## University of Oslo: Department of Informatics

> INF4820: Algorithms for
> Artificial Intelligence and
> Natural Language Processing
> Live Coding, Parser Evaluation, Quiz

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## Overview

Last Time

- Generalized Chart Parsing
- Inside the Parse Forest
- Viterbi Tree Decoding


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## Today

- Exhaustive Unpacking
- Viterbi Tree Decoding
- Parser Evaluation
- Wrap-Up Quiz


## Chart Parsing: Key Ideas

- The parse chart is a two-dimensional matrix of edges (aka chart items);
- an edge is a (possibly partial) rule instantiation over a substring of input;
- the chart indexes edges by start and end string position (aka vertices);
- dot in rule RHS indicates degree of completion: $\alpha \rightarrow \beta_{1} \ldots \beta_{i-1} \bullet \beta_{i} \ldots \beta_{n}$;
- active edges (aka incomplete items) — partial RHS: [1, 2, VP $\rightarrow \mathrm{V} \bullet \mathrm{NP}]$;
- passive edges (aka complete items) — full RHS: [1, 3, VP $\rightarrow$ V NP•];

The Fundamental Rule

$$
\begin{aligned}
{[i, j, \alpha} & \left.\rightarrow \beta_{1} \ldots \beta_{i-1} \bullet \beta_{i} \ldots \beta_{n}\right]+\left[j, k, \beta_{i} \rightarrow \gamma^{+} \bullet\right] \\
& \mapsto\left[i, k, \alpha \rightarrow \beta_{1} \ldots \beta_{i} \bullet \beta_{i+1} \ldots \beta_{n}\right]
\end{aligned}
$$

## Ambiguity Packing in the Chart

## General Idea

- Maintain only one edge for each $\alpha$ from $i$ to $j$ (the 'representative');
- record alternate sequences of daughters for $\alpha$ in the representative.


## Implementation

- Group passive edges into equivalence classes by identity of $\alpha, i$, and $j$;
- search chart for existing equivalent edge ( $h$, say) for each new edge $e$;
- when $h$ (the 'host' edge) exists, pack $e$ into $h$ to record equivalence;
- e not added to the chart, no derivations with or further processing of $e$;
$\rightarrow$ unpacking multiply out all alternative daughters for all result edges.


## An Example (Hypothetical) Parse Forest



Chart Parsing Wrap-Up (4)

## Unpacking: Cross-Multiplying Local Ambiguity



How many complete trees in total?

## Live Coding: Exhaustive Unpacking

Chart Parsing Wrap-Up (6)

## Probability Theory and Natural Language?

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Every time I fire a linguist, system performance improves. (Fredrick Jelinek, 1980s)

## Viterbi Decoding over the Parse Forest

- Recall the Viterbi algorithm for HMMs

$$
v_{i}(x)=\max _{k=1}^{L}\left[v_{i-1}(k) \cdot P(x \mid k) \cdot P\left(o_{i} \mid x\right)\right]
$$

- Over the (complete, result edges from the) parse forest, compute Viterbi scores for sub-trees of increasing size:

$$
v(e)=\max \left[P\left(\beta_{1}, \ldots \beta_{n} \mid \alpha\right) \times \prod_{i} v\left(\beta_{i}\right)\right]
$$

- Similar to HMM decoding, we also need to keep track of the set of daughters that led to the maximum probability.


## Parser Evaluation

There are a number of aspects to consider in judging parser performance:

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- Accuracy Sentence accuracy measures the percentage of input sentences which received the correct tree.


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- Accuracy Sentence accuracy measures the percentage of input sentences which received the correct tree.
Since full trees can be quite complex, this is a very strict metric, and so most statistical parsers report accuracy according to the granular ParsEval metric.


## ParsEval

- The ParsEval metric (Black, et al., 1991) measures constituent overlap.
- The original formulation only considered the shape of the (unlabeled) bracketing.
- The modern 'standard' uses a tool called evalb, which reports precision, recall and $F_{1}$ score for labeled brackets, as well as the number of crossing brackets.


## ParsEval

## Gold Standard

(NP (DT a)
(ADVP (RB pretty)
(JJ big))
(NOM (NN dog) (POS 's) (NN house)) )

## System Output

(NP (DT $a$ )
(JJ pretty)
(NOM (JJ big)
(NOM (NN dog)
(POS 's)
(NN house))))

## ParsEval

## Gold Standard

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## System Output

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(NOM (JJ big)
(NOM (NN dog)
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(NN house))))
$0,6 \mathrm{NP}$

## ParsEval

Gold Standard<br>(NP (DT a)<br>(ADVP (RB pretty)<br>(JJ big))<br>(NOM (NN dog) (POS 's) (NN house)) )

## System Output

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(JJ pretty)
(NOM (JJ big)
(NOM (NN dog)
(POS 's)
(NN house))))

0,6 np
0,1 dт

## ParsEval

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## System Output

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(JJ pretty)
(NOM (JJ big)
(NOM (NN dog)
(POS 's)
(NN house))))

0,6 np
0,1 dT
1,3 ADVP

## ParsEval

## Gold Standard

(NP (DT a)
(ADVP (RB pretty)
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(NOM (NN dog) (POS 's) (NN house)) )

## System Output

(NP (DT a)
(JJ pretty)
(NOM (JJ big)
(NOM (NN dog)
(POS 's)
(NN house))))
$0,6 \mathrm{NP} \quad 1,2 \mathrm{RB}$
0,1 dT
1,3 adve

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(NN house))))

| $0,6 \mathrm{NP}$ | 1,2 | RB |
| :--- | :---: | :---: |
| 0,1 | DT | 2,3 |
| 1,3 | JJ |  |
| 1,3 |  |  |

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(JJ pretty)
(NOM (JJ big)
(NOM (NN dog)
(POS 's)
(NN house))))

| 0,6 | NP | 1,2 |
| :--- | :--- | :--- |
| Rb |  |  |
| 0,1 | dT | 2,3 |
| JJ |  |  |
| 1,3 | ADVP | 3,6 | NOM

## ParsEval

## Gold Standard

(NP (DT a)
(ADVP (RB pretty)
(JJ big))
(NOM (NN dog)
(POS 's) (NN house)) )

## System Output

(NP (DT a)
(JJ pretty)
(NOM (JJ big)
(NOM (NN dog)
(POS 's)
(NN house))))

| 0,6 | NP | 1,2 | Rb | 3,4 |
| :--- | :--- | :--- | :--- | :--- |
| 0,1 | NN |  |  |  |
| 1,3 | 2,3 | JJ |  |  |
| 1,3 | ADVP | 3,6 | NOM |  |
|  |  |  |  |  |

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(NP (DT a)
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(NP (DT a)
(JJ pretty)
(NOM (JJ big)
(NOM (NN dog)
(POS 's)
(NN house))))

| 0,6 | NP | 1,2 | RB | 3,4 |
| :--- | :--- | :--- | :--- | :--- |
| NN |  |  |  |  |
| 0,1 | dT | 2,3 | JJ | 4,5 |
| 1,3 | PDVP | 3,6 | NOM |  |

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## System Output

(NP (DT $a$ )
(JJ pretty)
(NOM (JJ big)
(NOM (NN dog)
(POS 's)
(NN house))))

| 0,6 | NP | 1,2 | RB | 3,4 |
| :--- | :--- | :--- | :--- | :--- |
| NN |  |  |  |  |
| 0,1 | DT | 2,3 | JJ | 4,5 |
| 1,3 | ADVP | 3,6 | NOM | 5,6 |

## ParsEval

## Gold Standard

(NP (DT a)
(ADVP (RB pretty)
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(NOM (NN dog) (POS 's) (NN house)) )

## System Output

(NP (DT $a$ )
(JJ pretty)
(NOM (JJ big)
(NOM (NN dog) (POS 's)
(NN house))))

| $0,6 \mathrm{NP}$ | 1,2 | RB | 3,4 | NN |
| :--- | :---: | :---: | :---: | :---: |
| 0,1 | DT | 2,3 | JJ | 4,5 | POS


| $0,6 \mathrm{NP}$ | $2,6 \mathrm{NOM}$ | $3,4 \mathrm{NN}$ |
| :--- | :--- | :--- |
| $0,1 \mathrm{dT}$ | $2,3 \mathrm{JJ}$ | $4,5 \mathrm{POS}$ |
| $1,2 \mathrm{JJ}$ | $3,6 \mathrm{NOM}$ | $5,6 \mathrm{NN}$ |

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| 0,6 | NP | 1,2 | Rb | 3,4 |
| :--- | :--- | :--- | :--- | :--- |
| NN |  |  |  |  |
| 0,1 | dT | 2,3 | JJ | 4,5 |
| POS |  |  |  |  |
| 1,3 | ADVP | 3,6 | NOM | 5,6 | NN


| $0,6 \mathrm{NP}$ | $2,6 \mathrm{NOM}$ | $3,4 \mathrm{NN}$ |
| :--- | :--- | :--- |
| $0,1 \mathrm{dT}$ | $2,3 \mathrm{JJ}$ | $4,5 \mathrm{pOs}$ |
| $1,2 \mathrm{JJ}$ | 3,6 | NOM |
| $5,6 \mathrm{NN}$ |  |  |

Correct: 7

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(NN house))))

| 0,6 np | 1,2 Rв | 3,4 nn |
| :---: | :---: | :---: |
| 0,1 dT | 2,3 JJ | 4,5 PO |
| 1,3 ADVP | 3,6 nom | 5,6 |


| $0,6 \mathrm{NP}$ | 2,6 nom | $3,4 \mathrm{NN}$ |
| :--- | :--- | :--- |
| $0,1 \mathrm{dT}$ | $2,3 \mathrm{JJ}$ | $4,5 \mathrm{pOs}$ |
| $1,2 \mathrm{JJ}$ | 3,6 | NOM |
| $5,6 \mathrm{NN}$ |  |  |

Recall: $\frac{\text { Correct }}{\text { Gold }}=\frac{7}{9} \quad$ Precision: $\frac{\text { Correct }}{\text { System }}=\frac{7}{9}$

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| $0,6 \mathrm{NP}$ | $1,2 \mathrm{Rb}$ | 3,4 | NN |  |
| :--- | :---: | :--- | :--- | :--- |
| $0,1 \mathrm{dT}$ | $2,3 \mathrm{JJ}$ | 4,5 | pos |  |
| 1,3 | ADVP | 3,6 | NOM | 5,6 |


| $0,6 \mathrm{NP}$ | 2,6 nom | $3,4 \mathrm{nN}$ |
| :--- | :--- | :--- |
| $0,1 \mathrm{dt}$ | $2,3 \mathrm{JJ}$ | $4,5 \mathrm{pos}$ |
| $1,2 \mathrm{JJ}$ | 3,6 nom | $5,6 \mathrm{NN}$ |

Recall: $\frac{\text { Correct }}{\text { Gold }}=\frac{7}{9} \quad$ Precision: $\frac{\text { Correct }}{\text { System }}=\frac{7}{9} \quad \mathrm{~F}_{1}$ score: $\frac{7}{9}$

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(NN house))))

|  |  |  |  | $0,6 \mathrm{NP}$ | $2,6 \mathrm{NOM}$ | $3,4 \mathrm{NN}$ |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $0,6 \mathrm{NP}$ | $1,2 \mathrm{RB}$ | $3,4 \mathrm{NN}$ | $0,1 \mathrm{dT}$ | $2,3 \mathrm{JJ}$ | $4,5 \mathrm{POS}$ |  |
| $0,1 \mathrm{NT}$ | 2,3 | JJ | $4,5 \mathrm{POS}$ | $1,2 \mathrm{JJ}$ | $3,6 \mathrm{NOM}$ | $5,6 \mathrm{NN}$ |
| 1,3 | ADVP | 3,6 | NOM | $5,6 \mathrm{NN}$ |  |  |

Recall: $\frac{\text { Correct }}{\text { Gold }}=\frac{2}{3} \quad$ Precision: $\frac{\text { Correct }}{\text { System }}=\frac{2}{3} \quad \mathrm{~F}_{1}$ score: $\frac{2}{3}$

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|  |  |  | $0,6 \mathrm{NP}$ | $2,6 \mathrm{NOM}$ | $3,4 \mathrm{NN}$ |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $0,6 \mathrm{NP}$ | $1,2 \mathrm{RB}$ | $3,4 \mathrm{NN}$ | $0,1 \mathrm{dT}$ | $2,3 \mathrm{JJ}$ | $4,5 \mathrm{POS}$ |  |
| $0,1 \mathrm{DT}$ | $2,3 \mathrm{JJ}$ | $4,5 \mathrm{POS}$ | $1,2 \mathrm{JJ}$ | $3,6 \mathrm{NOM}$ | $5,6 \mathrm{NN}$ |  |
| 1,3 | ADVP | 3,6 | NOM | $5,6 \mathrm{NN}$ |  |  |

Recall: $\frac{\text { Correct }}{\text { Gold }}=\frac{2}{3} \quad$ Precision: $\frac{\text { Correct }}{\text { System }}=\frac{2}{3} \quad \mathrm{~F}_{1}$ score: $\frac{2}{3}$
Crossing Brackets: 1

## In Conclusion

In the second half of the class, we set out to determine:

- which string is most likely:
- How to recognise speech vs. How to wreck a nice beach


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- NNS VB NNS vs. VBZ P NNS


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- which tag sequence is most likely for flies like flowers:
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- which syntactic analysis is most likely:



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- How to recognise speech vs. How to wreck a nice beach
- which tag sequence is most likely for flies like flowers:
- NNS VB NNS vs. VBZ P NNS
- which syntactic analysis is most likely: $\checkmark$



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## Rules of the Game

- Up to four bonus points towards completion of Obligatory Exercise (3).


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## After the Quiz

- Post your answers at the front of your table, we will collect all notes.
- Discuss your answers with your neighbor(s); find out who is right.


## Question (1): Natural Language Ambiguity

Assume the following 'toy' grammar of English:

$$
\begin{aligned}
\mathrm{S} & \rightarrow \mathrm{NP} \\
\mathrm{NP} & \rightarrow \operatorname{Det} \mathrm{~N} \\
\mathrm{~N} & \rightarrow \mathrm{~N} \mathrm{~N}
\end{aligned}
$$

Det $\rightarrow$ the
$\mathrm{N} \rightarrow$ kitchen | gold $\mid$ towel | rack

## Question (1): Natural Language Ambiguity

Assume the following 'toy' grammar of English:

$$
\begin{aligned}
& \mathrm{S} \rightarrow \mathrm{NP} \\
& \mathrm{NP} \rightarrow \mathrm{Det} \mathrm{~N} \\
& \mathrm{~N} \rightarrow \mathrm{~N} \mathrm{~N} \\
& \text { Det } \rightarrow \text { the } \\
& \mathrm{N} \rightarrow \text { kitchen } \mid \text { gold } \mid \text { towel } \mid \text { rack }
\end{aligned}
$$

(1) How many different syntactic analyses, if any, does the grammar assign to the following strings?
(a) the kitchen towel rack
(b) the kitchen gold towel rack

## Question (2): CKY Parsing

Assume the following grammar and CKY parse table:

$$
\begin{gathered}
\mathrm{S} \rightarrow \mathrm{NP} \mathrm{VP} \\
\mathrm{VP} \rightarrow \mathrm{VNP} \\
\mathrm{VP} \rightarrow \mathrm{VP} P \mathrm{PP} \\
\mathrm{NP} \rightarrow \mathrm{NP} \mathrm{VP} \\
\mathrm{PP} \rightarrow \mathrm{P} \text { NP }
\end{gathered}
$$

| 1 | 2 | 3 | 4 | 5 |
| :---: | :---: | :---: | :---: | :---: |
| 0 NP |  | S |  | S |
| 1 | V | VP |  | VP |
| 2 |  | NP |  | NP |
| 3 |  |  | P | PP |
| 4 |  |  |  | NP |

## Question (2): CKY Parsing

Assume the following grammar and CKY parse table:

$$
\begin{gathered}
\mathrm{S} \rightarrow \mathrm{NP} \mathrm{VP} \\
\mathrm{VP} \rightarrow \mathrm{~V} \mathrm{NP} \\
\mathrm{VP} \rightarrow \mathrm{VPPP} \\
\mathrm{NP} \rightarrow \mathrm{NP} \mathrm{VP} \\
\mathrm{PP} \rightarrow \mathrm{P} \text { NP }
\end{gathered}
$$

|  | 1 | 2 | 3 | 4 | 5 |
| :--- | :--- | :---: | :---: | :---: | :---: | :---: |
|  | NP |  | S |  | S |
| 1 |  | V | VP |  | VP |
| 2 |  |  | NP |  | NP |
|  |  |  |  | P | PP |
| 4 |  |  |  |  | NP |

(2) Which pair(s) of 'input' cells and which production(s) gave rise to the derivation of category $S$ in 'target' cell $\langle 0,5\rangle$ ?

## Question (3): Packed Parse Forests



## Question (3): Packed Parse Forests


(3) How many complete trees are represented in this forest?

## Question (4): Parser Evaluation




## Question (4): Parser Evaluation


(4) What are the ParsEval precision and recall scores for this pair of trees (gold on the left; system on the right)?

