Structured Perceptron

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Hands-On Demo

Problem setup

- Restricted set of POS tags: adjective, preposition, verb, determiner, noun
- We first have sentence “answer the question” with true POS sequence DET NN VB PRO
- Features are $(z_i, z_{i+1}), (z_i, w_i)$
- What’s a maximum violation POS sequence?

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- What’s a maximum violation POS sequence?
- Can do on paper because search is tractable
- So we’re all on the same page, let’s all use DET DET DET
- Break ties lexicographically

- Correct answer: VB DET NN
- Prediction: DET DET DET

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Gold Features

(START, VB)
(VB, DET)
(DET, NN)
(VB, answer)
(NN, question)

Shared Features

(DET, the)

Predicted Features

(START, DET)
(DET, DET)
(DET, answer)
(DET, question)

- Correct answer: VB DET NN
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Gold Features	Shared Features	Predicted Features
(START, VB) (VB, DET) (DET, NN) (VB, answer) (NN, question)	(DET, the)	(START, DET) (DET, DET) (DET, answer) (DET, question)

- New feature vector: (DET, DET): -2.00; (DET, NN): 1.00; (DET, answer): -1.00; (DET, question): -1.00; (NN, question): 1.00; (VB, DET): 1.00; (VB, answer): 1.00; (START, DET): -1.00; (START, VB): 1.00

- Correct answer: VB DET NN
- Prediction: DET DET DET

Gold Features	Shared Features	Predicted Features
(START, VB)	(DET, the)	(START, DET)
(VB, DET)		(DET, DET)
(DET, NN)		(DET, answer)
(VB, answer)		(DET, question)
(NN, question)		

- New feature vector: (DET, DET): -2.00; (DET, NN): 1.00; (DET, answer): -1.00; (DET, question): -1.00; (NN, question): 1.00; (VB, DET): 1.00; (VB, answer): 1.00; (START, DET): -1.00; (START, VB): 1.00

Decoding Sentence 2

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} & & \\ & & \\ & & \\ & & \end{pmatrix} \end{array} \tag{1}$$

Decoding Sentence 2

$w_{\text{START, PRO}} + w_{\text{PRO, question}} = 0.00 + 0.00 = 0.00$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} 0.00 & & \\ & & \\ & & \\ & & \end{pmatrix} \end{array} \tag{1}$$

Decoding Sentence 2

$w_{\text{START, NN}} + w_{\text{NN, question}} = 0.00 + 1.00 = 1.00$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} 0.00 & & \\ 1.00 & & \\ & & \\ & & \end{pmatrix} \end{array} \tag{1}$$

Decoding Sentence 2

$w_{\text{START, DET}} + w_{\text{DET, question}} = -1.00 + -1.00 = -2.00$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} 0.00 & & \\ 1.00 & & \\ -2.00 & & \\ & & \end{pmatrix} \end{array} \tag{1}$$

Decoding Sentence 2

$w_{\text{START, VB}} + w_{\text{VB, question}} = 1.00 + 0.00 = 1.00$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{c} \text{question}_0 \quad \text{the}_1 \quad \text{answer}_2 \end{array} \\ \begin{pmatrix} 0.00 & & \\ 1.00 & & \\ -2.00 & & \\ 1.00 & & \end{pmatrix} \end{array} \tag{1}$$

Decoding Sentence 2

$\delta_0(NN) + w_{\text{NN, PRO}} + w_{\text{PRO, the}} = 1.00 + 0.00 + 0.00 = 1.00$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & \\ 1.00 & & \\ -2.00 & & \\ 1.00 & & \end{pmatrix} \end{array} \tag{1}$$

Decoding Sentence 2

$\delta_0(NN) + w_{\text{NN, NN}} + w_{\text{NN, the}} = 1.00 + 0.00 + 0.00 = 1.00$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & \\ 1.00 & 1.00 & \\ -2.00 & & \\ 1.00 & & \end{pmatrix} \end{array} \tag{1}$$

Decoding Sentence 2

$$\delta_0(VB) + w_{\text{VB, DET}} + w_{\text{DET, the}} = 1.00 + 1.00 + 0.00 = 2.00$$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & \\ 1.00 & 1.00 & \\ -2.00 & 2.00 & \\ 1.00 & & \end{pmatrix} \end{array} \tag{1}$$

Decoding Sentence 2

$$\delta_0(NN) + w_{\text{NN, VB}} + w_{\text{VB, the}} = 1.00 + 0.00 + 0.00 = 1.00$$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & \\ 1.00 & 1.00 & \\ -2.00 & 2.00 & \\ 1.00 & 1.00 & \end{pmatrix} \end{array} \tag{1}$$

Decoding Sentence 2

$$\delta_1(DET) + w_{\text{DET, PRO}} + w_{\text{PRO, answer}} = 2.00 + 0.00 + 0.00 = 2.00$$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & \\ -2.00 & 2.00 & \\ 1.00 & 1.00 & \end{pmatrix} \end{array} \tag{1}$$

Decoding Sentence 2

$$\delta_1(DET) + w_{\text{DET, NN}} + w_{\text{NN, answer}} = 2.00 + 1.00 + 0.00 = 3.00$$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & 3.00 \\ -2.00 & 2.00 & \\ 1.00 & 1.00 & \end{pmatrix} \end{array} \tag{1}$$

Decoding Sentence 2

$$\delta_1(VB) + w_{\text{VB, DET}} + w_{\text{DET, answer}} = 1.00 + 1.00 + -1.00 = 1.00$$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & 3.00 \\ -2.00 & 2.00 & 1.00 \\ 1.00 & 1.00 & \end{pmatrix} \end{array} \tag{1}$$

Decoding Sentence 2

$$\delta_1(DET) + w_{\text{DET, VB}} + w_{\text{VB, answer}} = 2.00 + 0.00 + 1.00 = 3.00$$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & 3.00 \\ -2.00 & 2.00 & 1.00 \\ 1.00 & 1.00 & 3.00 \end{pmatrix} \end{array} \tag{1}$$

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- Backpointers

$$\beta = \begin{array}{c} \\ \text{PRO} \\ \text{NN} \\ \text{DET} \\ \text{VB} \end{array} \begin{array}{c} \begin{array}{cc} \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} NN & DET \\ NN & DET \\ VB & VB \\ NN & DET \end{pmatrix} \end{array} \tag{2}$$

Decoding Sentence 2

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & 3.00 \\ -2.00 & 2.00 & 1.00 \\ 1.00 & 1.00 & 3.00 \end{pmatrix} \end{array} \tag{1}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{PRO} \\ \text{NN} \\ \text{DET} \\ \text{VB} \end{array} \begin{array}{c} \begin{array}{cc} \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} NN & DET \\ NN & DET \\ VB & VB \\ NN & DET \end{pmatrix} \end{array} \tag{2}$$

Decoding Sentence 2

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & 3.00 \\ -2.00 & 2.00 & 1.00 \\ 1.00 & 1.00 & 3.00 \end{pmatrix} \end{array} \tag{1}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{PRO} \\ \text{NN} \\ \text{DET} \\ \text{VB} \end{array} \begin{array}{c} \begin{array}{cc} \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} NN & DET \\ NN & DET \\ VB & VB \\ NN & DET \end{pmatrix} \end{array} \tag{2}$$

- Reconstruction: VB DET NN

- Correct answer: VB DET NN
- Prediction: VB DET NN

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- Correct answer: VB DET NN
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Gold Features

Shared Features

(START, VB)
(VB, DET)
(DET, NN)
(VB, question)
(DET, the)
(NN, answer)

Predicted Features

- Correct answer: VB DET NN
- Prediction: VB DET NN

Gold Features

Shared Features

(START, VB)
(VB, DET)
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Predicted Features

- New feature vector: (DET, DET): -2.00; (DET, NN): 1.00; (DET, answer): -1.00; (DET, question): -1.00; (NN, question): 1.00; (VB, DET): 1.00; (VB, answer): 1.00; (START, DET): -1.00; (START, VB): 1.00

Decoding Sentence 3

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \left(\begin{array}{cccc} & & & \\ & & & \\ & & & \\ & & & \end{array} \right) \end{array} \tag{3}$$

Decoding Sentence 3

$w_{\text{START, PRO}} + w_{\text{PRO, you}} = 0.00 + 0.00 = 0.00$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{3}$$

Decoding Sentence 3

$w_{\text{START, NN}} + w_{\text{NN, you}} = 0.00 + 0.00 = 0.00$

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$w_{\text{START, DET}} + w_{\text{DET, you}} = -1.00 + 0.00 = -1.00$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.00 & & & \\ -1.00 & & & \\ & & & \end{pmatrix} \end{array} \tag{3}$$

Decoding Sentence 3

$w_{\text{START, VB}} + w_{\text{VB, you}} = 1.00 + 0.00 = 1.00$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.00 & & & \\ -1.00 & & & \\ 1.00 & & & \end{pmatrix} \end{array} \tag{3}$$

Decoding Sentence 3

$$\delta_0(VB) + w_{\text{VB, PRO}} + w_{\text{PRO, demand}} = 1.00 + 0.00 + 0.00 = 1.00$$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & & \\ 0.00 & & & \\ -1.00 & & & \\ 1.00 & & & \end{pmatrix} \end{array} \tag{3}$$

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$$\delta_0(VB) + w_{\text{VB, VB}} + w_{\text{VB, demand}} = 1.00 + 0.00 + 0.00 = 1.00$$

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$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & & \\ 0.00 & 1.00 & & \\ -1.00 & 2.00 & & \\ 1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{3}$$

Decoding Sentence 3

$$\delta_1(DET) + w_{\text{DET, PRO}} + w_{\text{PRO, the}} = 2.00 + 0.00 + 0.00 = 2.00$$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 & \\ 0.00 & 1.00 & & \\ -1.00 & 2.00 & & \\ 1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{3}$$

Decoding Sentence 3

$$\delta_1(DET) + w_{\text{DET, NN}} + w_{\text{NN, the}} = 2.00 + 1.00 + 0.00 = 3.00$$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 & \\ 0.00 & 1.00 & 3.00 & \\ -1.00 & 2.00 & & \\ 1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{3}$$

Decoding Sentence 3

$$\delta_1(VB) + w_{\text{VB, DET}} + w_{\text{DET, the}} = 1.00 + 1.00 + 0.00 = 2.00$$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 & \\ 0.00 & 1.00 & 3.00 & \\ -1.00 & 2.00 & 2.00 & \\ 1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{3}$$

Decoding Sentence 3

$$\delta_1(DET) + w_{\text{DET, VB}} + w_{\text{VB, the}} = 2.00 + 0.00 + 0.00 = 2.00$$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 & \\ 0.00 & 1.00 & 3.00 & \\ -1.00 & 2.00 & 2.00 & \\ 1.00 & 1.00 & 2.00 & \end{pmatrix} \end{array} \tag{3}$$

Decoding Sentence 3

$$\delta_2(NN) + w_{\text{NN, PRO}} + w_{\text{PRO, delay}} = 3.00 + 0.00 + 0.00 = 3.00$$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 & 3.00 \\ 0.00 & 1.00 & 3.00 & \\ -1.00 & 2.00 & 2.00 & \\ 1.00 & 1.00 & 2.00 & \end{pmatrix} \end{array} \tag{3}$$

Decoding Sentence 3

$$\delta_2(DET) + w_{\text{DET, NN}} + w_{\text{NN, delay}} = 2.00 + 1.00 + 0.00 = 3.00$$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 & 3.00 \\ 0.00 & 1.00 & 3.00 & 3.00 \\ -1.00 & 2.00 & 2.00 & \\ 1.00 & 1.00 & 2.00 & \end{pmatrix} \end{array} \tag{3}$$

Decoding Sentence 3

$$\delta_2(NN) + w_{\text{NN, DET}} + w_{\text{DET, delay}} = 3.00 + 0.00 + 0.00 = 3.00$$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 & 3.00 \\ 0.00 & 1.00 & 3.00 & 3.00 \\ -1.00 & 2.00 & 2.00 & 3.00 \\ 1.00 & 1.00 & 2.00 & \end{pmatrix} \end{array} \tag{3}$$

Decoding Sentence 3

$$\delta_2(NN) + w_{\text{NN, VB}} + w_{\text{VB, delay}} = 3.00 + 0.00 + 0.00 = 3.00$$

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 & 3.00 \\ 0.00 & 1.00 & 3.00 & 3.00 \\ -1.00 & 2.00 & 2.00 & 3.00 \\ 1.00 & 1.00 & 2.00 & 3.00 \end{pmatrix} \end{array} \tag{3}$$

Decoding Sentence 3

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 & 3.00 \\ 0.00 & 1.00 & 3.00 & 3.00 \\ -1.00 & 2.00 & 2.00 & 3.00 \\ 1.00 & 1.00 & 2.00 & 3.00 \end{pmatrix} \end{array} \tag{3}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{PRO} \\ \text{NN} \\ \text{DET} \\ \text{VB} \end{array} \begin{array}{c} \begin{array}{ccc} \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} VB & DET & NN \\ VB & DET & DET \\ VB & VB & NN \\ VB & DET & NN \end{pmatrix} \end{array} \tag{4}$$

Decoding Sentence 3

- Scores

$$\delta = \begin{array}{c} \\ \textit{PRO} \\ \textit{NN} \\ \textit{DET} \\ \textit{VB} \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 & 3.00 \\ 0.00 & 1.00 & 3.00 & 3.00 \\ -1.00 & 2.00 & 2.00 & 3.00 \\ 1.00 & 1.00 & 2.00 & 3.00 \end{pmatrix} \end{array} \tag{3}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{PRO} \\ \text{NN} \\ \text{DET} \\ \text{VB} \end{array} \begin{array}{c} \begin{array}{ccc} \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} \textit{VB} & \textit{DET} & \textit{NN} \\ \textit{VB} & \textit{DET} & \textit{DET} \\ \textit{VB} & \textit{VB} & \textit{NN} \\ \textit{VB} & \textit{DET} & \textit{NN} \end{pmatrix} \end{array} \tag{4}$$

Decoding Sentence 3

- Scores

$$\delta = \begin{array}{c} \\ PRO \\ NN \\ DET \\ VB \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 0.00 & 1.00 & 2.00 & 3.00 \\ 0.00 & 1.00 & 3.00 & 3.00 \\ -1.00 & 2.00 & 2.00 & 3.00 \\ 1.00 & 1.00 & 2.00 & 3.00 \end{pmatrix} \end{array} \tag{3}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{PRO} \\ \text{NN} \\ \text{DET} \\ \text{VB} \end{array} \begin{array}{c} \begin{array}{ccc} \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} VB & DET & NN \\ VB & DET & DET \\ VB & VB & NN \\ VB & DET & NN \end{pmatrix} \end{array} \tag{4}$$

- Reconstruction: VB DET NN DET

Wrapup

- Not just for POS tagging: parsing, machine translation
- Hard to overstate how important features $\vec{\Phi}$ are
- Deep learning: get algorithm to find features for us?

Wrapup

- Not just for POS tagging: parsing, machine translation
- Hard to overstate how important features $\vec{\Phi}$ are
- Deep learning: get algorithm to find features for us?
- Project ideas:
  - Deep learning of features
  - Applying perceptron to your favorite problem, designing great features
  - Efficient data structures for finding max violation