

61A Guest Lecture: Natural Language Processing

John DeNero

Ambiguity

Syntactic Ambiguity in English

Programs must be written for people to read

Syntactic Ambiguity in English

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¹Preface of **Structure and Interpretation of Computer Programs**
by Harold Abelson and Gerald Sussman with Julie Sussman

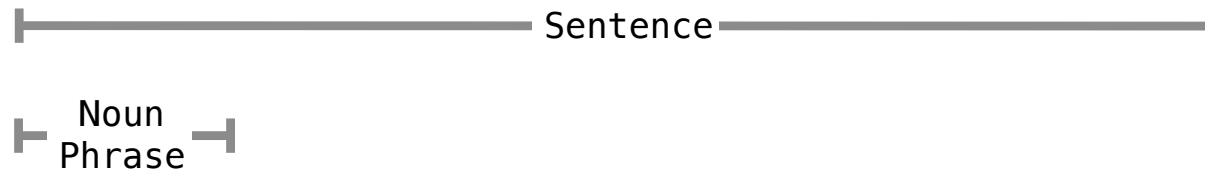
Syntactic Ambiguity in English

|----- Sentence -----|

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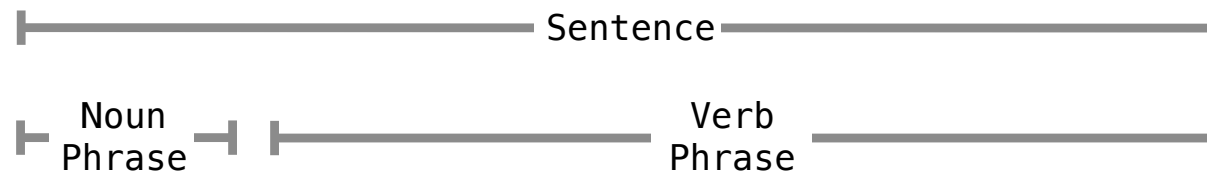
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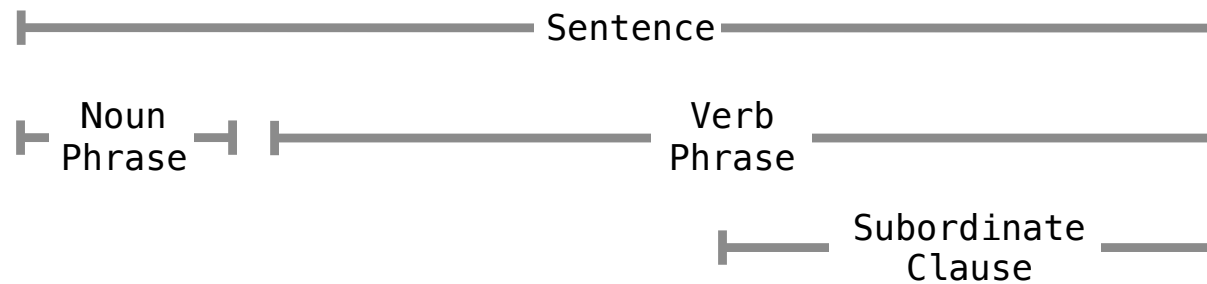
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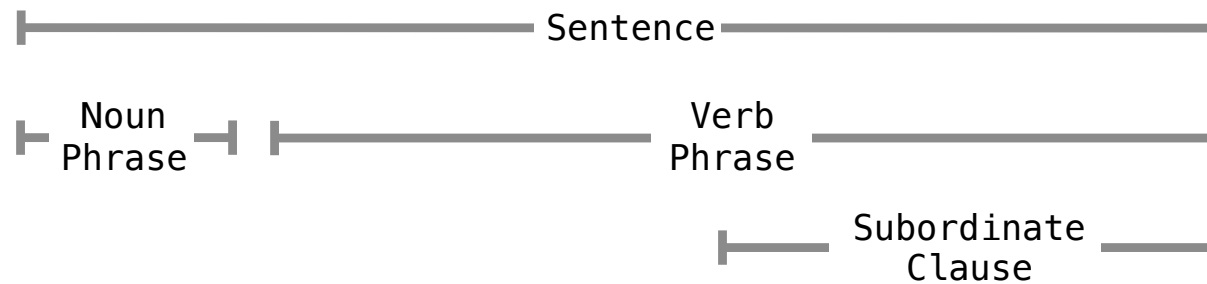
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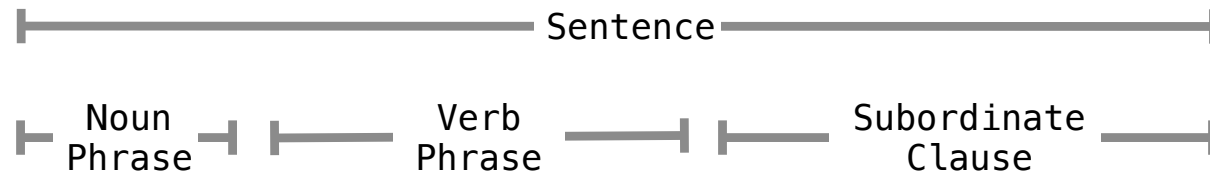


Programs must be written for people to read¹

(People read programs)

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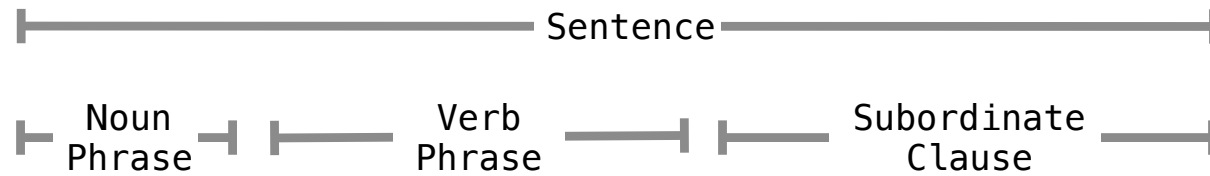
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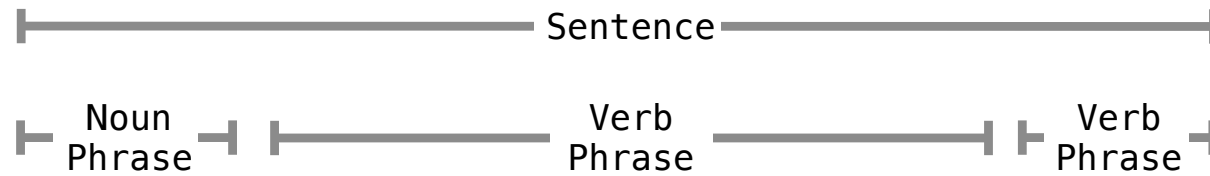


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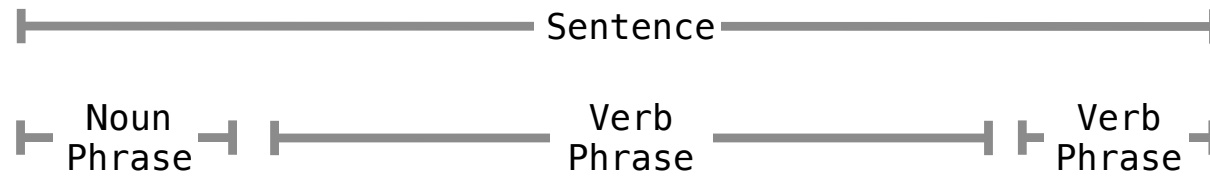
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Syntactic Ambiguity in English



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Syntactic Ambiguity in English

pro•gram (noun)

a series of coded software instructions

pro•gram (verb)

provide a computer with coded instructions

Programs must be written for people to read

must (verb)

be obliged to

must (noun)

dampness or mold

Syntax Trees

Representing Syntactic Structure

Representing Syntactic Structure

COWS

Representing Syntactic Structure

Noun

COWS

Representing Syntactic Structure



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Noun

COWS

Representing Syntactic Structure



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Noun

cows

intimidate

Representing Syntactic Structure



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Noun

cows

Verb

intimidate

Representing Syntactic Structure



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Noun

cows

Verb

intimidate

Noun

cows

Representing Syntactic Structure



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|—— Sentence ——|

Noun

cows

Verb

intimidate

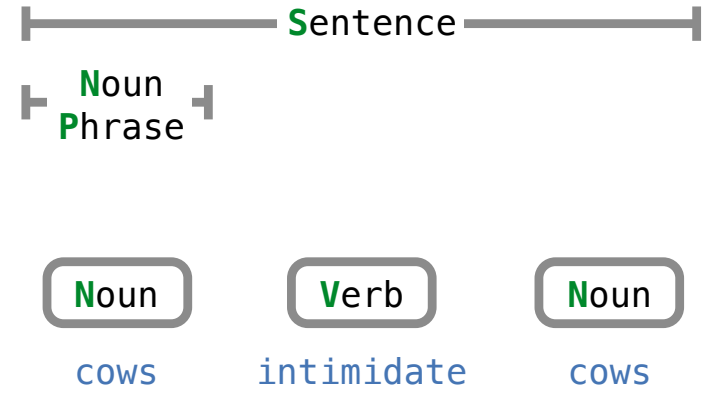
Noun

cows

Representing Syntactic Structure



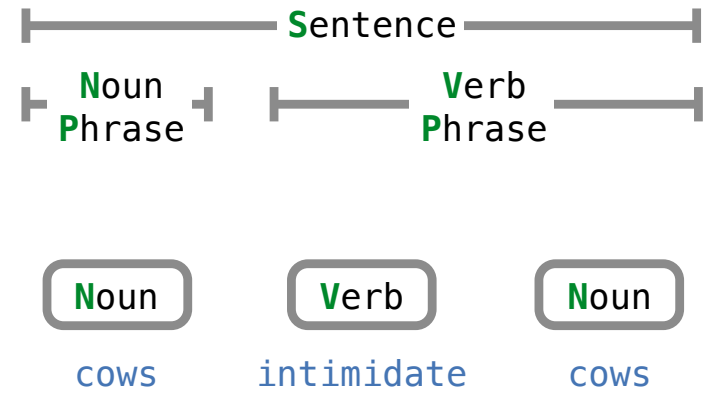
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Representing Syntactic Structure



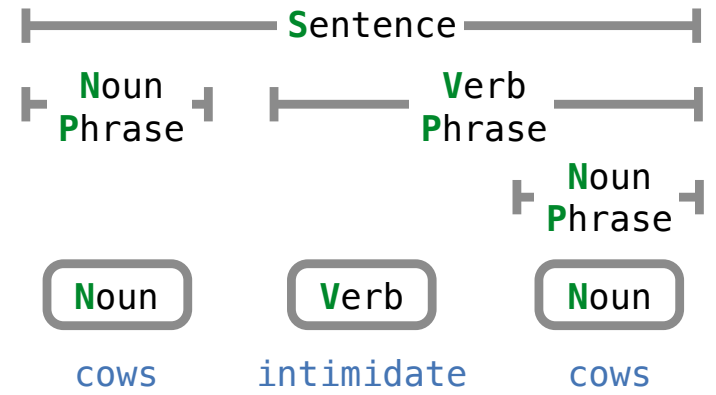
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Representing Syntactic Structure



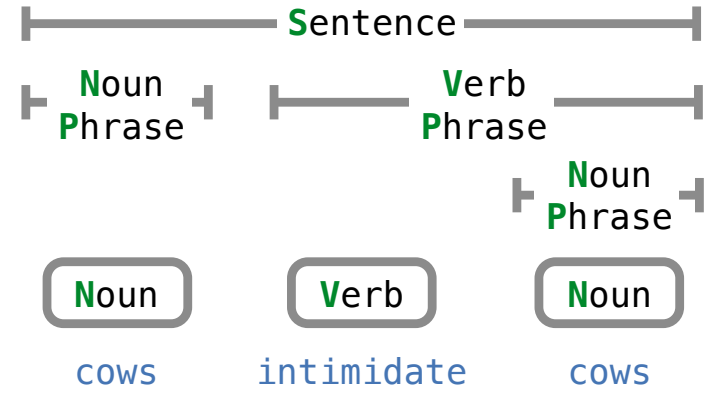
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Representing Syntactic Structure



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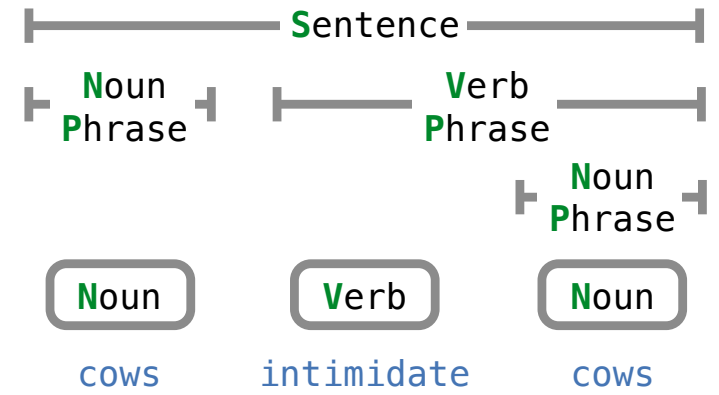


A **Tree** represents a phrase:

Representing Syntactic Structure



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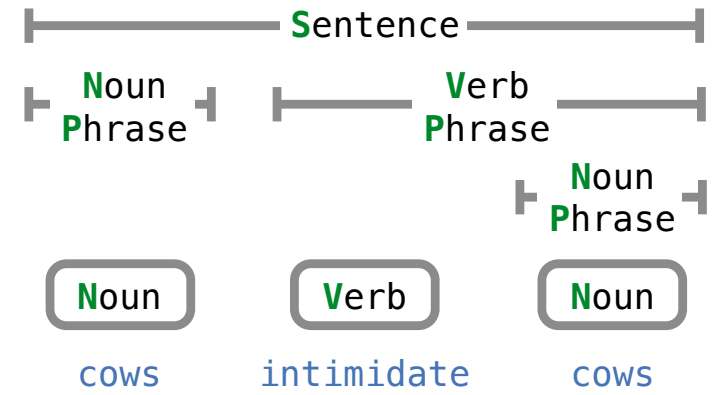
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- **tag** — What kind of phrase (e.g., **S**, **NP**, **VP**)

Representing Syntactic Structure



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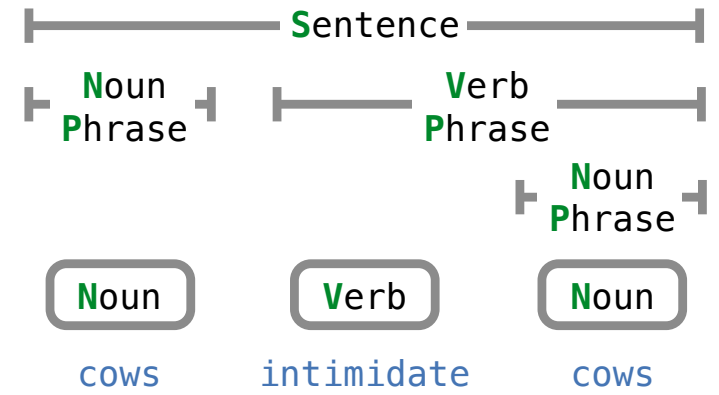
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Representing Syntactic Structure



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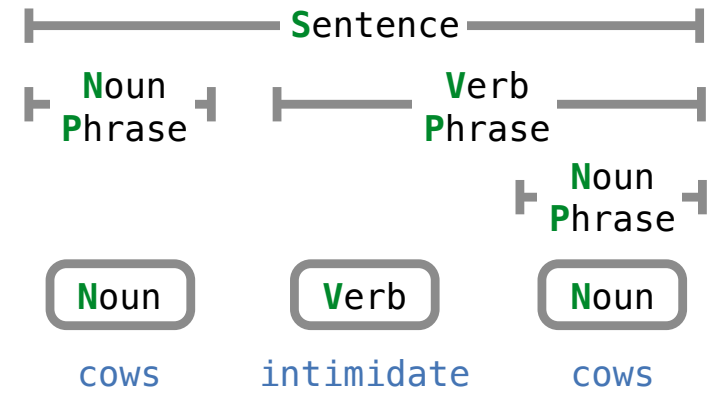
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Representing Syntactic Structure



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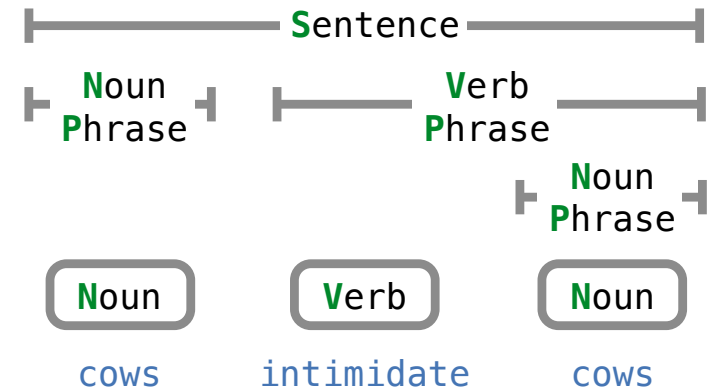
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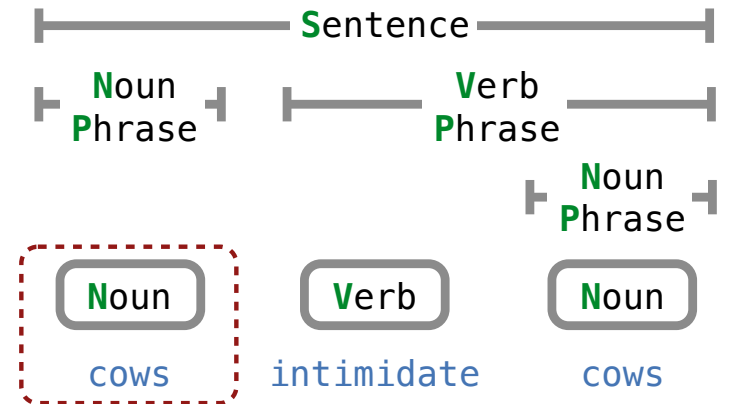
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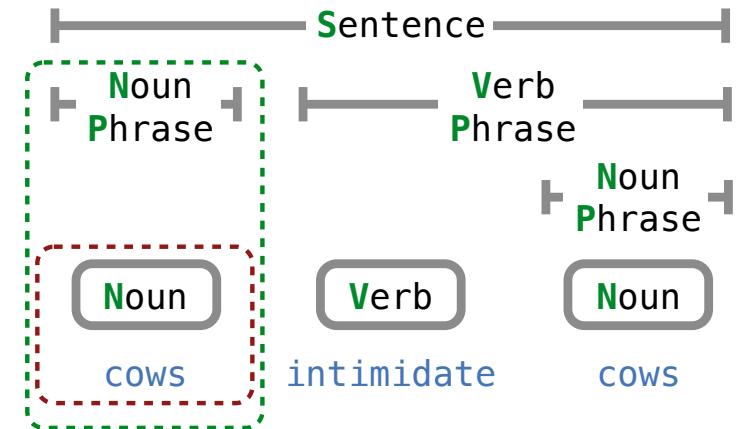
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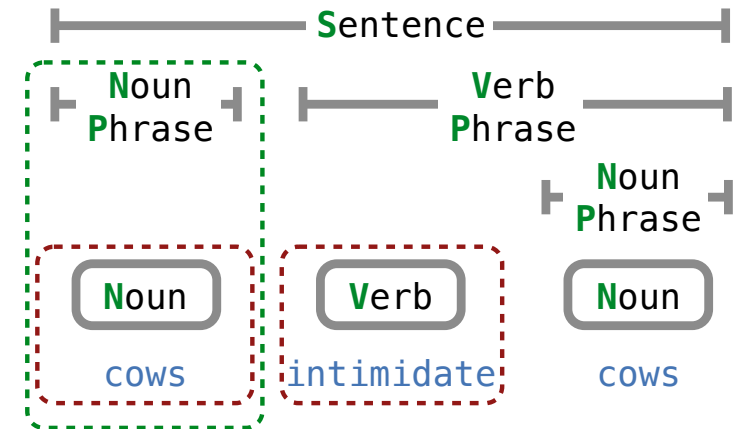
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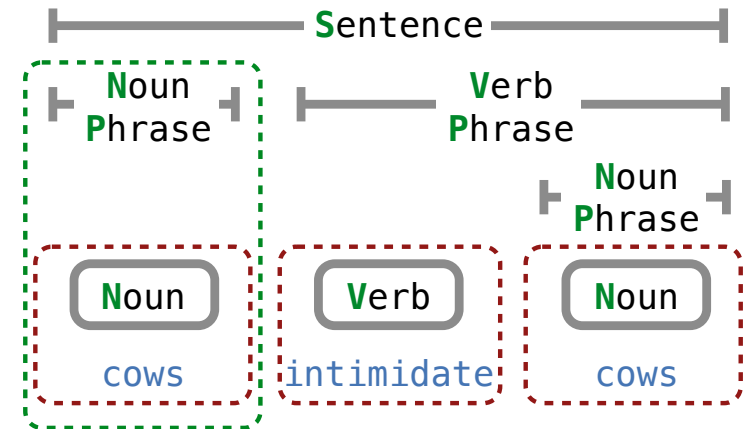
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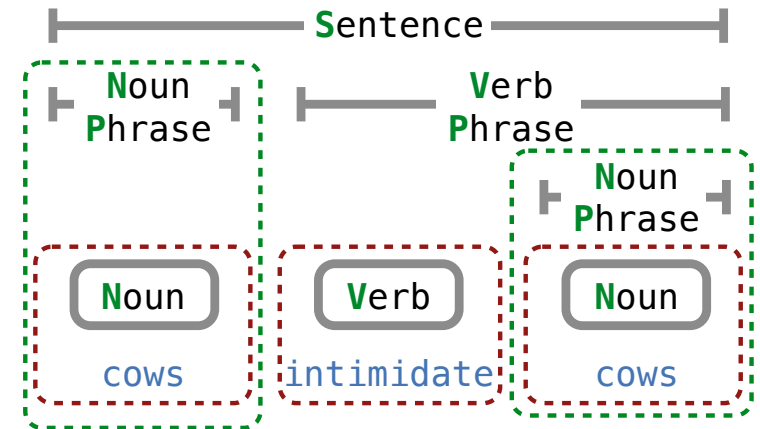
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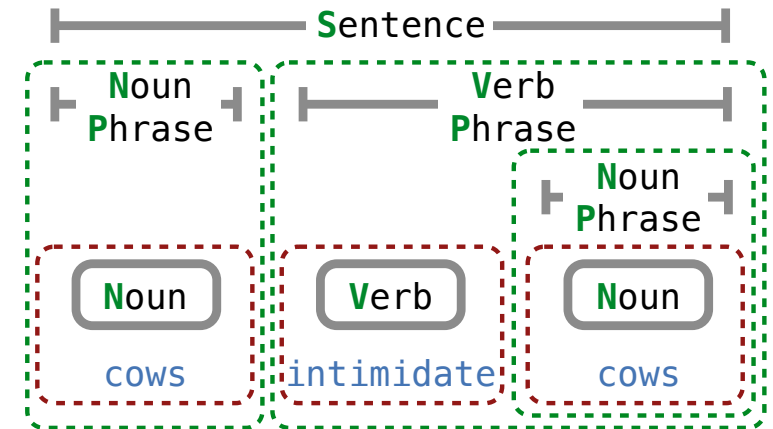
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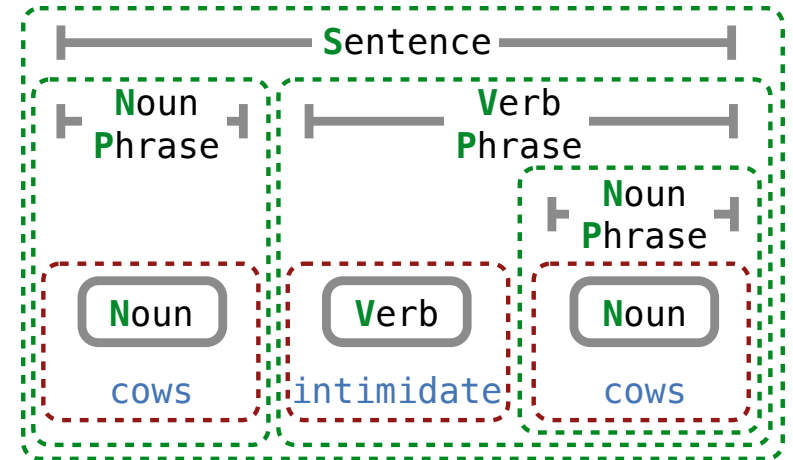
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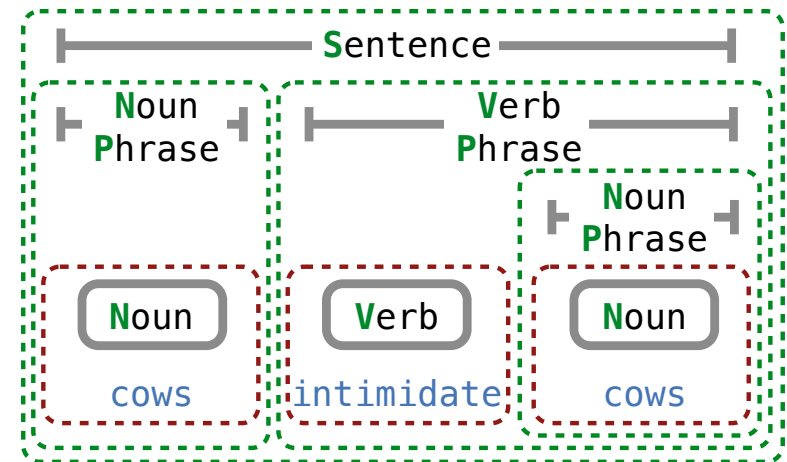
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- **word** -- The word

cows = **Leaf**('N', 'cows')

Representing Syntactic Structure



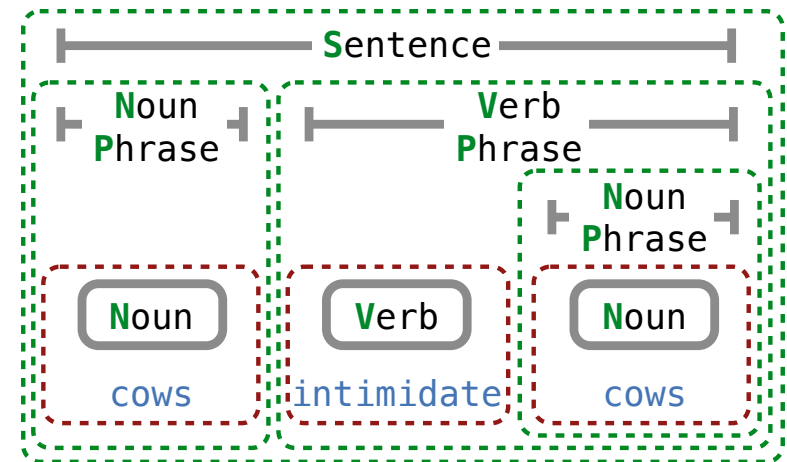
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cows = **Leaf**('N', 'cows')

intimidate = **Leaf**('V', 'intimidate')

Representing Syntactic Structure



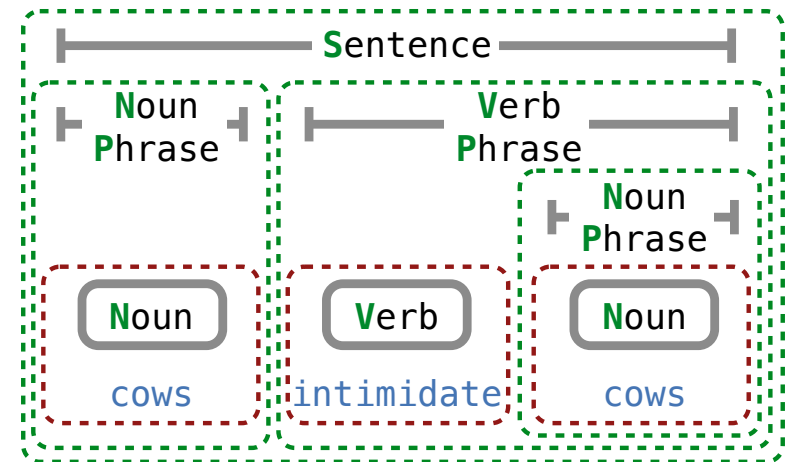
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cows = **Leaf**('N', 'cows')

intimidate = **Leaf**('V', 'intimidate')

S, **NP**, **VP** = 'S', 'NP', 'VP'

Representing Syntactic Structure



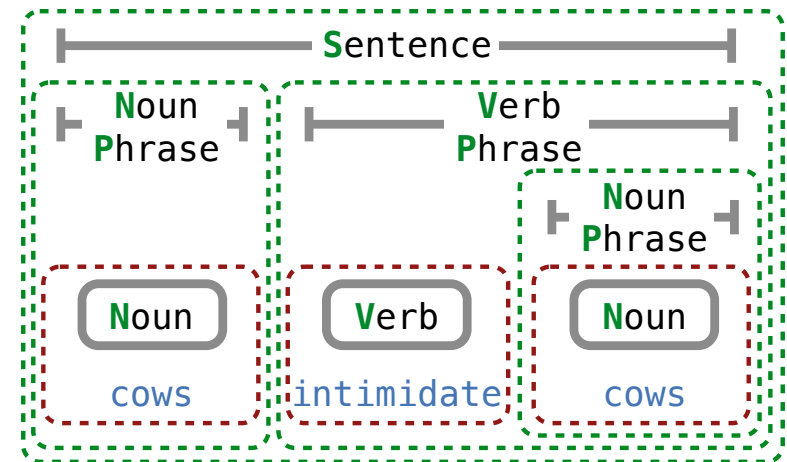
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```
cows = Leaf('N', 'cows')
```

```
intimidate = Leaf('V', 'intimidate')
```

```
S, NP, VP = 'S', 'NP', 'VP'
```

```
Tree(S, [Tree(NP, [cows]),
```

Representing Syntactic Structure



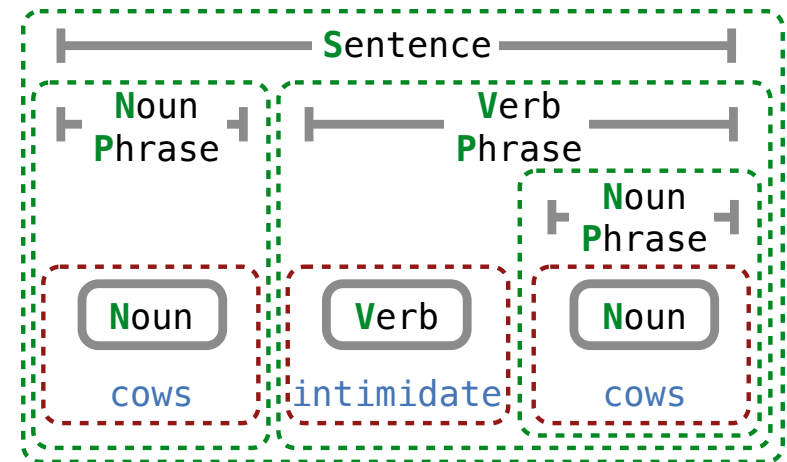
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```

```
intimidate = Leaf('V', 'intimidate')
```

```
S, NP, VP = 'S', 'NP', 'VP'
```

```
Tree(S, [Tree(NP, [cows]),  
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```


Representing Syntactic Structure



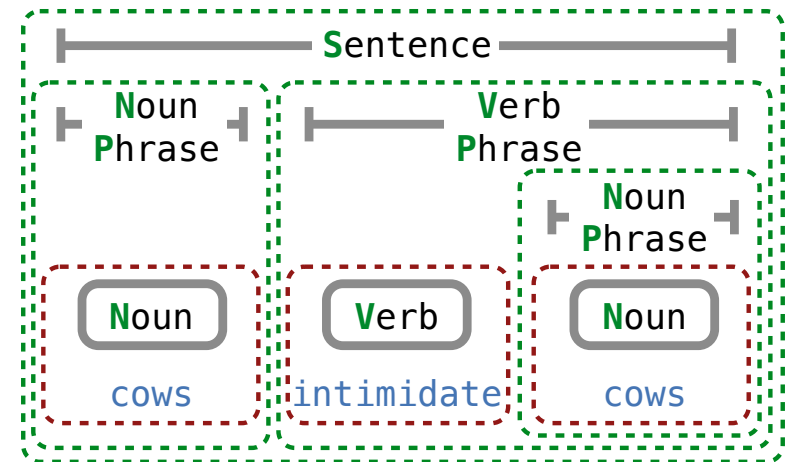
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- **tag** — What kind of word (e.g., **N**, **V**)
- **word** — The word



```
cows = Leaf('N', 'cows')
intimidate = Leaf('V', 'intimidate')
S, NP, VP = 'S', 'NP', 'VP'
Tree(S, [Tree(NP, [cows]),
          Tree(VP, [intimidate,
                    Tree(NP, [cows])])])
```

Representing Syntactic Structure



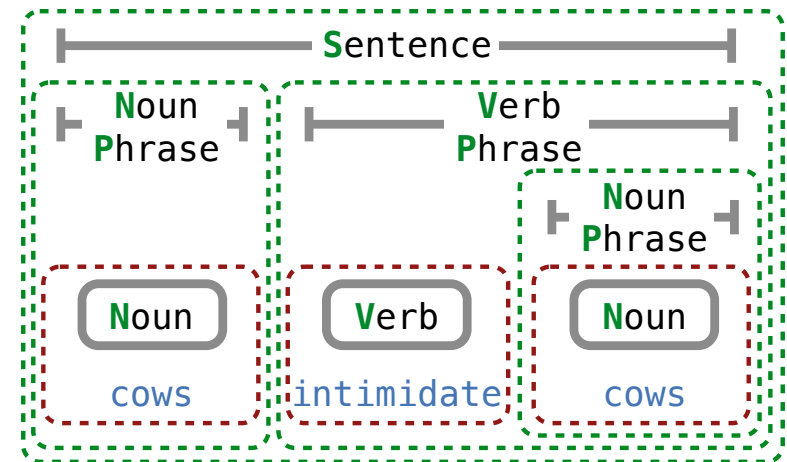
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- **tag** — What kind of word (e.g., **N**, **V**)
- **word** — The word



```
cows = Leaf('N', 'cows')
intimidate = Leaf('V', 'intimidate')
S, NP, VP = 'S', 'NP', 'VP'
Tree(S, [Tree(NP, [cows]),
      Tree(VP, [intimidate,
                  Tree(NP, [cows]))])
```

(Demo)

Grammars

Context-Free Grammar Rules

Context-Free Grammar Rules

A grammar rule describes how a tag can be expanded as a sequence of tags or words

Context-Free Grammar Rules

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S → **NP VP**

Context-Free Grammar Rules

A grammar rule describes how a tag can be expanded as a sequence of tags or words



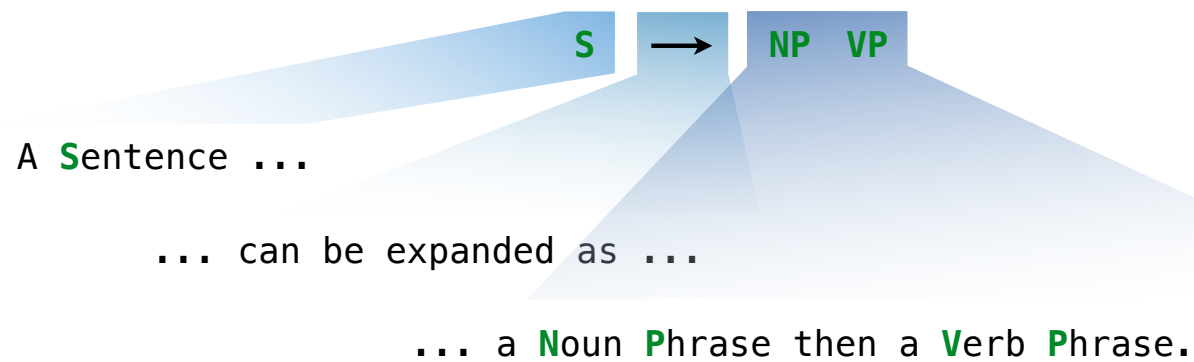
Context-Free Grammar Rules

A grammar rule describes how a tag can be expanded as a sequence of tags or words



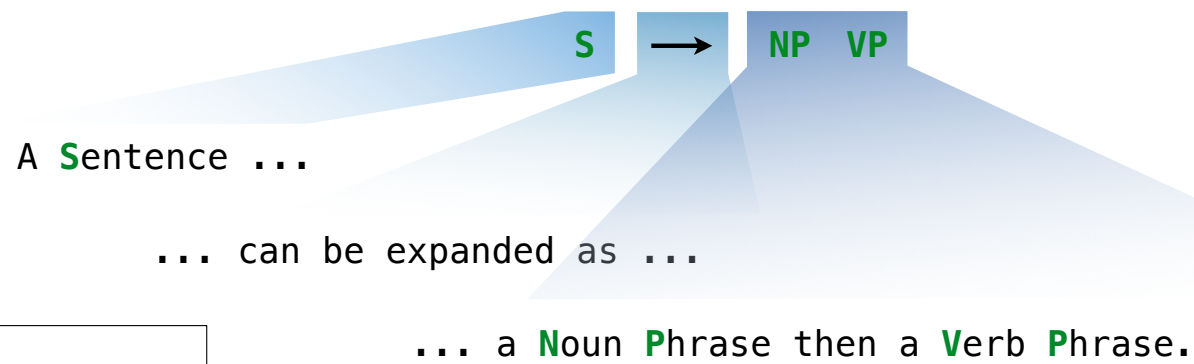
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Context-Free Grammar Rules

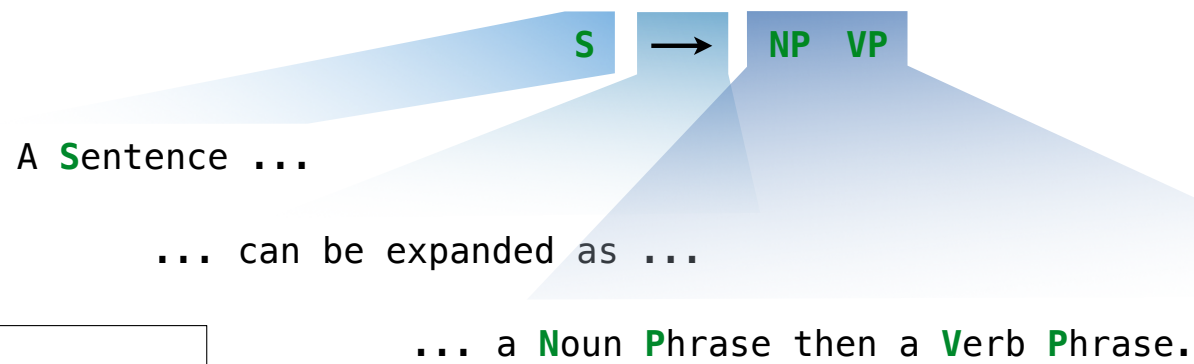
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Grammar

Context-Free Grammar Rules

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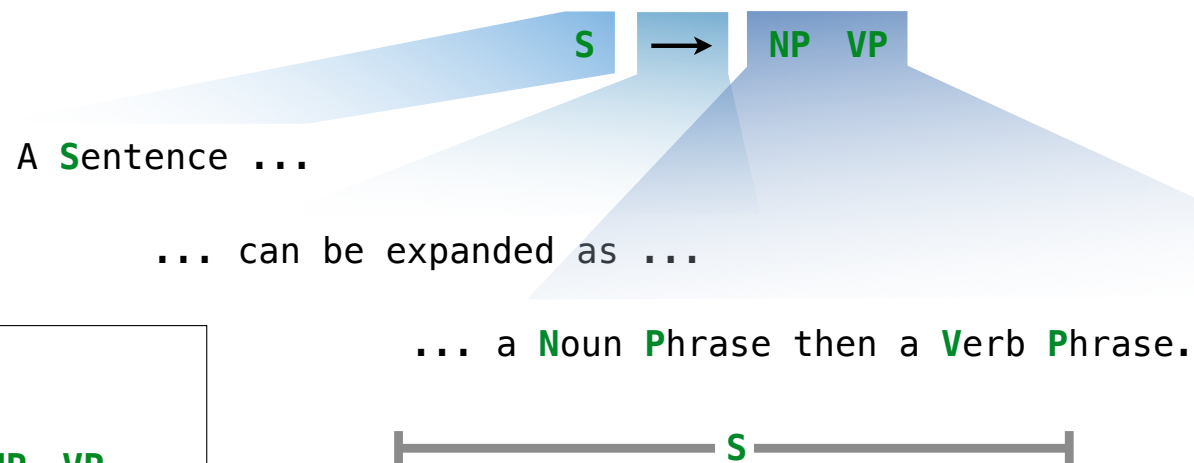


Grammar

S \rightarrow **NP VP**

Context-Free Grammar Rules

A grammar rule describes how a tag can be expanded as a sequence of tags or words

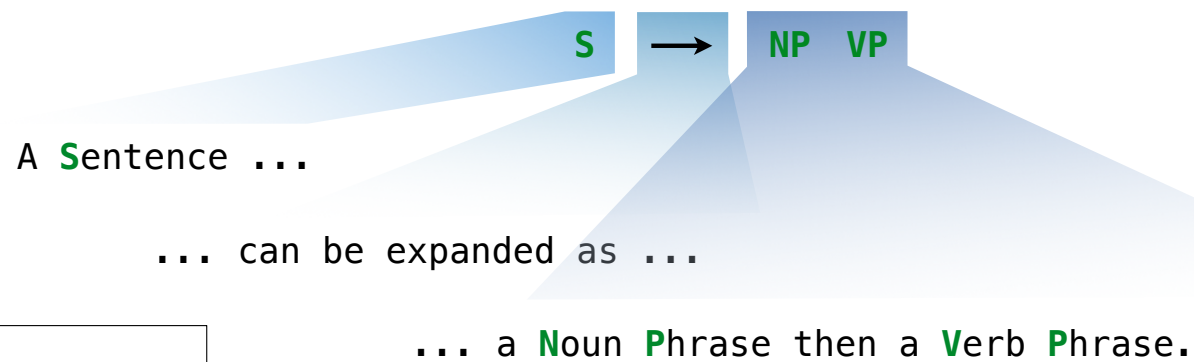


Grammar

S \rightarrow **NP VP**

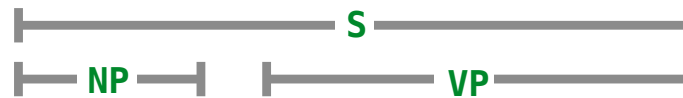
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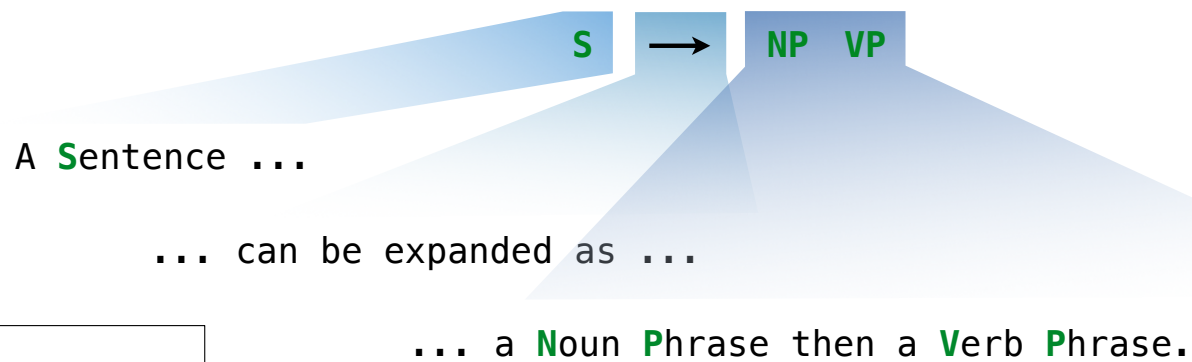
Grammar

S \rightarrow **NP** **VP**



Context-Free Grammar Rules

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Grammar

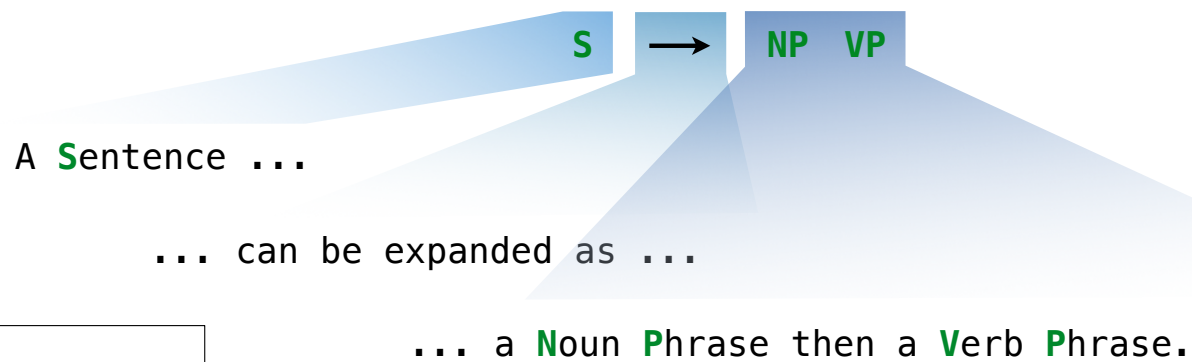
S \rightarrow **NP** **VP**

NP \rightarrow **N**



Context-Free Grammar Rules

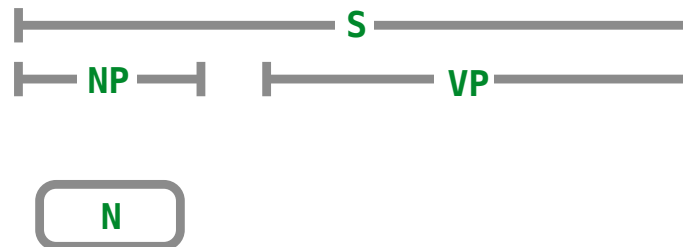
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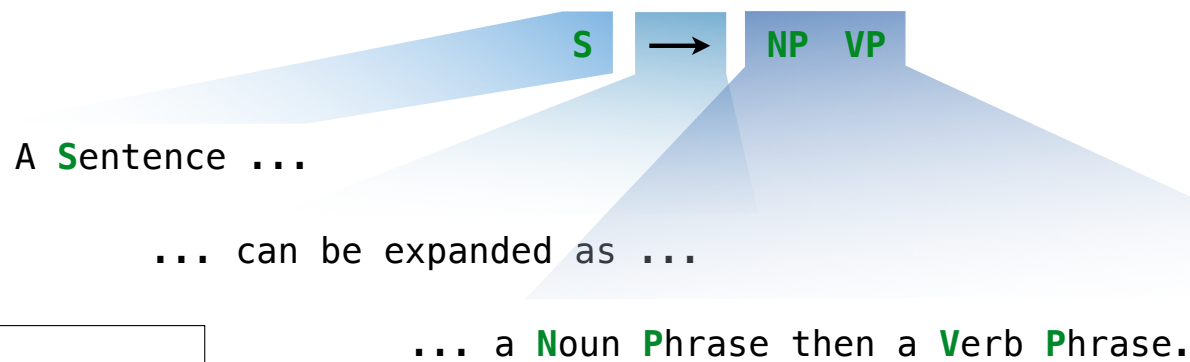
S → **NP VP**

NP → **N**



Context-Free Grammar Rules

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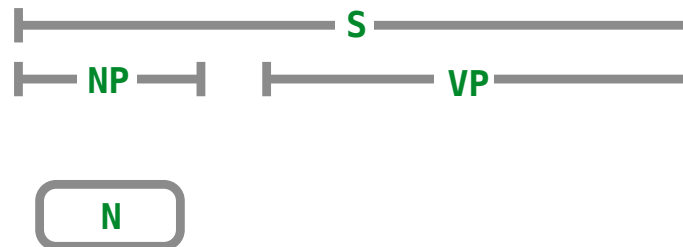


Grammar

S → **NP VP**

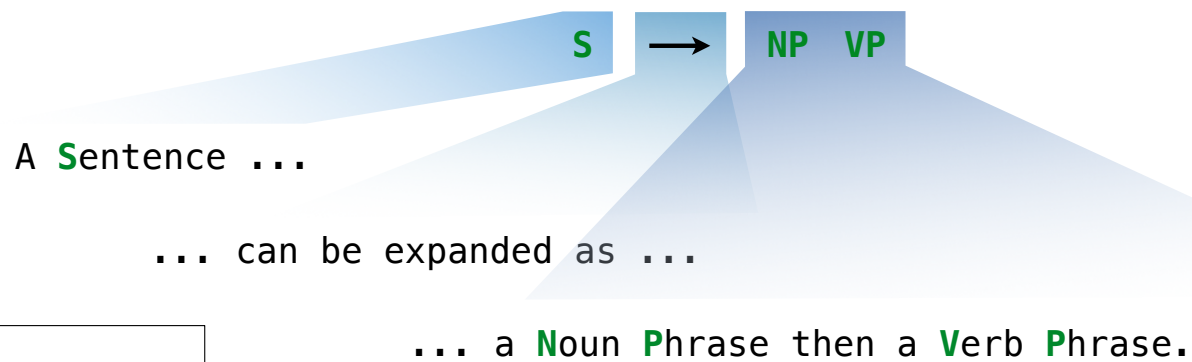
NP → **N**

N → COWS



Context-Free Grammar Rules

A grammar rule describes how a tag can be expanded as a sequence of tags or words

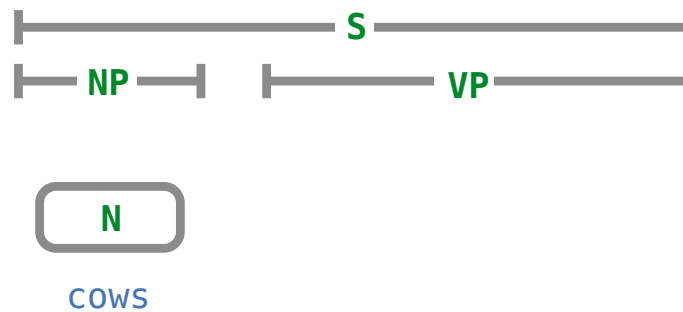


Grammar

S → **NP VP**

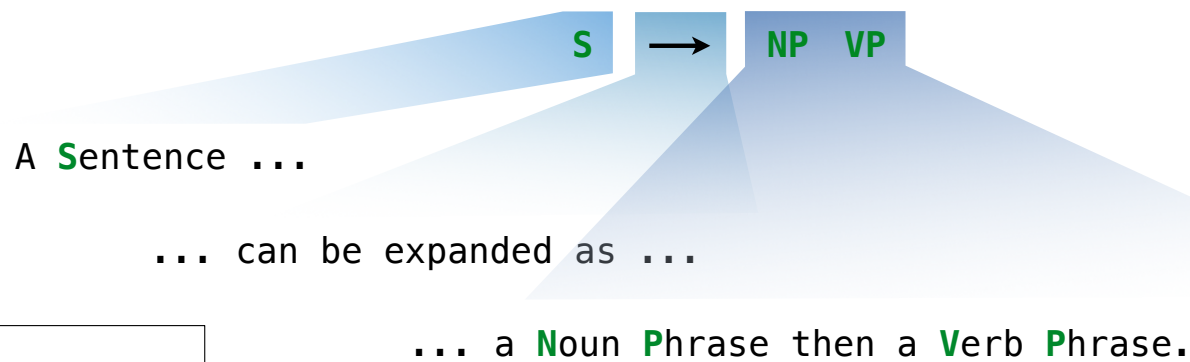
NP → **N**

N → COWS



Context-Free Grammar Rules

A grammar rule describes how a tag can be expanded as a sequence of tags or words

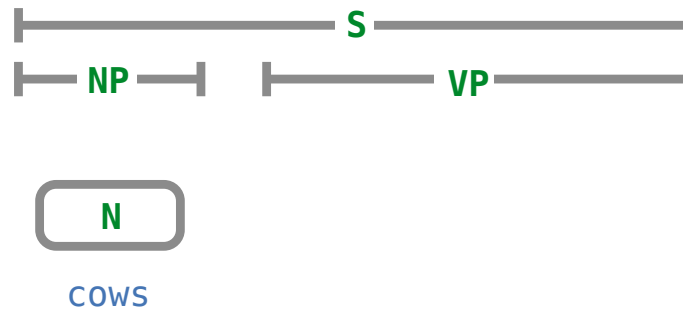


Grammar

S → **NP** **VP**

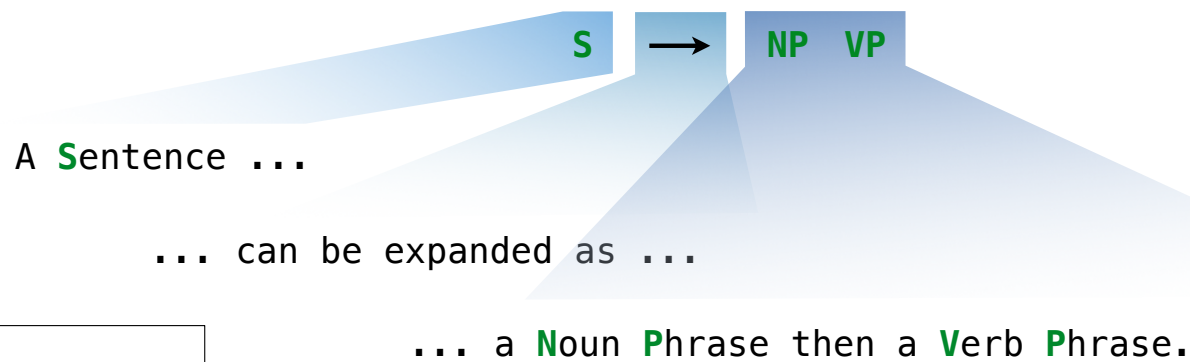
NP → **N**

N → COWS



Context-Free Grammar Rules

A grammar rule describes how a tag can be expanded as a sequence of tags or words



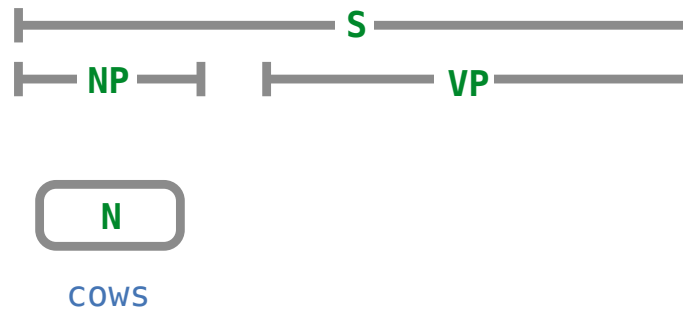
Grammar

S → **NP VP**

NP → **N**

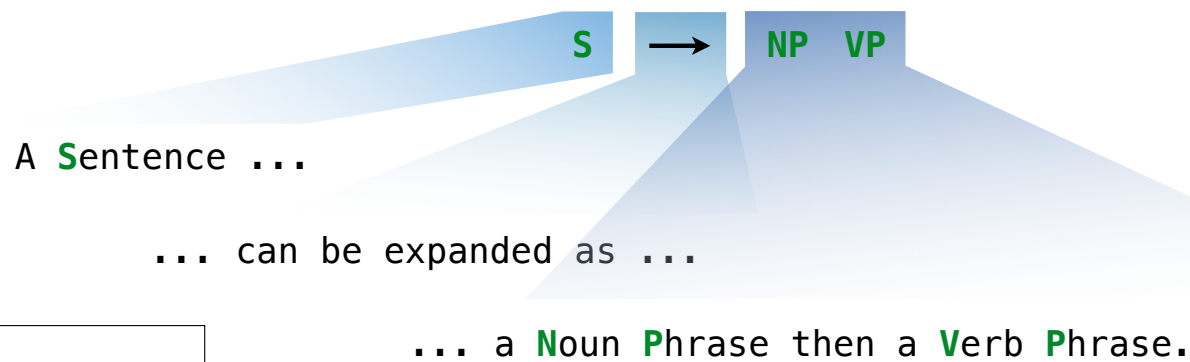
N → **COWS**

VP → **V NP**



Context-Free Grammar Rules

A grammar rule describes how a tag can be expanded as a sequence of tags or words



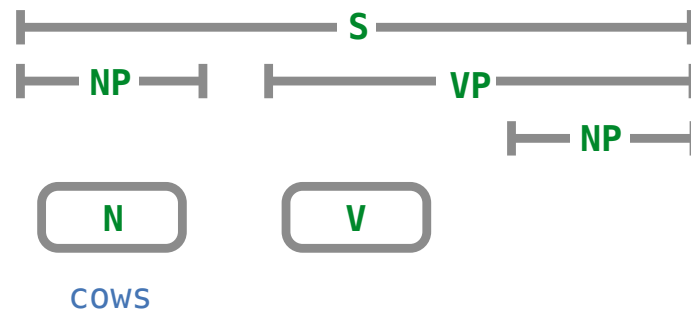
Grammar

S → **NP VP**

NP → **N**

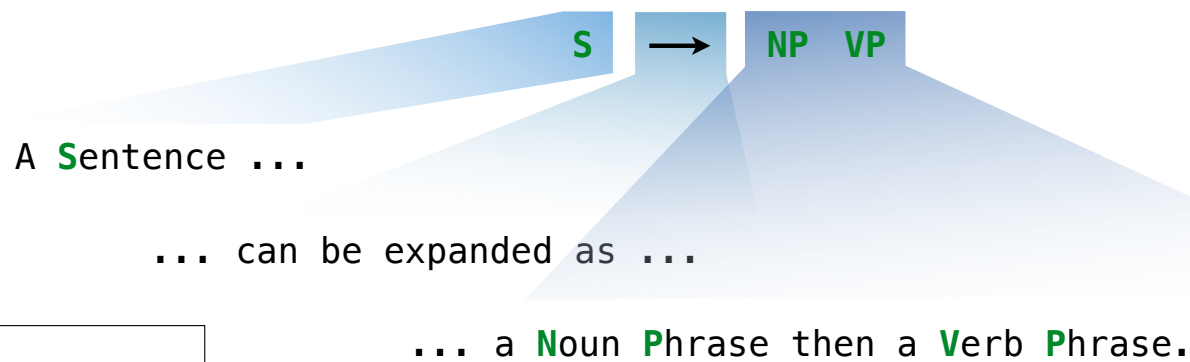
N → **COWS**

VP → **V NP**



Context-Free Grammar Rules

A grammar rule describes how a tag can be expanded as a sequence of tags or words



Grammar

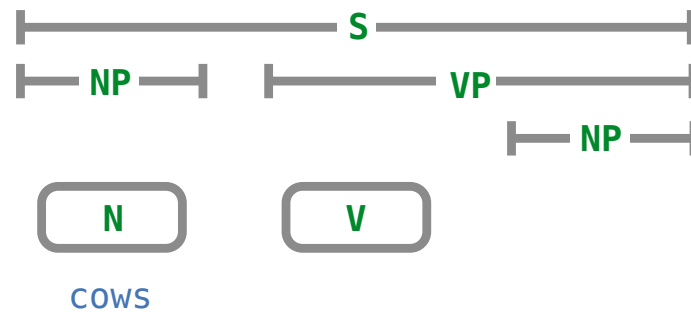
S → **NP VP**

NP → **N**

N → cows

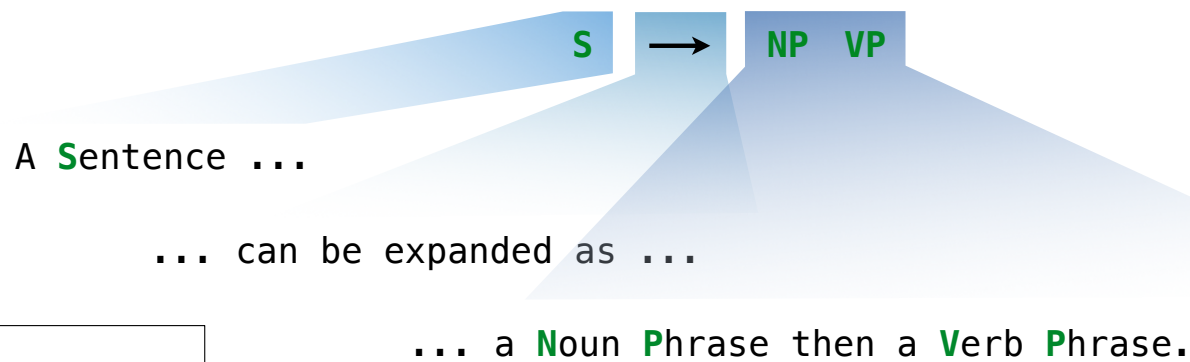
VP → **V NP**

V → intimidate



Context-Free Grammar Rules

A grammar rule describes how a tag can be expanded as a sequence of tags or words



Grammar

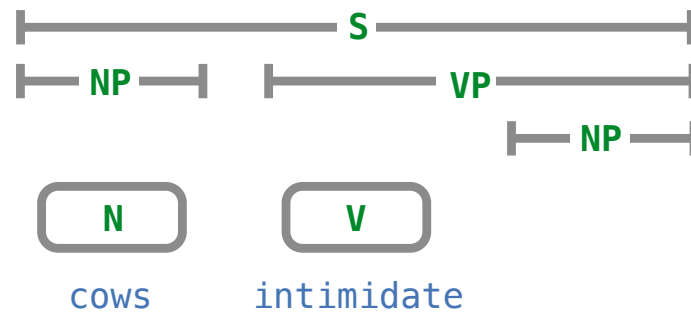
S → **NP** **VP**

NP → **N**

N → cows

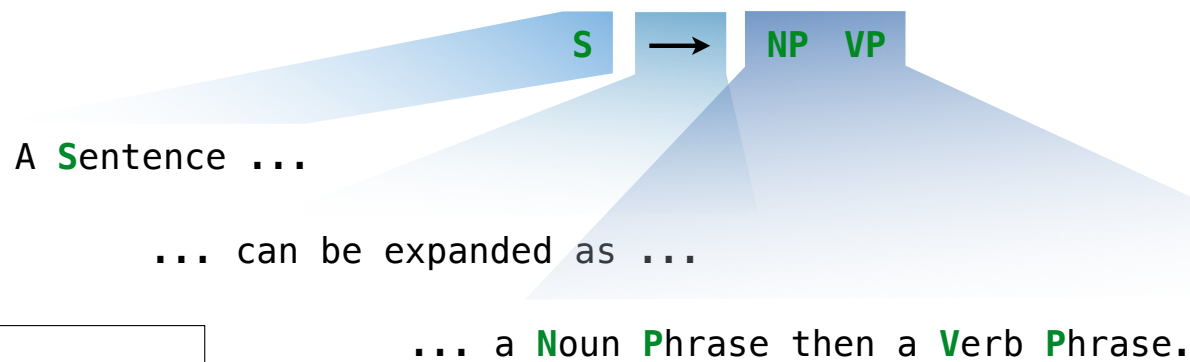
VP → **V** **NP**

V → intimidate



Context-Free Grammar Rules

A grammar rule describes how a tag can be expanded as a sequence of tags or words



Grammar

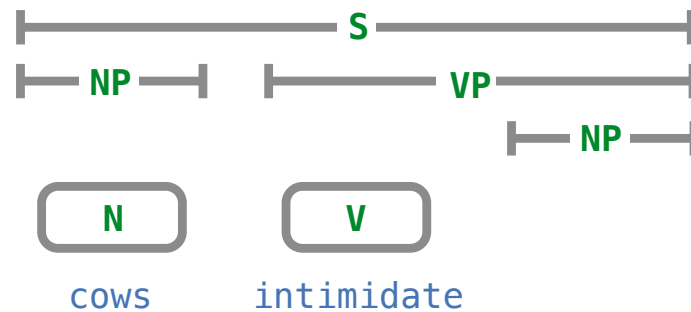
S → **NP** **VP**

NP → **N**

N → cows

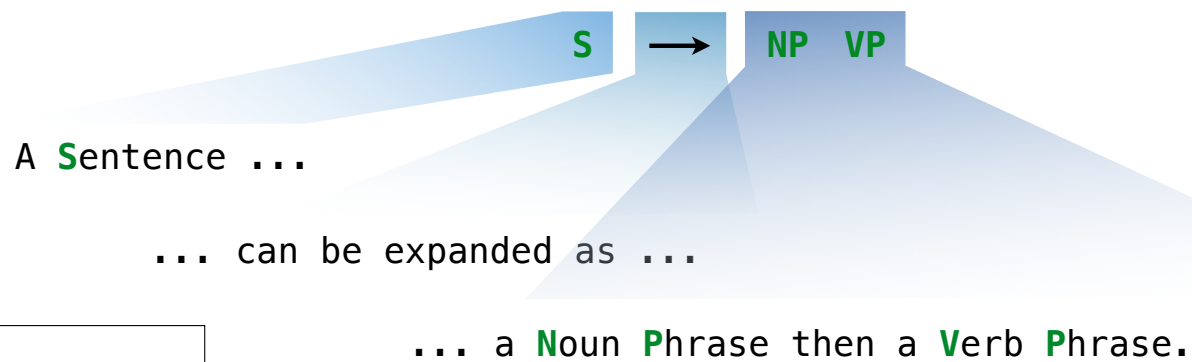
VP → **V** **NP**

V → intimidate



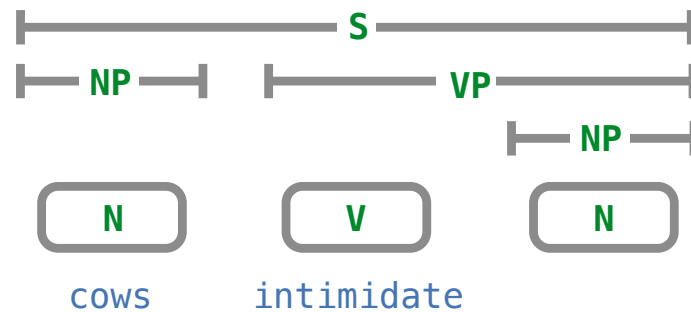
Context-Free Grammar Rules

A grammar rule describes how a tag can be expanded as a sequence of tags or words



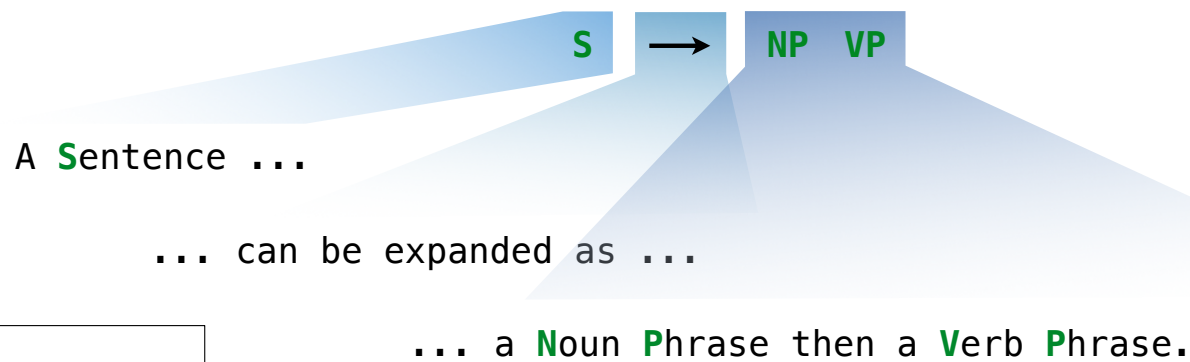
Grammar

S → **NP VP**
NP → **N**
N → cows
VP → **V NP**
V → intimidate



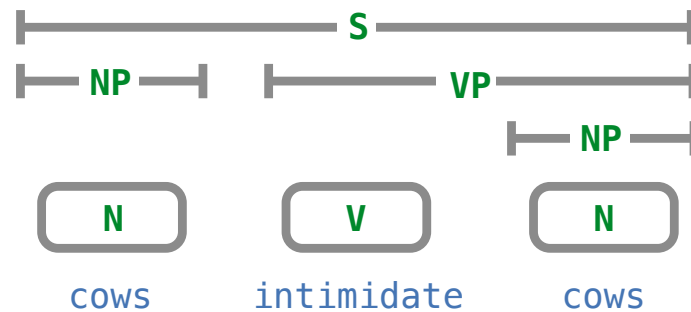
Context-Free Grammar Rules

A grammar rule describes how a tag can be expanded as a sequence of tags or words



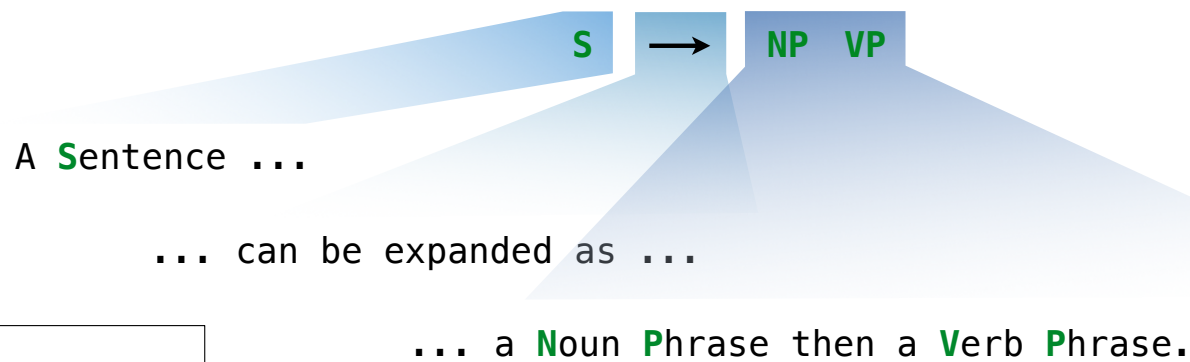
Grammar

S → **NP VP**
NP → **N**
N → cows
VP → **V NP**
V → intimidate



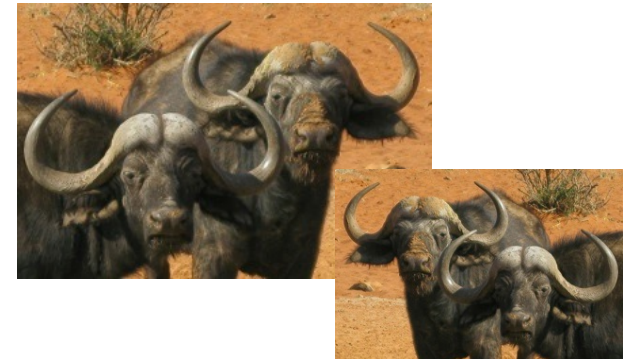
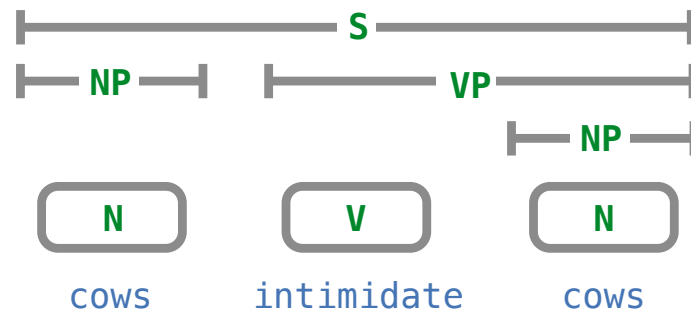
Context-Free Grammar Rules

A grammar rule describes how a tag can be expanded as a sequence of tags or words



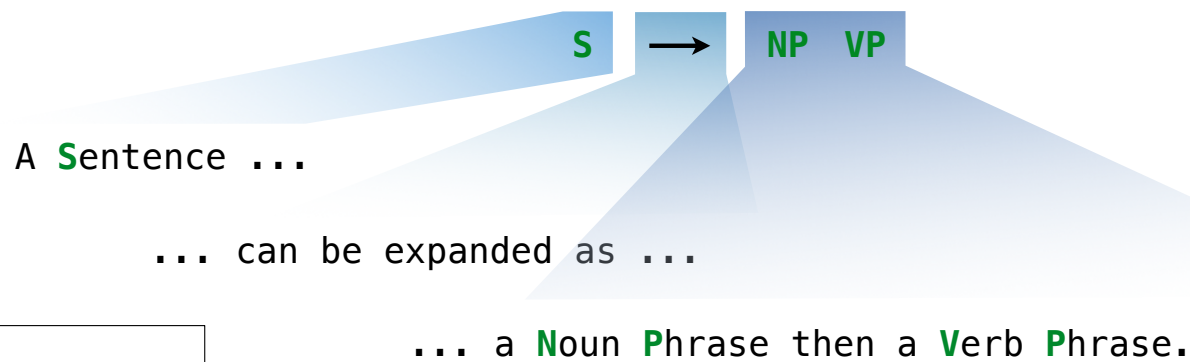
Grammar

S → **NP** **VP**
NP → **N**
N → cows
VP → **V** **NP**
V → intimidate



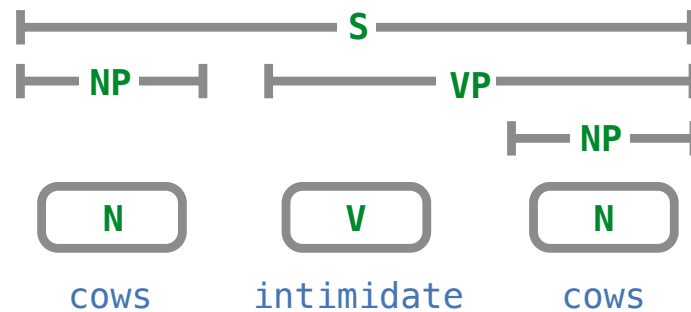
Context-Free Grammar Rules

A grammar rule describes how a tag can be expanded as a sequence of tags or words



Grammar

S → **NP** **VP**
NP → **N**
N → cows
VP → **V** **NP**
V → intimidate



(Demo)

Parsing

Exhaustive Parsing

Expand all tags recursively, but constrain words to match input

Exhaustive Parsing

Expand all tags recursively, but constrain words to match input

buffalo buffalo buffalo buffalo

Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



buffalo buffalo buffalo buffalo

Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



buffalo buffalo buffalo buffalo



Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



buffalo

buffalo

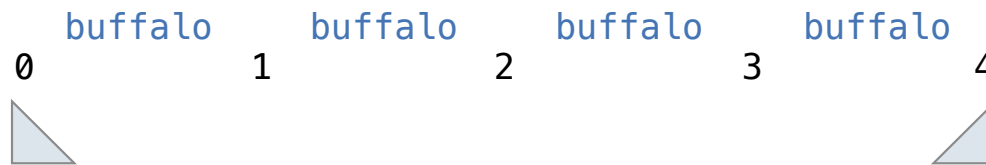
buffalo

buffalo



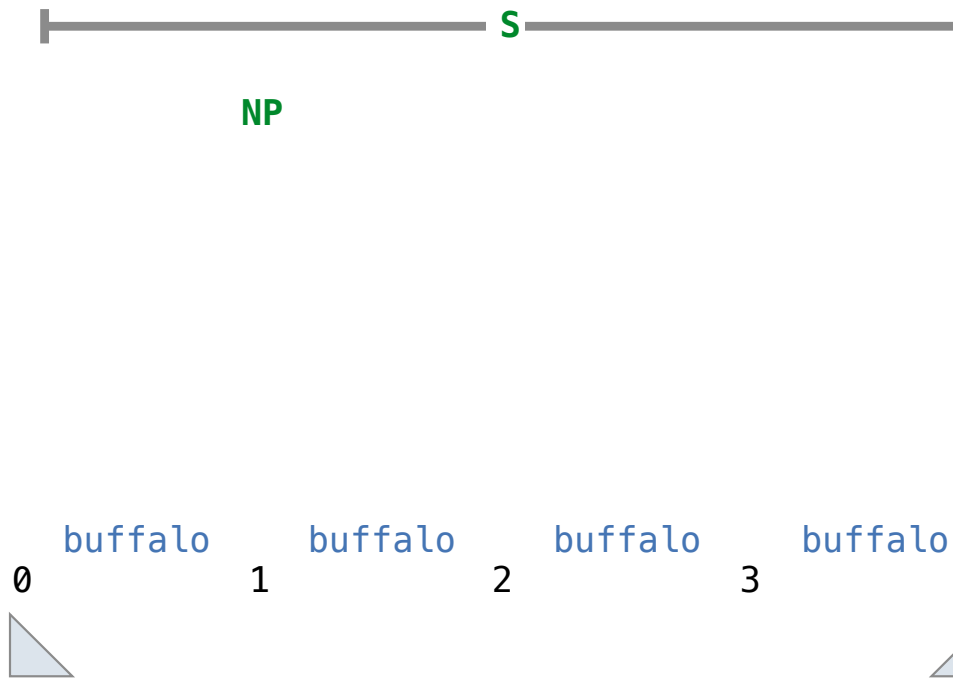
Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



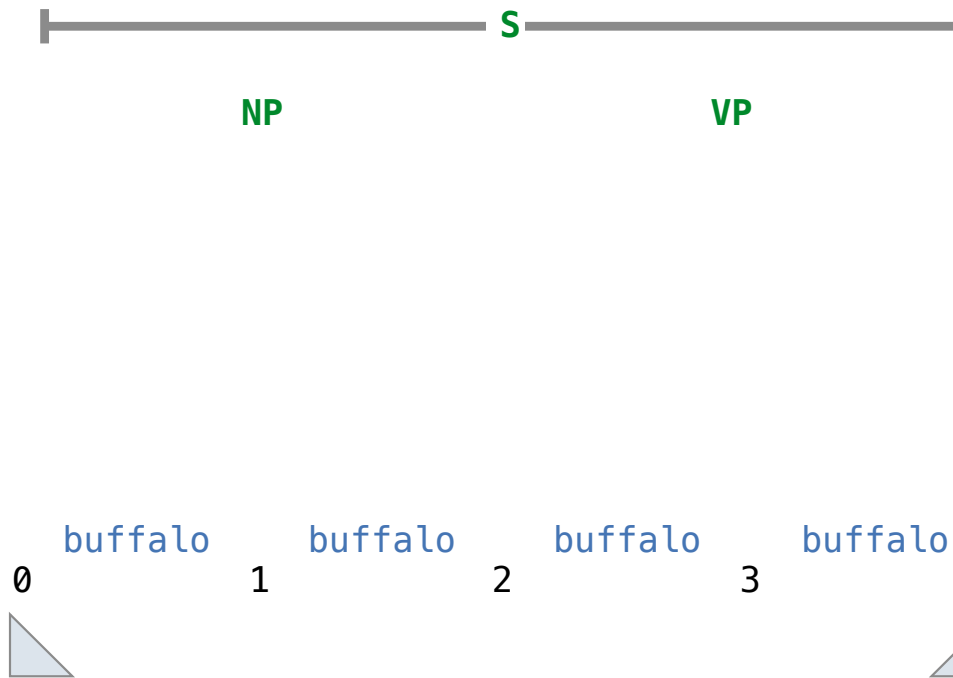
Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



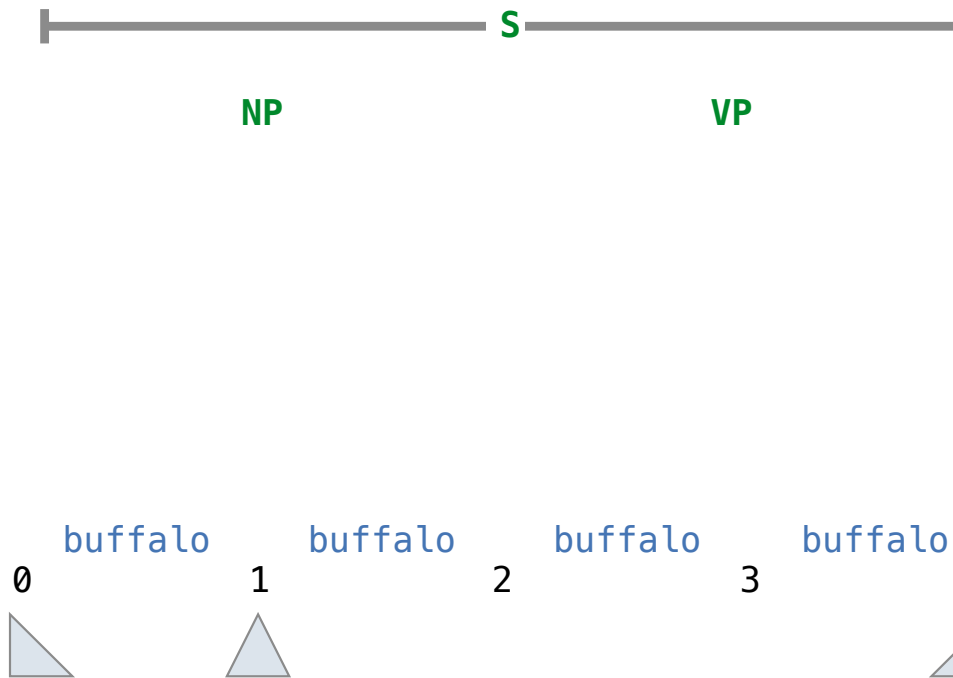
Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



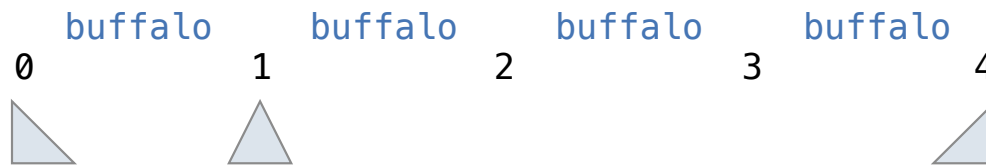
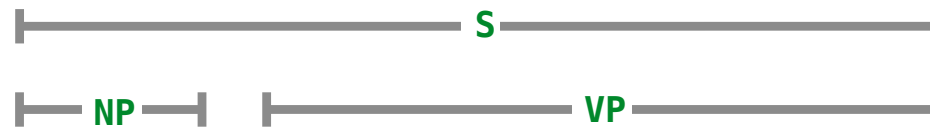
Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



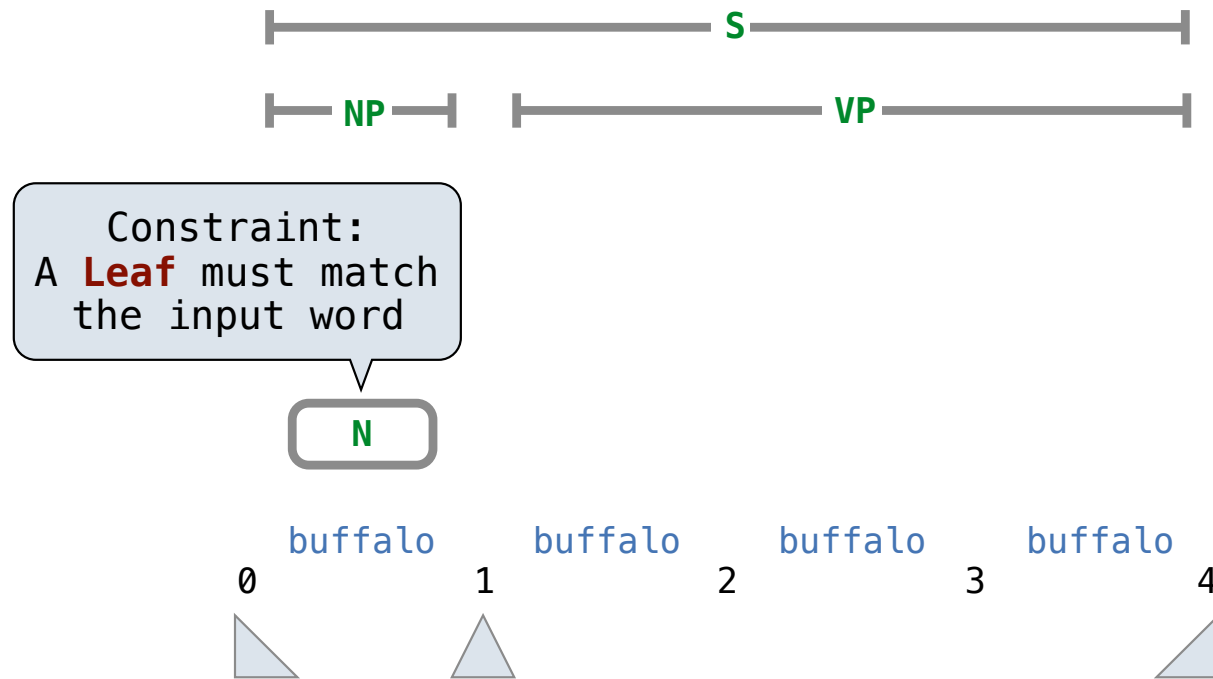
Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



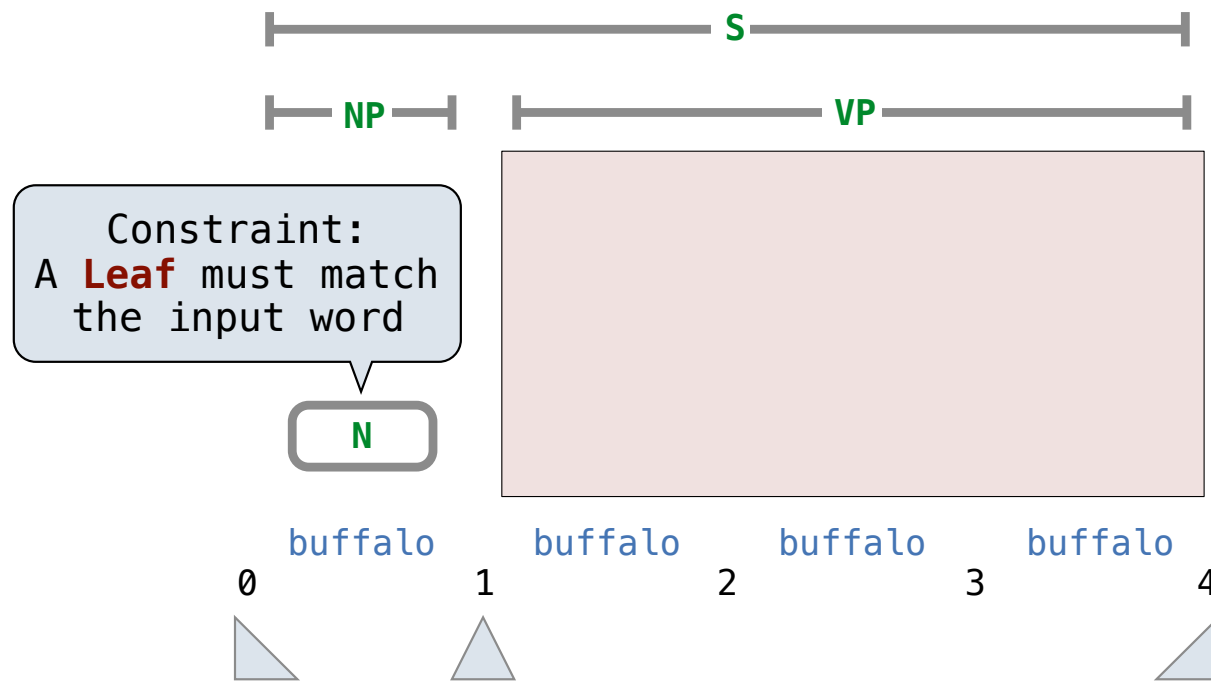
Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



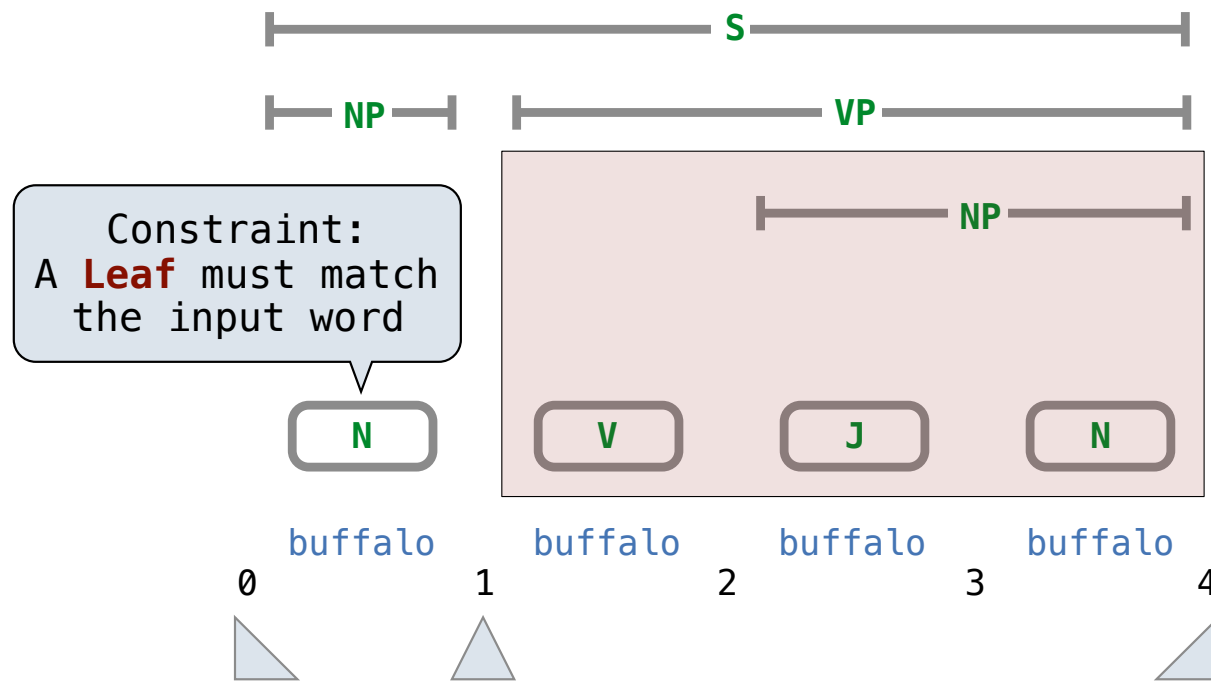
Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



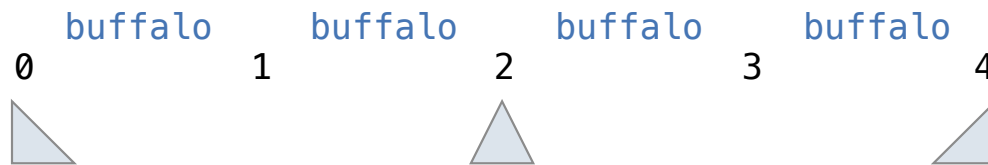
Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



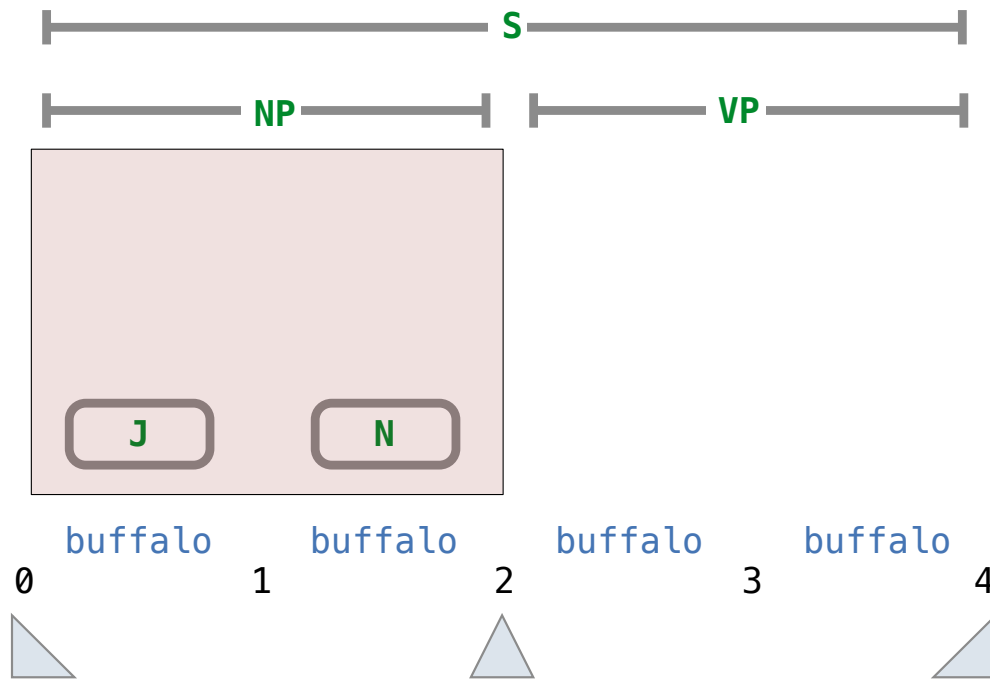
Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



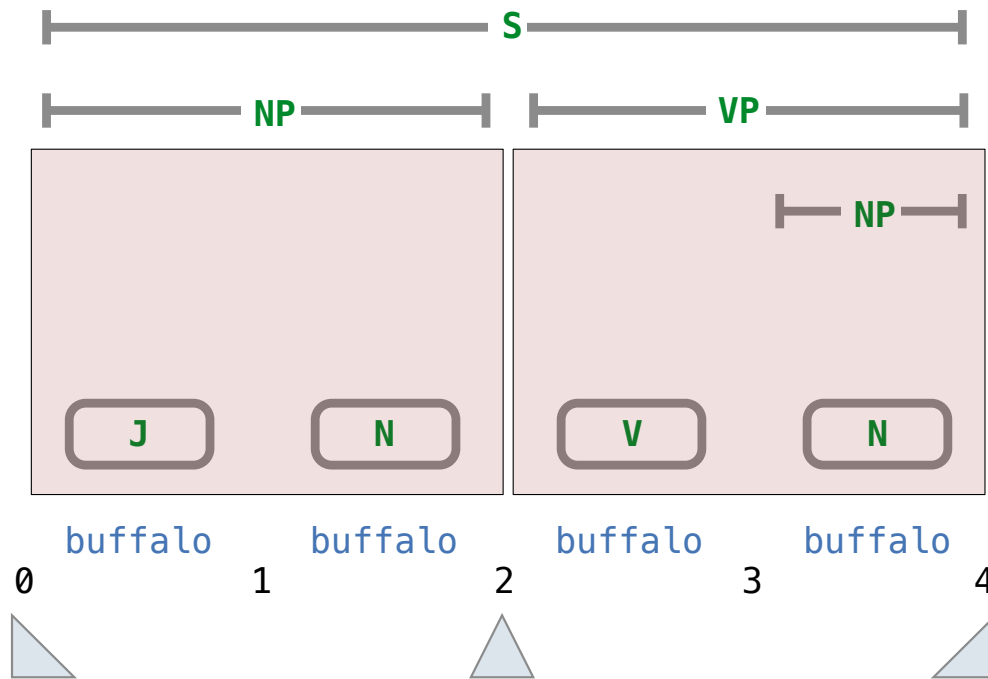
Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



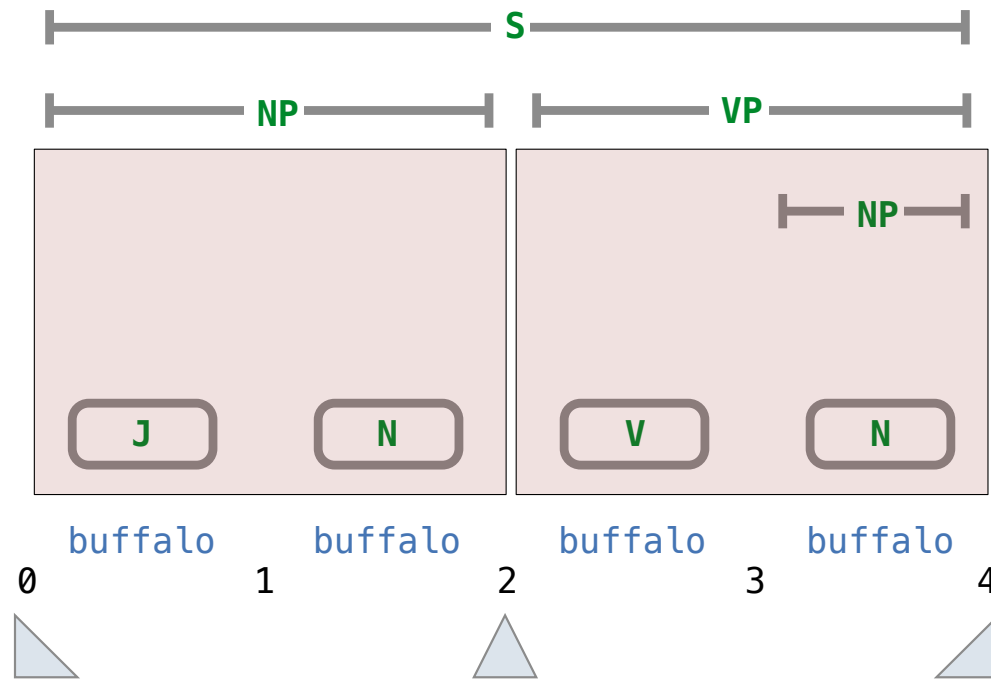
Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



Exhaustive Parsing

Expand all tags recursively, but constrain words to match input



(Demo)

Learning

(Demo)

Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common

Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common

teacher strikes idle kids

Scoring a Tree Using Relative Frequencies

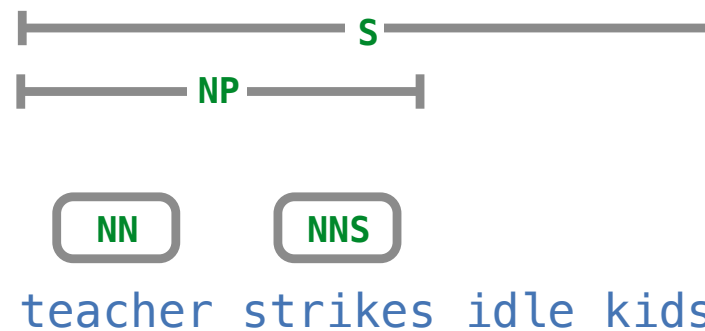
Not all syntactic structures are equally common



teacher strikes idle kids

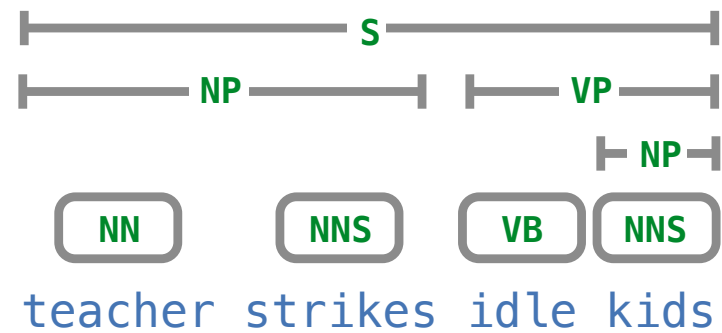
Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common



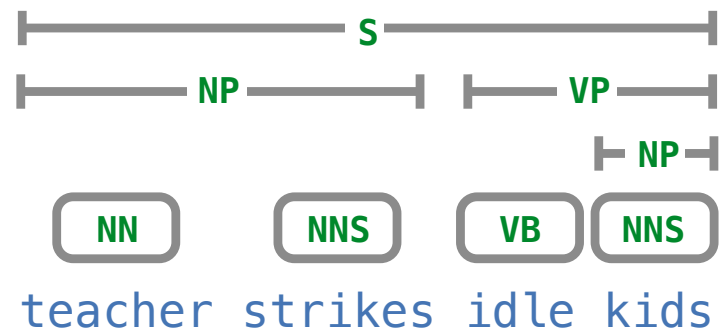
Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common



Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common



S → NP VP

NP → NN NNS

VP → VB NP

NP → NNS

NN → teacher

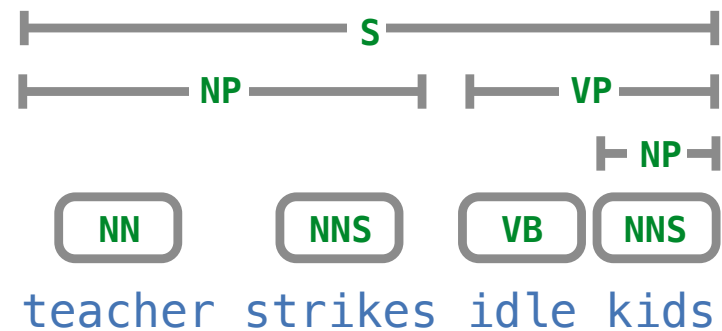
NNS → strikes

VB → idle

NNS → kids

Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common



Rule frequency per 100,000 tags

S → NP VP

NP → NN NNS

VP → VB NP

NP → NNS

NN → teacher

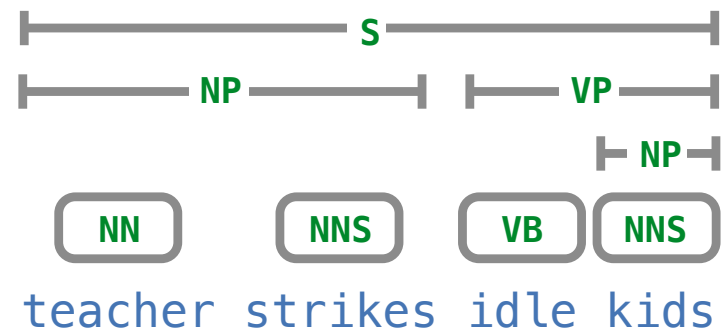
NNS → strikes

VB → idle

NNS → kids

Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common

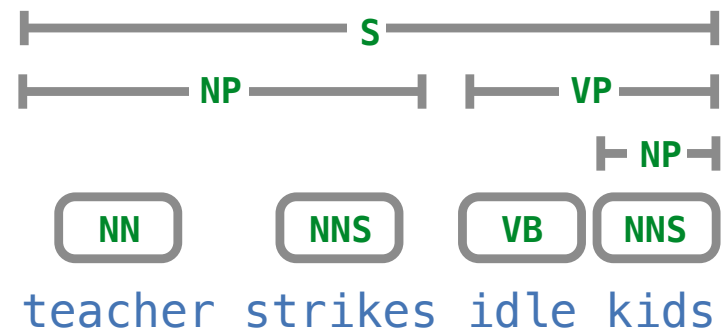


Rule frequency per 100,000 tags

S	→	NP	VP	25372	NN	→	teacher
NP	→	NN	NNS		NNS	→	strikes
VP	→	VB	NP		VB	→	idle
NP	→	NNS			NNS	→	kids

Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common

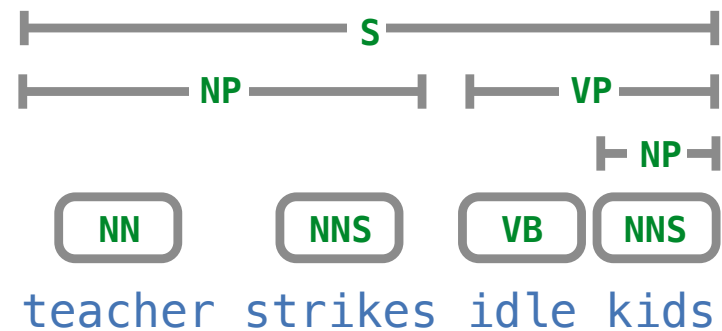


Rule frequency per 100,000 tags

S	→	NP	VP	25372	NN	→	teacher
NP	→	NN	NNS	1335	NNS	→	strikes
VP	→	VB	NP		VB	→	idle
NP	→	NNS			NNS	→	kids

Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common

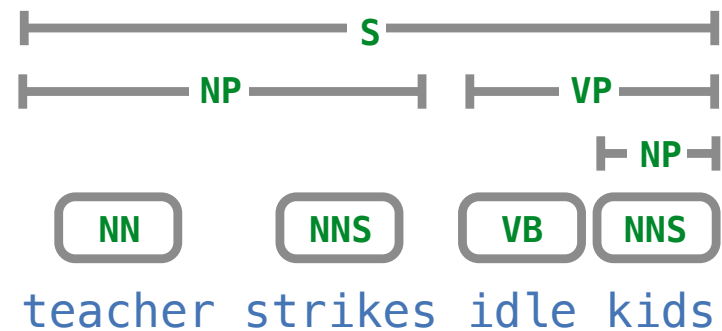


Rule frequency per 100,000 tags

S	→	NP	VP	25372	NN	→	teacher
NP	→	NN	NNS	1335	NNS	→	strikes
VP	→	VB	NP	6679	VB	→	idle
NP	→	NNS			NNS	→	kids

Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common

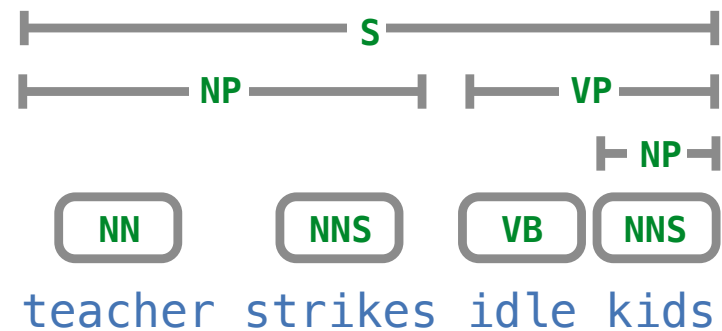


Rule frequency per 100,000 tags

S	→	NP	VP	25372	NN	→	teacher
NP	→	NN	NNS	1335	NNS	→	strikes
VP	→	VB	NP	6679	VB	→	idle
NP	→	NNS		4282	NNS	→	kids

Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common

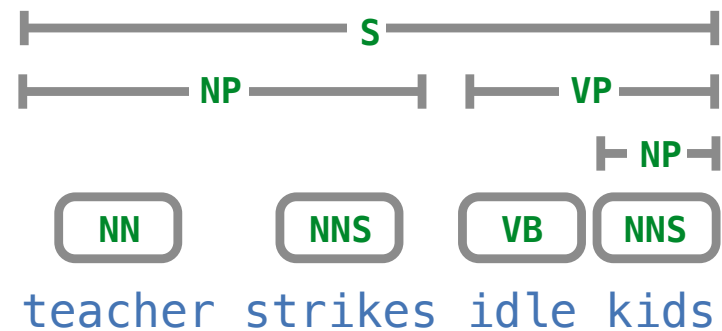


Rule frequency per 100,000 tags

S	→	NP	VP	25372	NN	→	teacher	5
NP	→	NN	NNS	1335	NNS	→	strikes	
VP	→	VB	NP	6679	VB	→	idle	
NP	→	NNS		4282	NNS	→	kids	

Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common

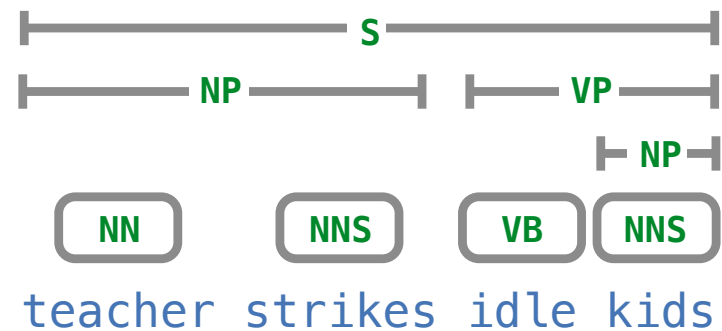


Rule frequency per 100,000 tags

S	→	NP	VP	25372	NN	→	teacher	5
NP	→	NN	NNS	1335	NNS	→	strikes	25
VP	→	VB	NP	6679	VB	→	idle	
NP	→	NNS		4282	NNS	→	kids	

Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common

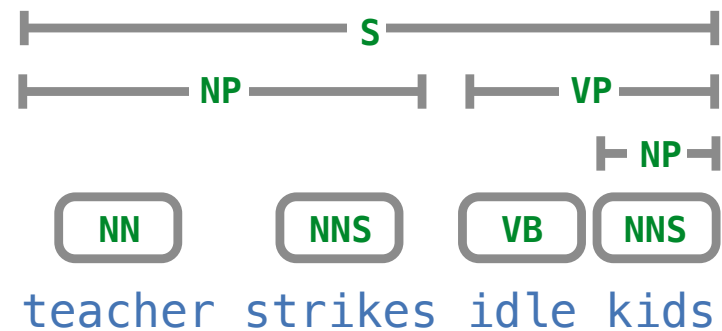


Rule frequency per 100,000 tags

S	→	NP	VP	25372	NN	→	teacher	5
NP	→	NN	NNS	1335	NNS	→	strikes	25
VP	→	VB	NP	6679	VB	→	idle	26
NP	→	NNS		4282	NNS	→	kids	

Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common

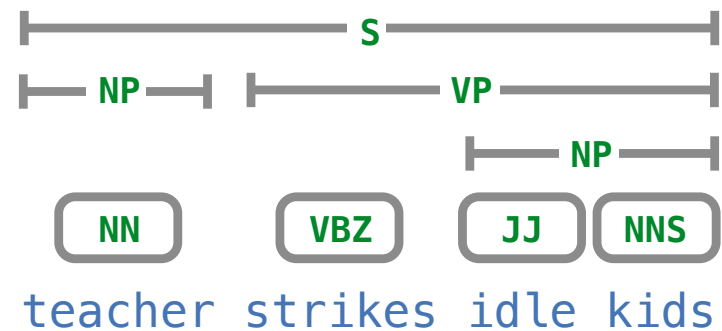


Rule frequency per 100,000 tags

S	→	NP	VP	25372	NN	→	teacher	5
NP	→	NN	NNS	1335	NNS	→	strikes	25
VP	→	VB	NP	6679	VB	→	idle	26
NP	→	NNS		4282	NNS	→	kids	32

Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common

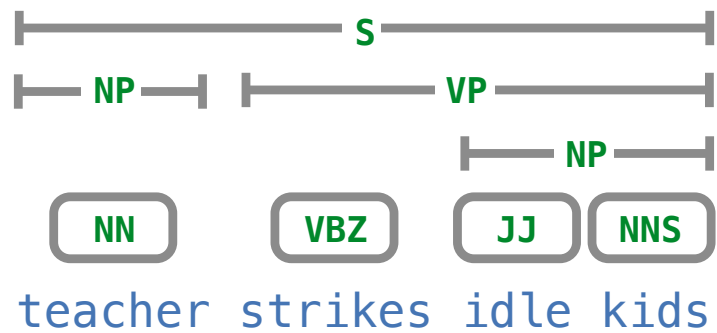


Rule frequency per 100,000 tags

S	→	NP	VP	25372	NN	→	teacher	5	
NP	→	NN		1335	4358	VBZ	→	strikes	25 19
VP	→	VBZ	NP	6679	3160	JJ	→	idle	26 18
NP	→	JJ	NNS	4282	2526	NNS	→	kids	32

Scoring a Tree Using Relative Frequencies

Not all syntactic structures are equally common



Rule frequency per 100,000 tags

S	→	NP	VP	25372	NN	→	teacher	5	
NP	→	NN		1335	4358	VBZ	→	strikes	25 19
VP	→	VBZ	NP	6679	3160	JJ	→	idle	26 18
NP	→	JJ	NNS	4282	2526	NNS	→	kids	32

(Demo)

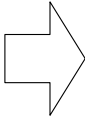
Translation

Syntactic Reordering

Syntactic Reordering

English

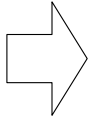
Syntactic Reordering

English  **Yoda-English**



Syntactic Reordering

English



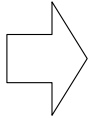
Yoda-English

Help you, I can!
Yes! Mm!



Syntactic Reordering

English



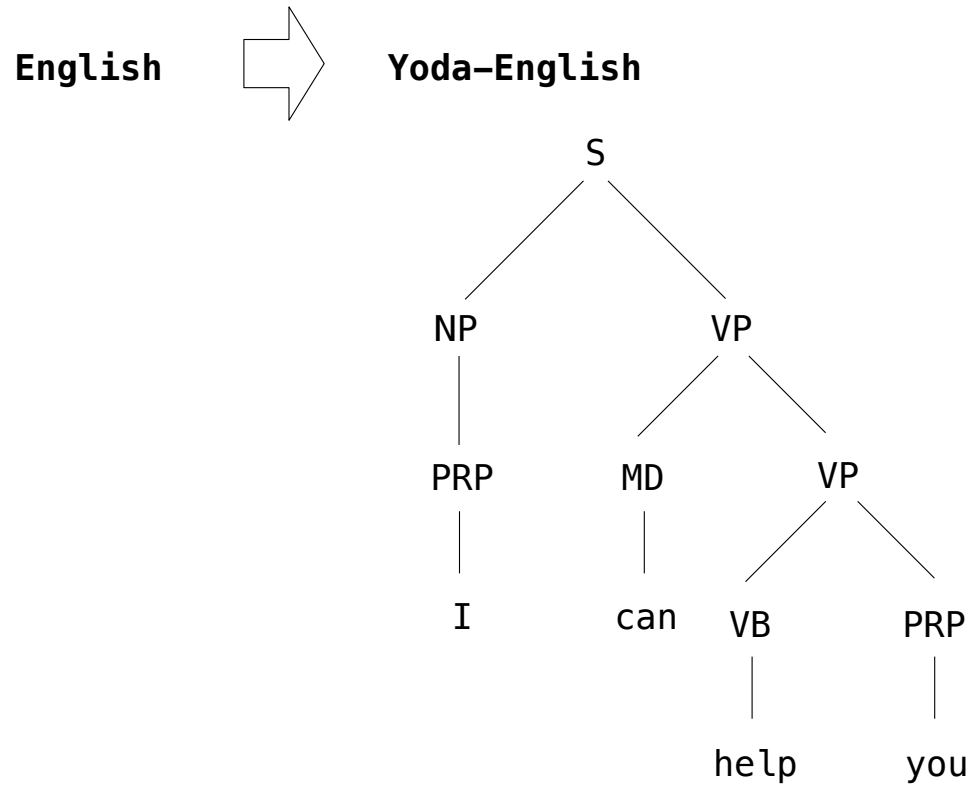
Yoda-English

Help you, I can!
Yes! Mm!



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

Syntactic Reordering

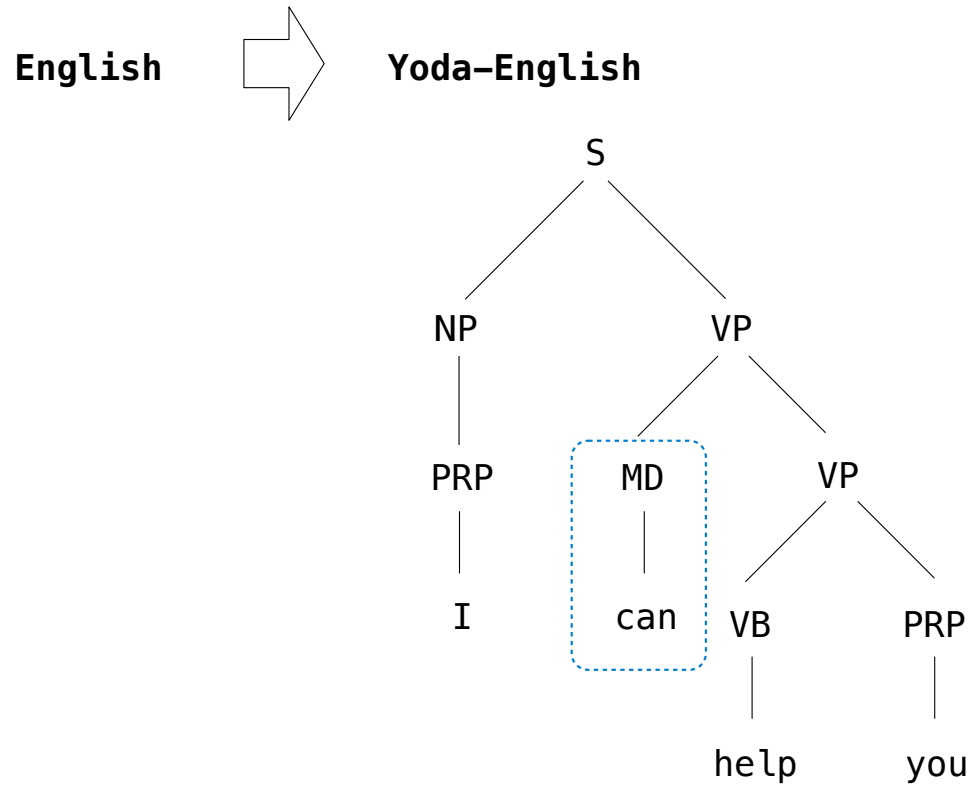


Help you, I can!
Yes! Mm!



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

Syntactic Reordering

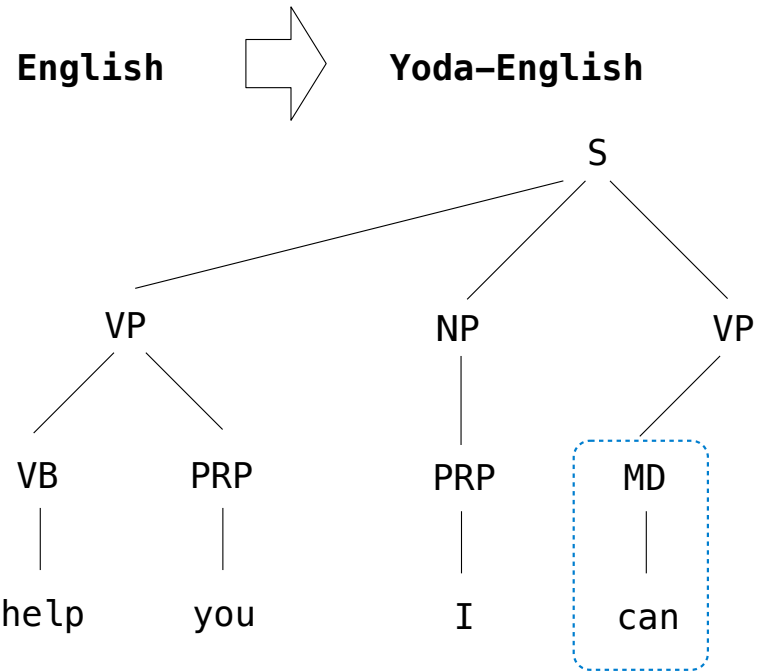


Help you, I can!
Yes! Mm!



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

Syntactic Reordering

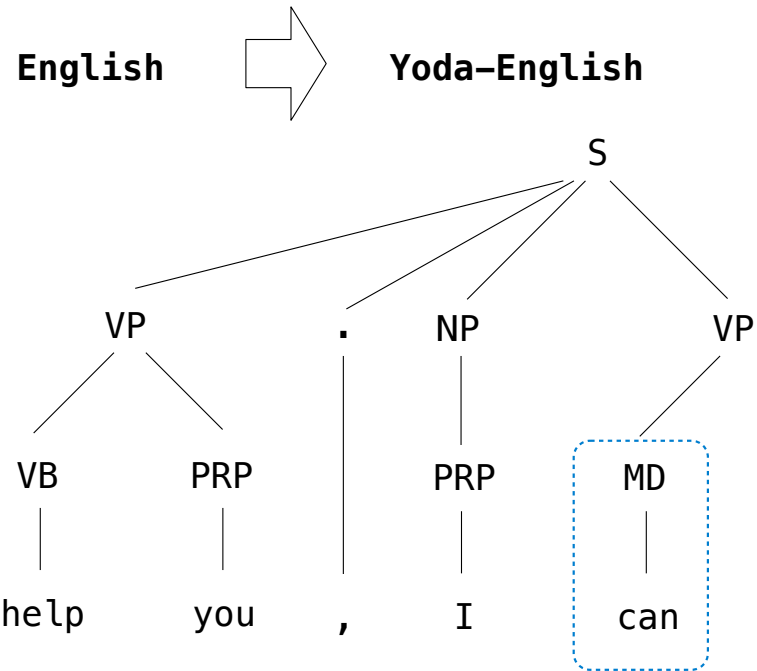


Help you, I can!
Yes! Mm!



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

Syntactic Reordering

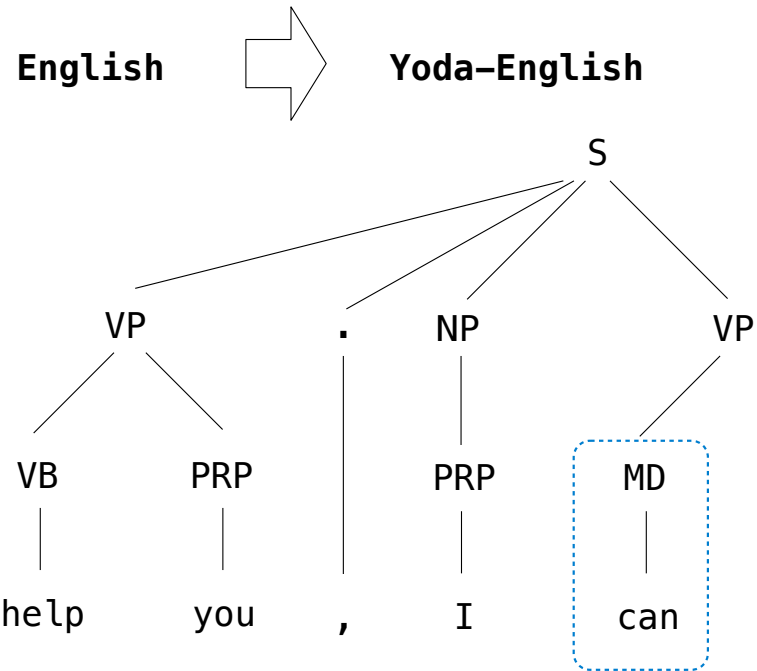


Help you, I can!
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When 900 years old you reach,
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Syntactic Reordering



Help you, I can!
Yes! Mm!



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

(Demo)

Neural Networks

Choosing Tags Using a Neural Network

NN **NNS** **VB** **NNS**

teacher strikes idle kids

VS

NN **VBZ** **JJ** **NNS**

teacher strikes idle kids

<http://projector.tensorflow.org/>

Choosing Tags Using a Neural Network

NN **NNS** VB NNS
teacher strikes idle kids

VS

NN **VBZ** JJ NNS
teacher strikes idle kids

<http://projector.tensorflow.org/>

Choosing Tags Using a Neural Network

NN **NNS** VB NNS
teacher strikes idle kids

VS

NN **VBZ** JJ NNS
teacher strikes idle kids

0.2
-0.4
0.7
0.0
0.3

...

-0.3
0.6
0.3
-0.7
-0.8

...

0.1
-0.3
-0.3
-0.1
0.3

...

0.2
0.3
-0.3
0.7
0.0

...

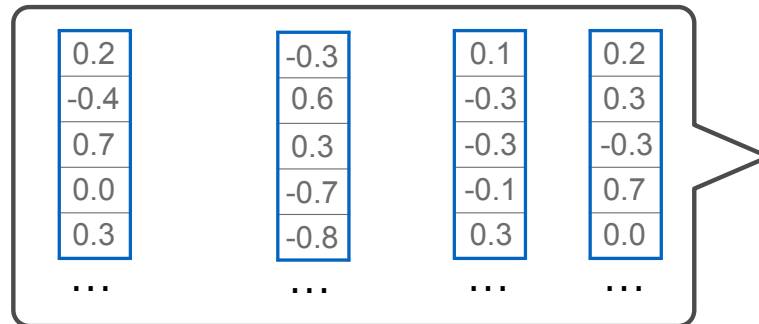
<http://projector.tensorflow.org/>

Choosing Tags Using a Neural Network

NN **NNS** VB NNS
teacher strikes idle kids

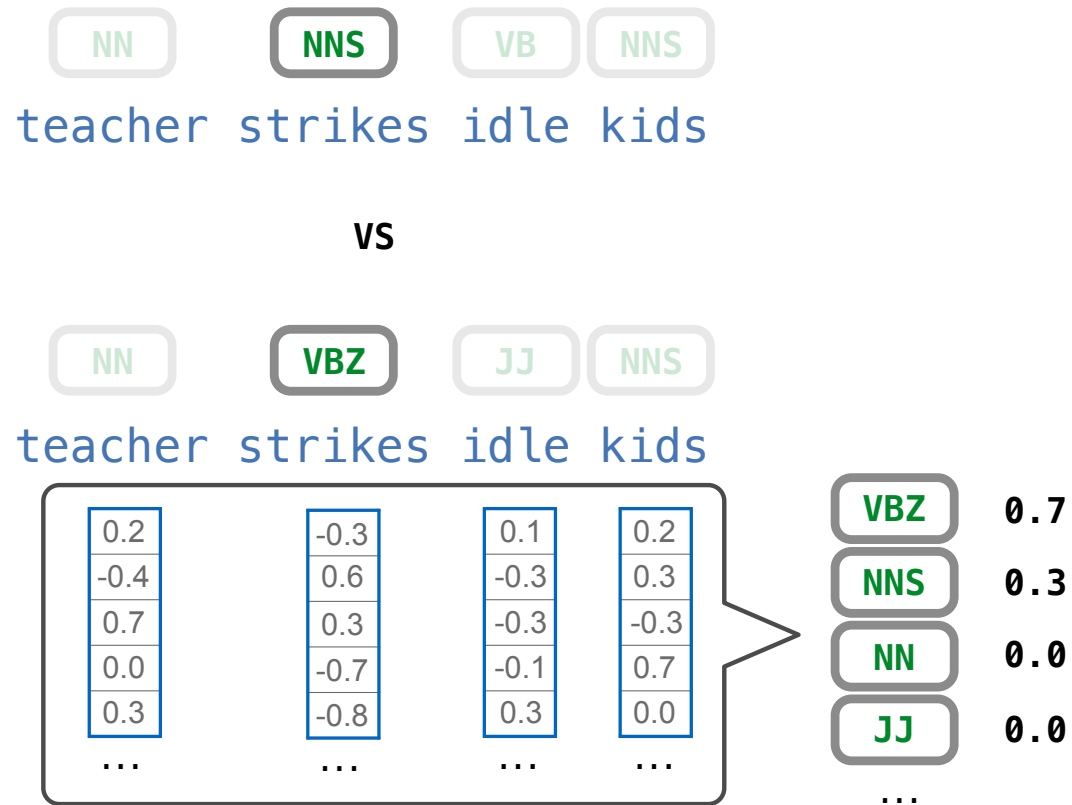
VS

NN **VBZ** JJ NNS
teacher strikes idle kids



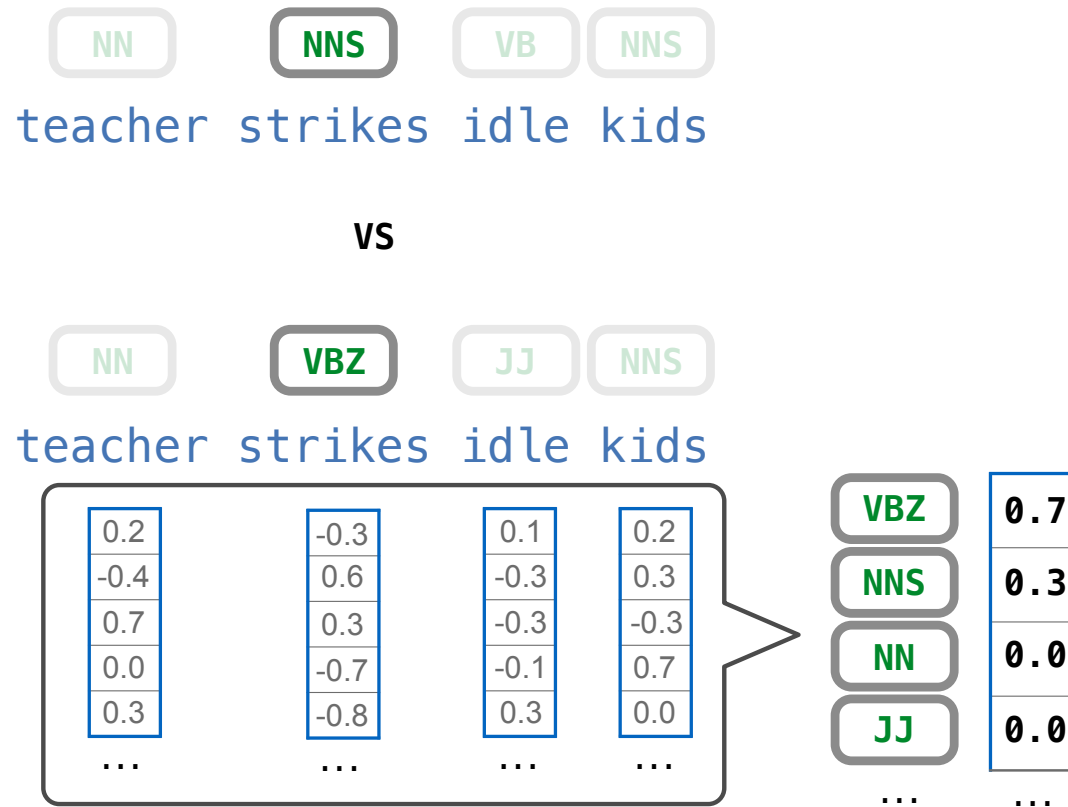
<http://projector.tensorflow.org/>

Choosing Tags Using a Neural Network



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