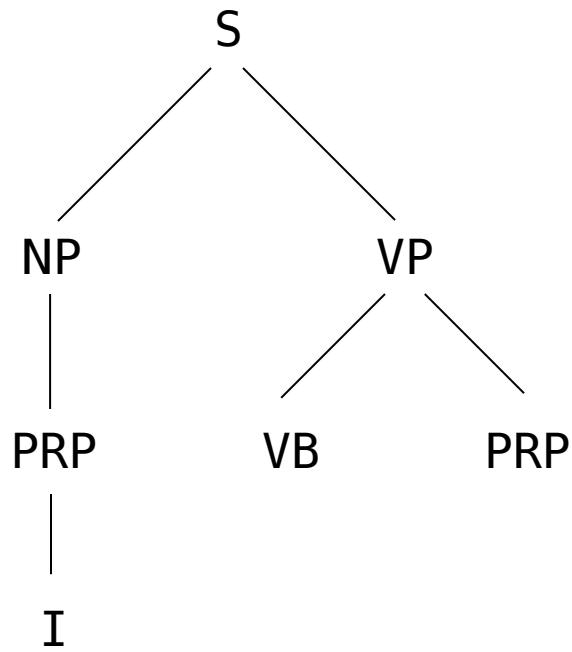
$PRP \rightarrow I$

$PRP \rightarrow you$

$VB \rightarrow know$

$VB \rightarrow help$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP\ VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB\ PRP$

"Lexicon"

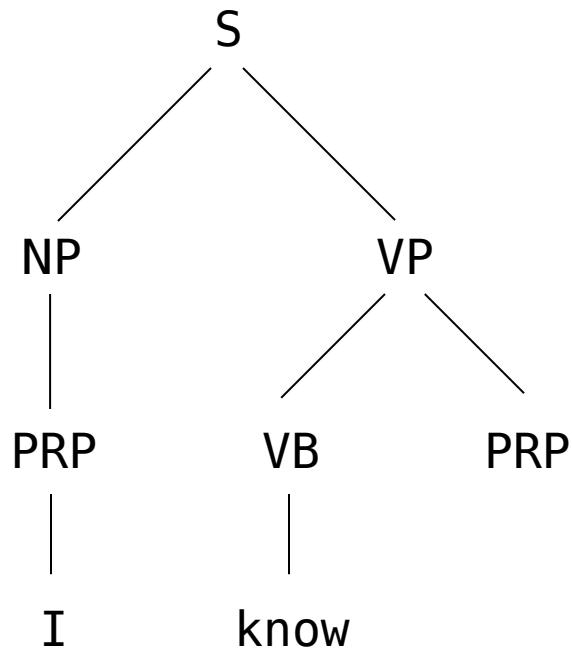
$PRP \rightarrow I$

$PRP \rightarrow you$

$VB \rightarrow know$

$VB \rightarrow help$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP \ VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB \ PRP$

"Lexicon"

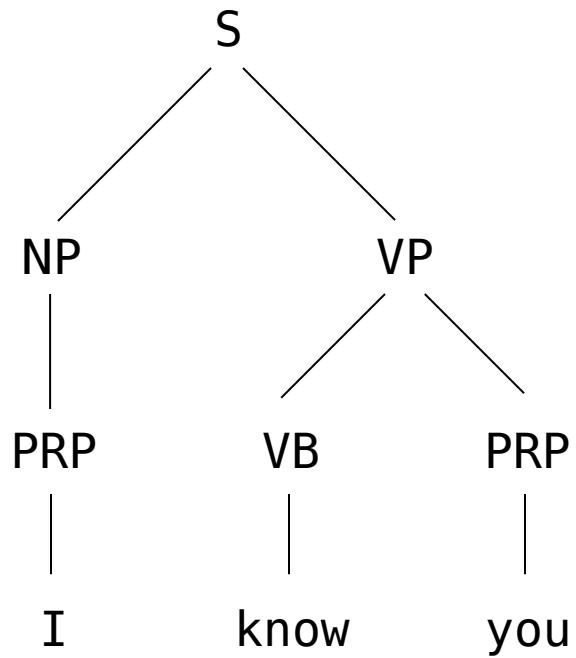
$PRP \rightarrow I$

$PRP \rightarrow you$

$VB \rightarrow know$

$VB \rightarrow help$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP \ VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB \ PRP$

"Lexicon"

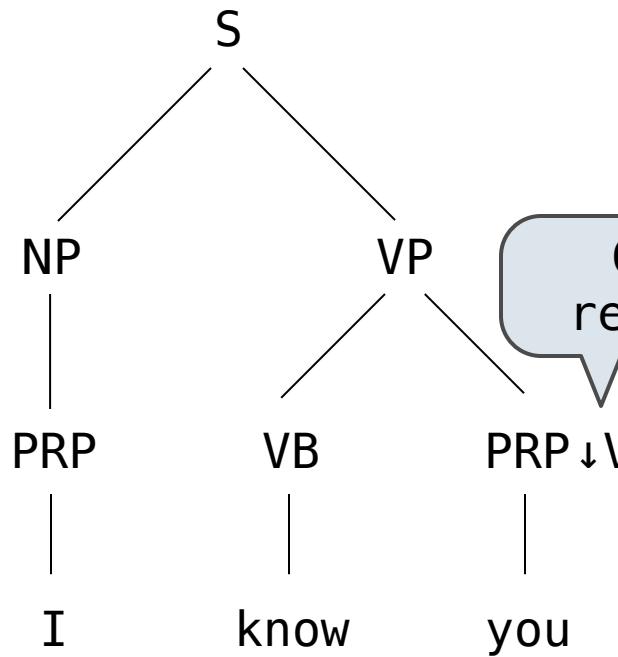
$PRP \rightarrow I$

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A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP \ VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB \ PRP$

"Lexicon"

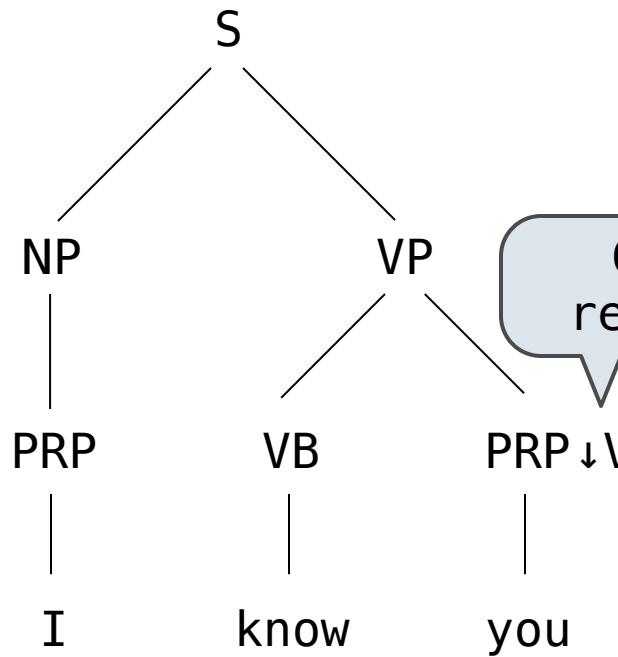
$PRP \rightarrow I$

$PRP \rightarrow you$

$VB \rightarrow know$

$VB \rightarrow help$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP \ VP$

$NP \rightarrow PRP \downarrow NP$

$VP \rightarrow VB$

$VP \rightarrow VB \ PRP$

"Lexicon"

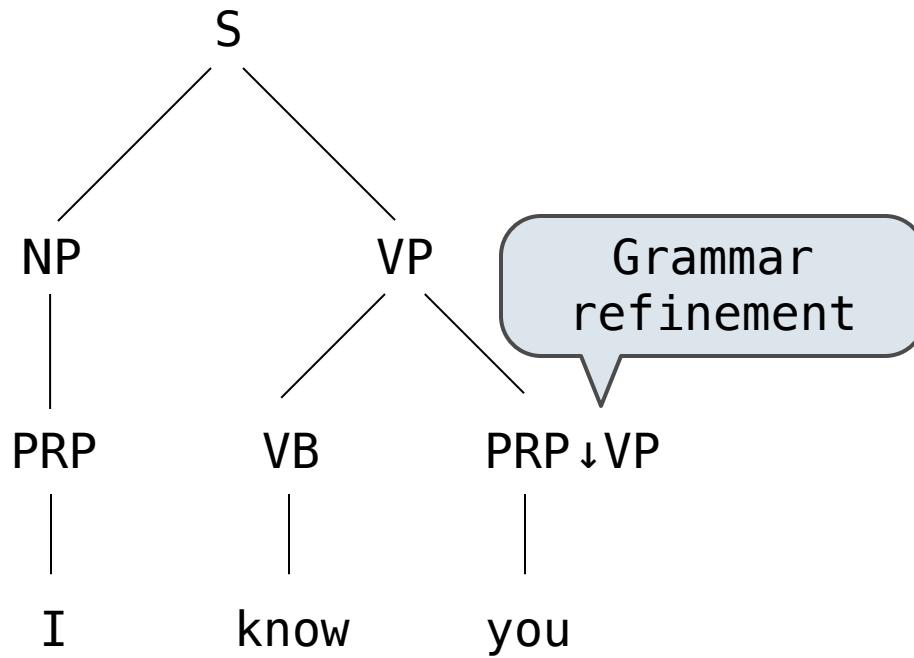
$PRP \rightarrow I$

$PRP \rightarrow you$

$VB \rightarrow know$

$VB \rightarrow help$

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"

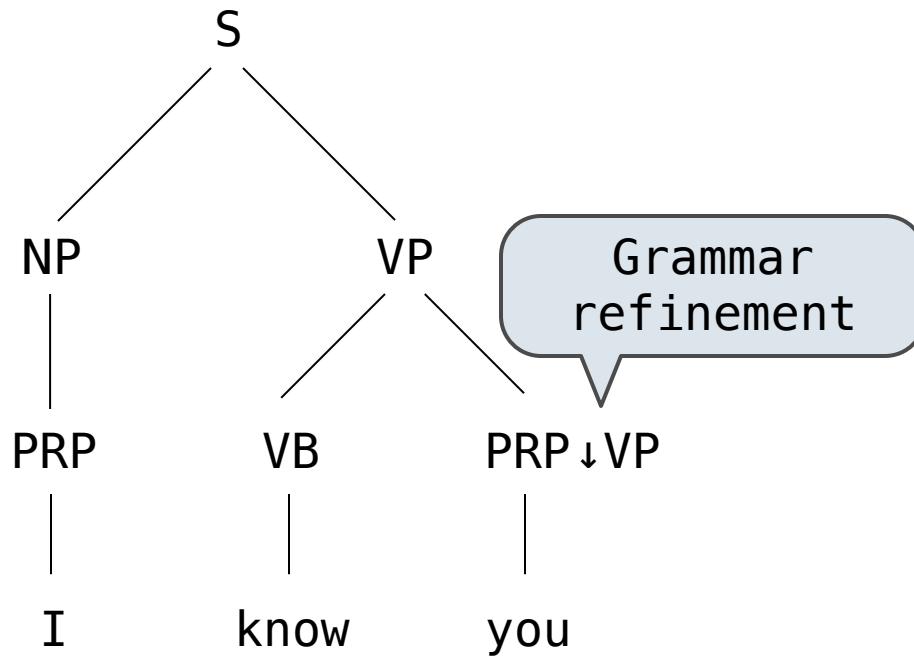
$PRP \rightarrow I$

$PRP \rightarrow you$

$VB \rightarrow know$

$VB \rightarrow help$

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"

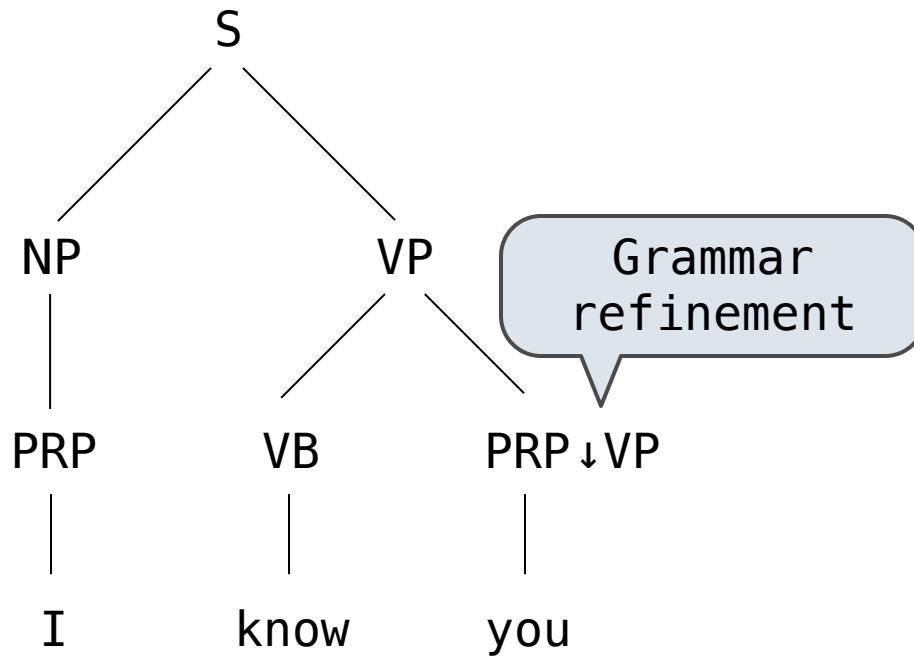
$$PRP \downarrow NP \rightarrow I$$

$$PRP \rightarrow you$$

$$VB \rightarrow know$$

$$VB \rightarrow help$$

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"

$$PRP \downarrow NP \rightarrow I$$

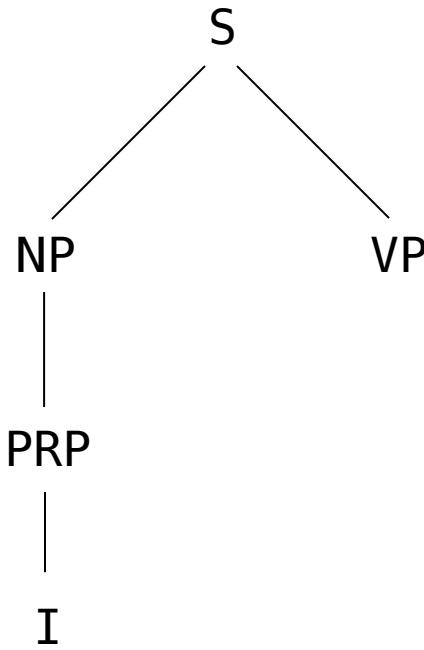
$$PRP \rightarrow you$$

$$VB \rightarrow know$$

$$VB \rightarrow help$$

$$PRP \downarrow VP \rightarrow me$$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP \ VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB \ PRP$

"Lexicon"

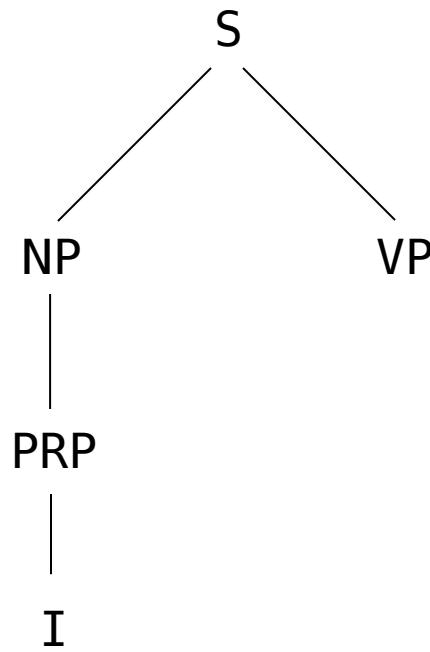
$PRP \rightarrow I$

$PRP \rightarrow you$

$VB \rightarrow know$

$VB \rightarrow help$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP\ VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB\ PRP$

$VP \rightarrow MD\ VP$

"Lexicon"

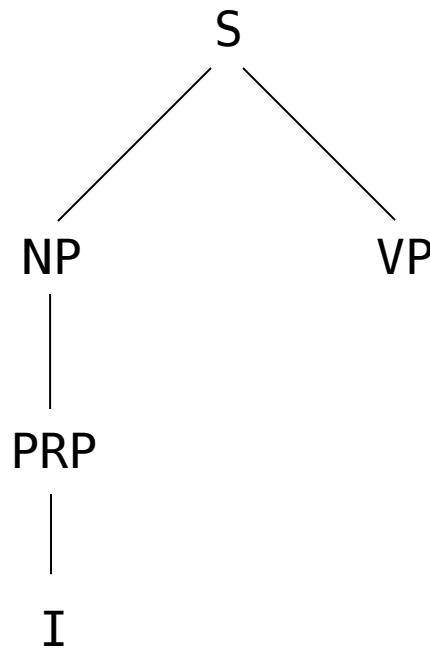
$PRP \rightarrow I$

$PRP \rightarrow you$

$VB \rightarrow know$

$VB \rightarrow help$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP\ VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB\ PRP$

$VP \rightarrow MD\ VP$

"Lexicon"

$PRP \rightarrow I$

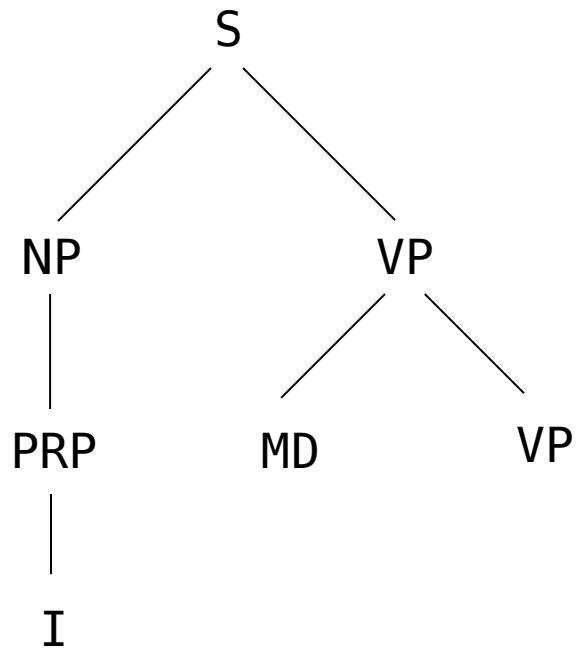
$PRP \rightarrow you$

$VB \rightarrow know$

$VB \rightarrow help$

$MD \rightarrow can$

A Context-Free Grammar Describes Generation



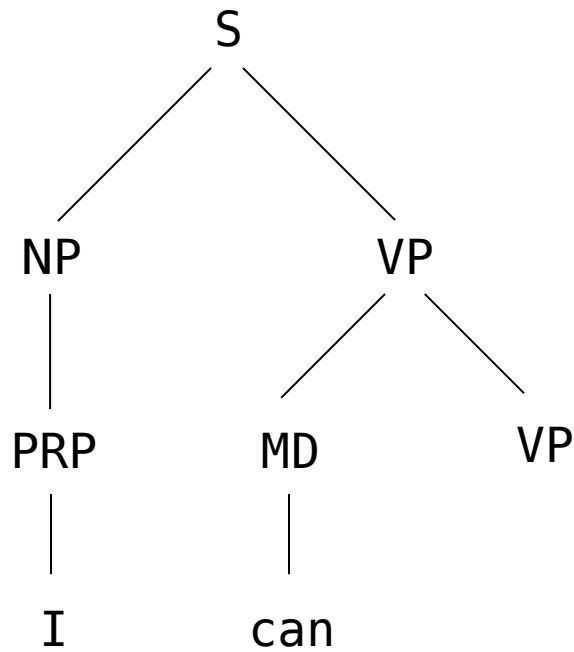
"Grammar"

$S \rightarrow NP\ VP$
 $NP \rightarrow PRP$
 $VP \rightarrow VB$
 $VP \rightarrow VB\ PRP$
 $VP \rightarrow MD\ VP$

"Lexicon"

$PRP \rightarrow I$
 $PRP \rightarrow you$
 $VB \rightarrow know$
 $VB \rightarrow help$
 $MD \rightarrow can$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP \ VP$

$NP \rightarrow PRP$

$VP \rightarrow VB$

$VP \rightarrow VB \ PRP$

$VP \rightarrow MD \ VP$

"Lexicon"

$PRP \rightarrow I$

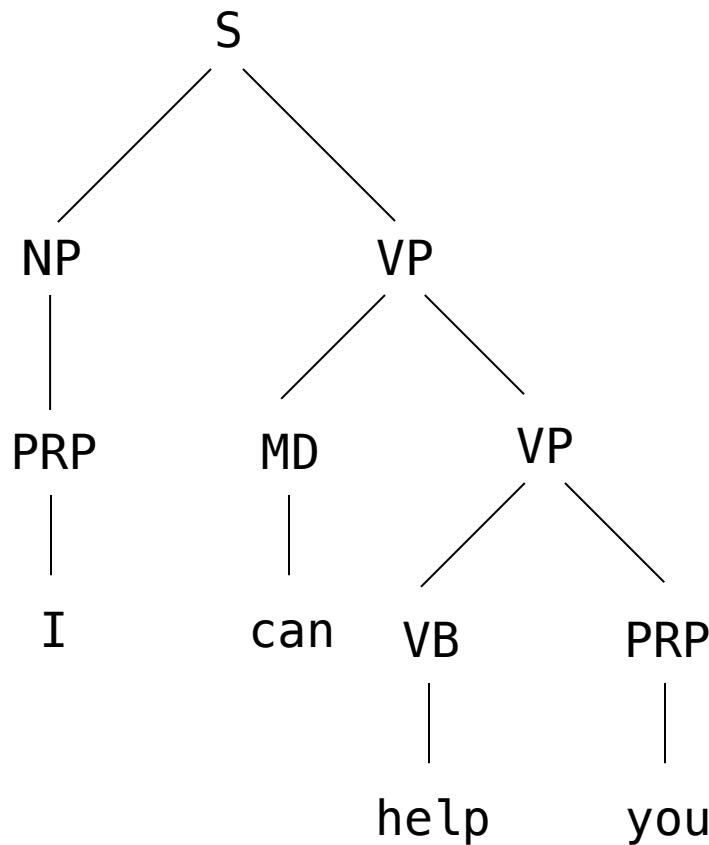
$PRP \rightarrow you$

$VB \rightarrow know$

$VB \rightarrow help$

$MD \rightarrow can$

A Context-Free Grammar Describes Generation



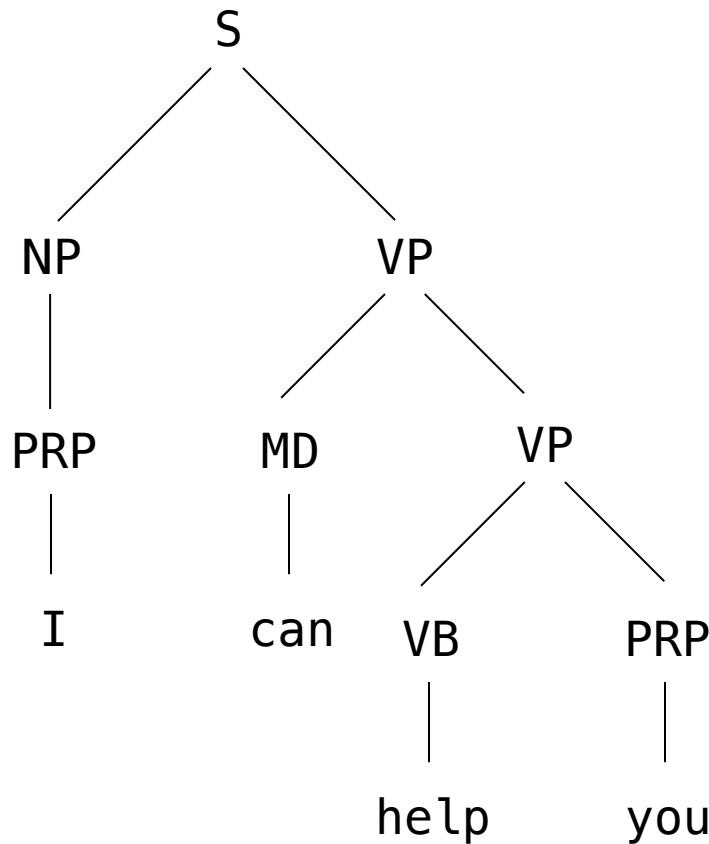
"Grammar"

$S \rightarrow NP\ VP$
 $NP \rightarrow PRP$
 $VP \rightarrow VB$
 $VP \rightarrow VB\ PRP$
 $VP \rightarrow MD\ VP$

"Lexicon"

$PRP \rightarrow I$
 $PRP \rightarrow you$
 $VB \rightarrow know$
 $VB \rightarrow help$
 $MD \rightarrow can$

A Context-Free Grammar Describes Generation



"Grammar"

$S \rightarrow NP\ VP$
 $NP \rightarrow PRP$
 $VP \rightarrow VB$
 $VP \rightarrow VB\ PRP$
 $VP \rightarrow MD\ VP$

"Lexicon"

$PRP \rightarrow I$
 $PRP \rightarrow you$
 $VB \rightarrow know$
 $VB \rightarrow help$

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

$MD \rightarrow can$

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

i know you

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

► i know you ■

VB → help

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)

S

"Grammar"

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

Left corners

"Lexicon"

PRP



► i know you ■

PRP → I

PRP → you

VB → know

VB → help

Left-Corner Parsing Builds Trees For Sentences

parse_next(S, 1)

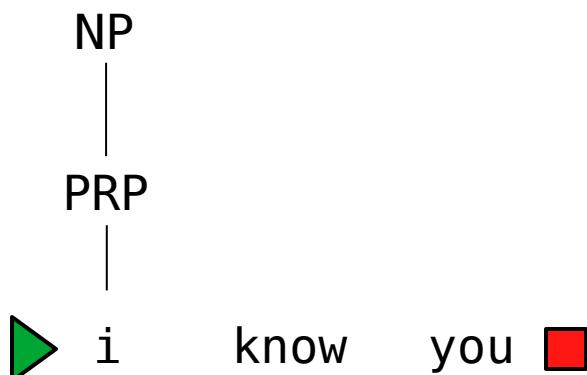
complete(S, (PRP i), 1)

S

"Grammar"

$S \rightarrow NP\ VP$
 $NP \rightarrow PRP$
 $VP \rightarrow VB$
 $VP \rightarrow VB\ PRP$

Left corners



"Lexicon"

$PRP \rightarrow I$
 $PRP \rightarrow you$
 $VB \rightarrow know$
 $VB \rightarrow help$

Left-Corner Parsing Builds Trees For Sentences

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

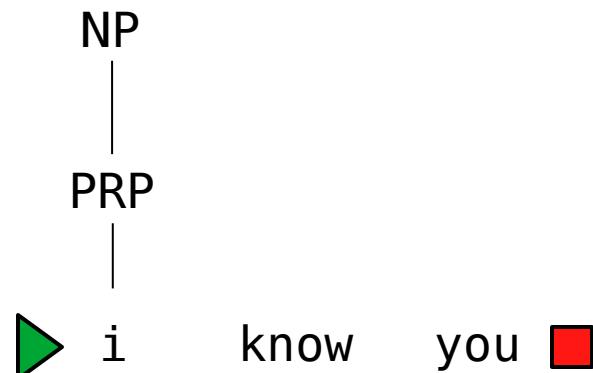
```
  complete(S, (PRP i), 1)  
  complete(S, (NP (PRP i)), 1)
```

S

"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)
```

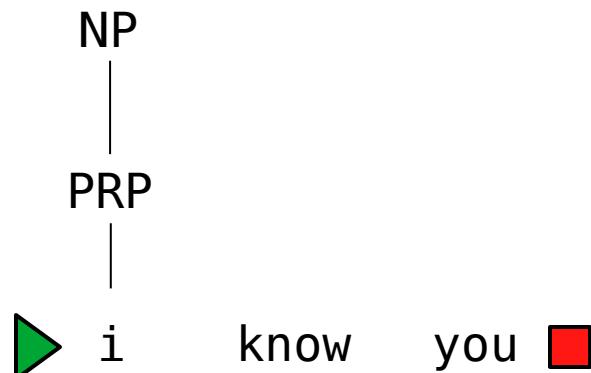
```
parse_next(VP, 2)
```

S

"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)
```

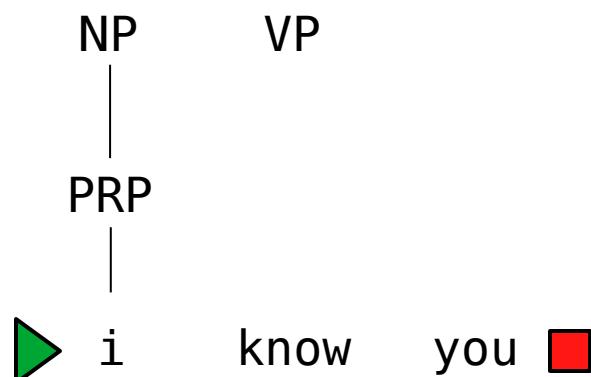
```
parse_next(VP, 2)
```

S

"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)
```

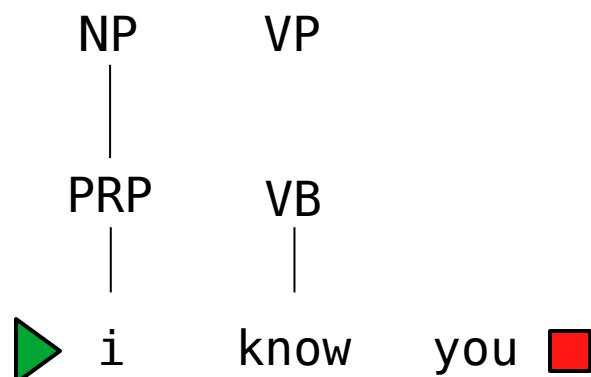
```
parse_next(VP, 2)
```

S

"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

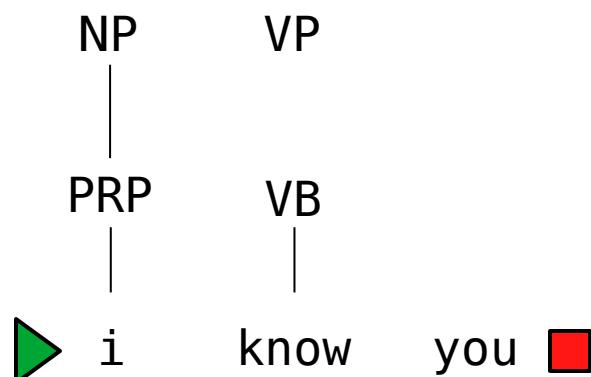
```
parse_next(S, 1)
  complete(S, (PRP i), 1)
  complete(S, (NP (PRP i)), 1)
  parse_next(VP, 2)
    complete(VP, (VB know), 2)
```

S

"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

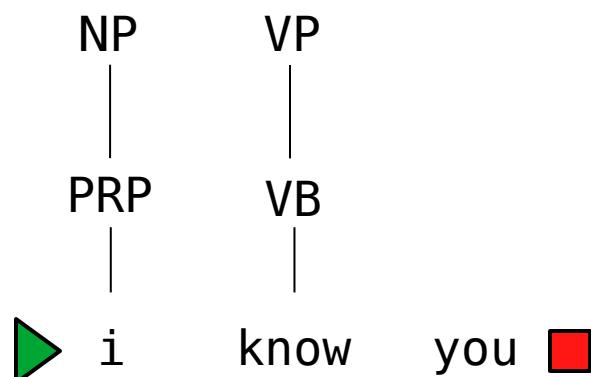
```
parse_next(S, 1)
  complete(S, (PRP i), 1)
  complete(S, (NP (PRP i)), 1)
  parse_next(VP, 2)
    complete(VP, (VB know), 2)
```

S

"Grammar"

```
S -> NP VP
NP -> PRP
VP -> VB
VP -> VB PRP
```

Left corners



"Lexicon"

```
PRP -> I
PRP -> you
VB -> know
VB -> help
```

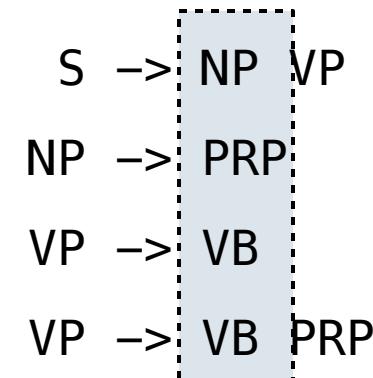
Left-Corner Parsing Builds Trees For Sentences

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

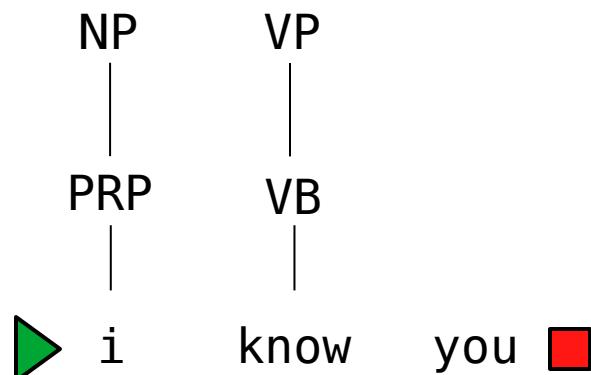
    parse_next(VP, 2)
        complete(VP, (VB know), 2)
        complete(VP, (VP (VB know)), 2)
```

S

"Grammar"



Left corners



"Lexicon"

```
PRP -> I
PRP -> you
VB -> know
VB -> help
```

Left-Corner Parsing Builds Trees For Sentences

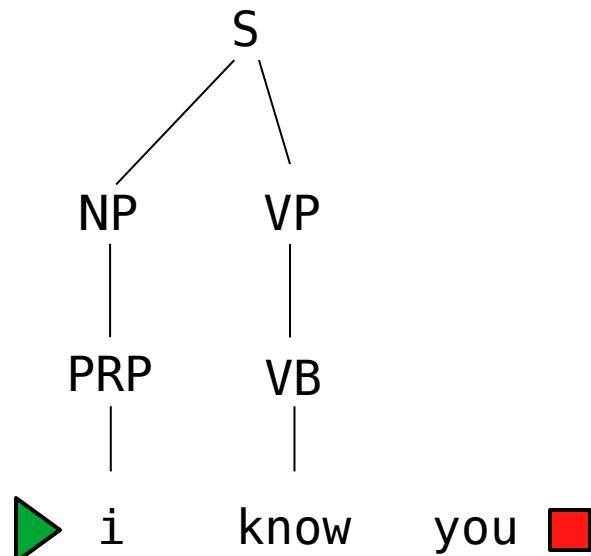
```
parse_next(S, 1)
  complete(S, (PRP i), 1)
  complete(S, (NP (PRP i)), 1)

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

"Grammar"

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

Left corners



"Lexicon"

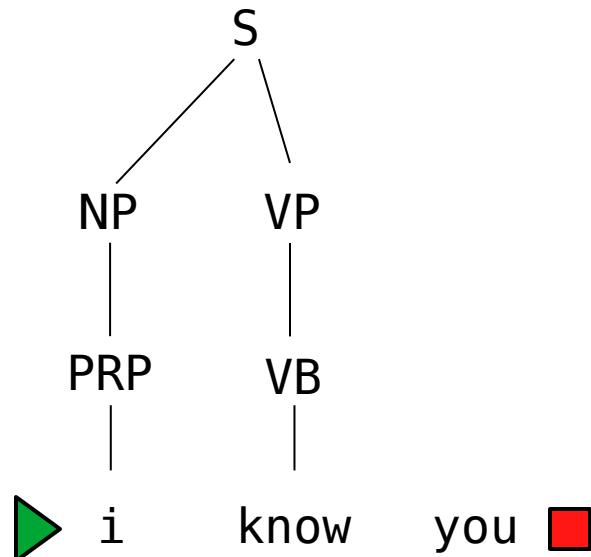
PRP → I
PRP → you
VB → know
VB → help

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

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



"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

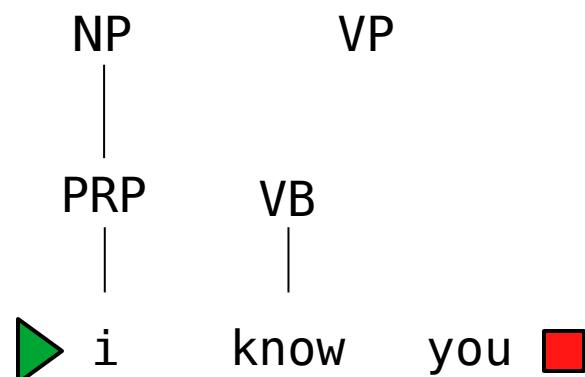
```
parse_next(S, 1)
  complete(S, (PRP i), 1)
  complete(S, (NP (PRP i)), 1)
  parse_next(VP, 2)
    complete(VP, (VB know), 2)
```

S

"Grammar"

```
S -> NP VP
NP -> PRP
VP -> VB
VP -> VB PRP
```

Left corners



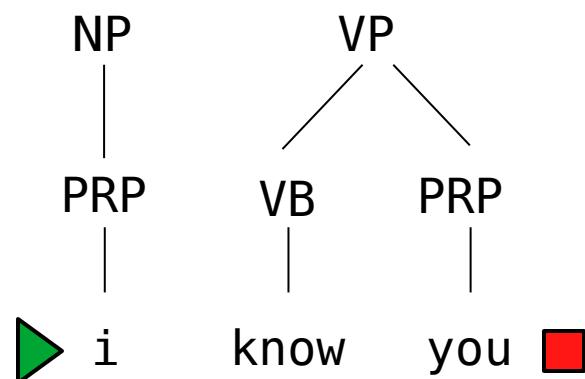
"Lexicon"

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

S



"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)
```

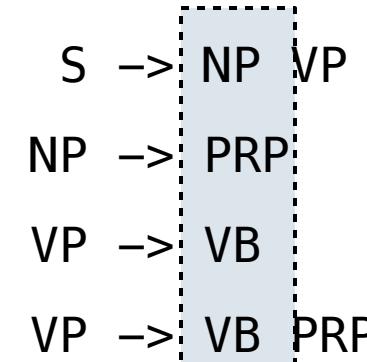
```
parse_next(VP, 2)
```

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

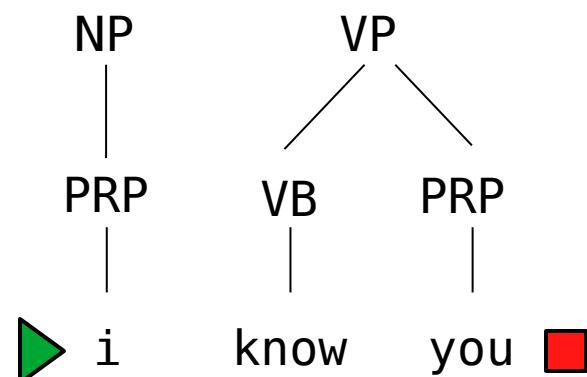
```
  complete(VP, (VP (VB know) (PRP you)), 2)
```

S

"Grammar"



Left corners



"Lexicon"

PRP -> I

PRP -> you

VB -> know

VB -> help

Left-Corner Parsing Builds Trees For Sentences

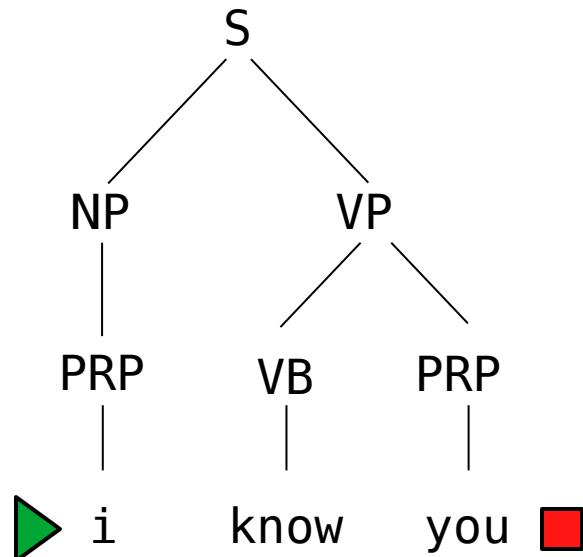
```
parse_next(S, 1)
  complete(S, (PRP i), 1)
  complete(S, (NP (PRP i)), 1)

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

"Grammar"

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

Left corners



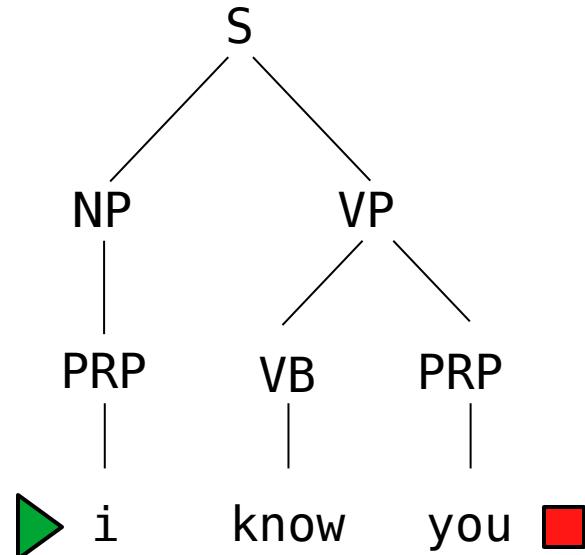
"Lexicon"

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)
    complete(VP, (VB know), 2)
    complete(VP, (VP (VB know) (PRP you)), 2)
    complete(S, (S ...), 1)
```



"Grammar"

```
S -> NP VP
NP -> PRP
VP -> VB
VP -> VB PRP
```

Left corners

"Lexicon"

```
PRP -> I
PRP -> you
VB -> know
VB -> help
```