Online Learning

Natural Language Processing: Jordan Boyd-Graber
University of Colorado Boulder
LECTURE 21

Perceptron Algorithm

$\vec{w}_1 \leftarrow \vec{0}$;
for $t \leftarrow 1 \dots T$ **do**
    Receive x_t;
    $\hat{y}_t \leftarrow \text{sgn}(\vec{w}_t \cdot \vec{x}_t)$;
    Receive y_t;
    if $\hat{y}_t \neq y_t$ **then**
        $\vec{w}_{t+1} \leftarrow \vec{w}_t + y_t \vec{x}_t$;
    else
        $\vec{w}_{t+1} \leftarrow w_t$;
return w_{T+1}

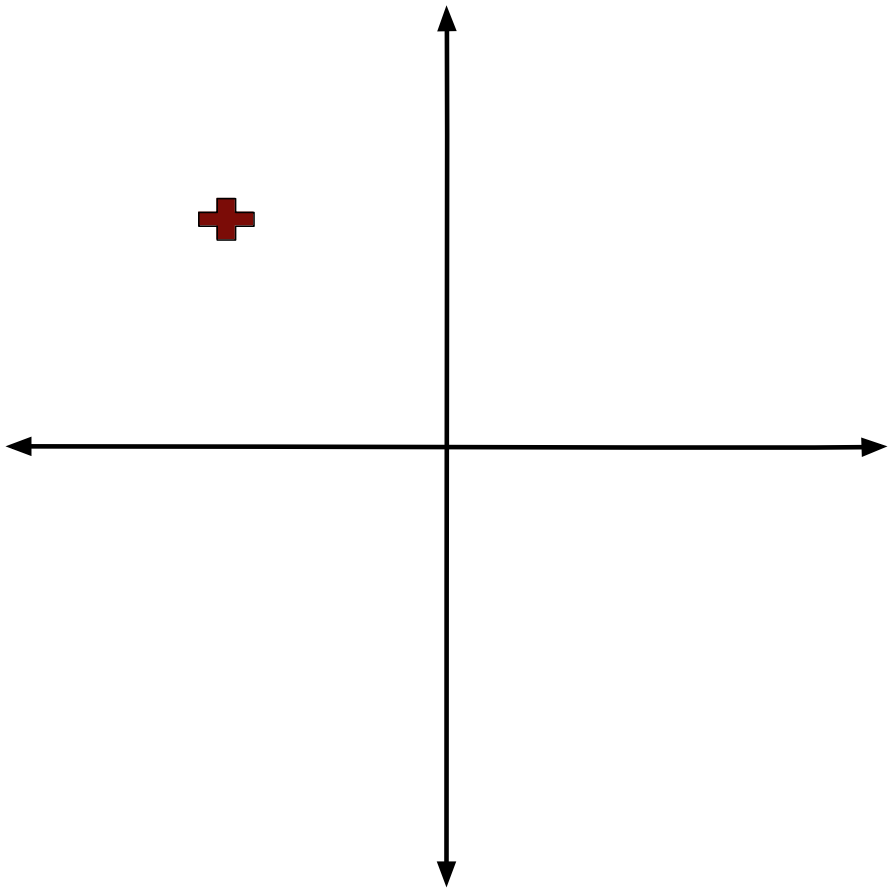
Algorithm 1: Perceptron Algorithm (Rosenblatt, 1958)

2D Example

Initially, weight vector is zero:

$$\vec{w}_1 = \langle 0, 0 \rangle \tag{1}$$

Observation 1



$$x_1 = \langle -2, 2 \rangle \quad (2)$$

$$\hat{y}_1 = 0 \quad (3)$$

$$y_1 = +1 \quad (4)$$

Update 1

$$\vec{w}_{t+1} \leftarrow \vec{w}_t + y_t \vec{x}_t \tag{5}$$

$$\vec{w}_2 \leftarrow \tag{6}$$

Update 1

$$\vec{w}_{t+1} \leftarrow \vec{w}_t + y_t \vec{x}_t \tag{5}$$

$$\vec{w}_2 \leftarrow \langle 0, 0 \rangle + \langle -2, 2 \rangle \tag{6}$$

$$\tag{7}$$

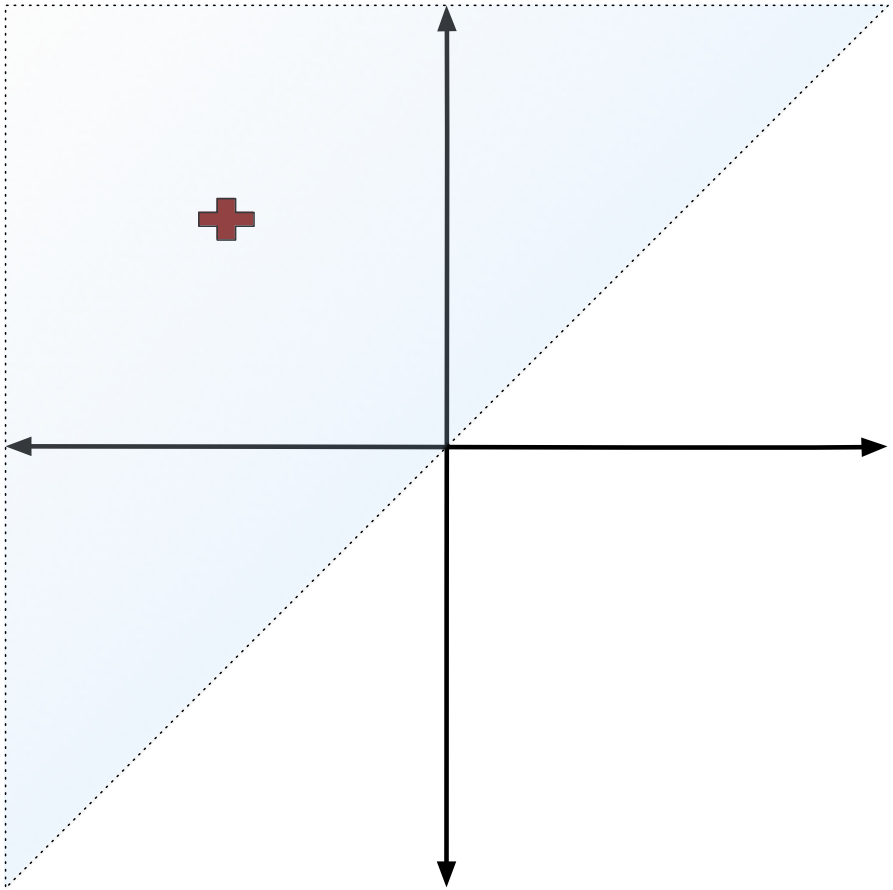
Update 1

$$\vec{w}_{t+1} \leftarrow \vec{w}_t + y_t \vec{x}_t \tag{5}$$

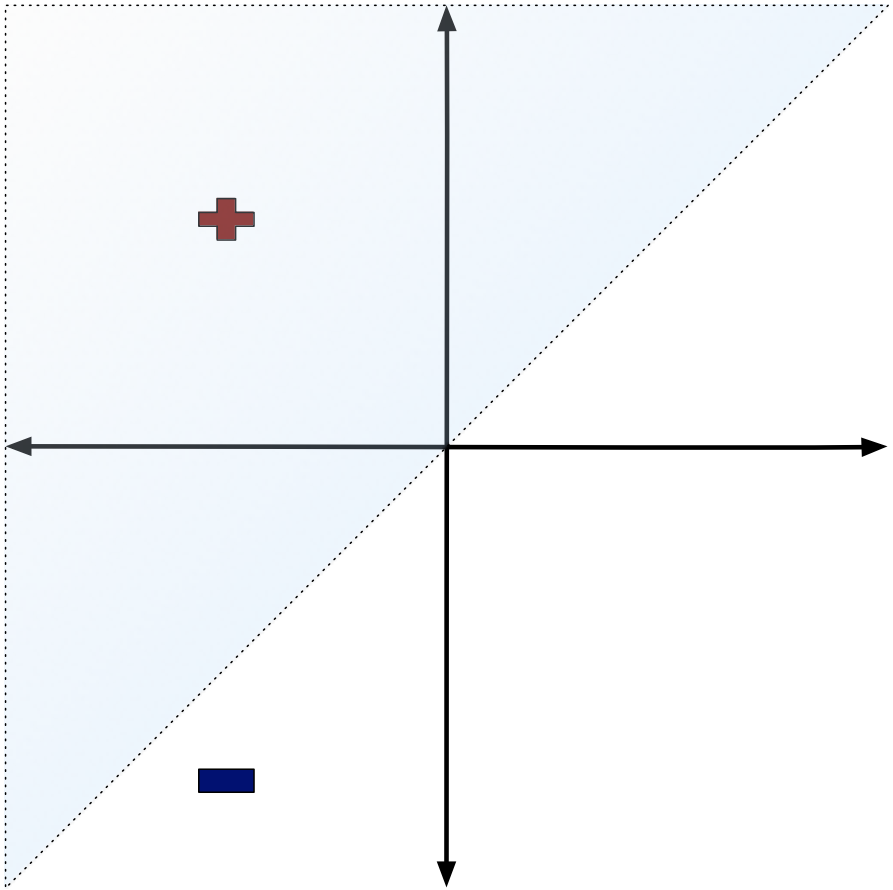
$$\vec{w}_2 \leftarrow \langle 0, 0 \rangle + \langle -2, 2 \rangle \tag{6}$$

$$\vec{w}_2 = \langle -2, 2 \rangle \tag{7}$$

Observation 2



Observation 2



$$x_2 = \langle -2, -3 \rangle \tag{8}$$

$$\hat{y}_2 = +4 + -6 = -2 \tag{9}$$

$$y_2 = -1 \tag{10}$$

Update 2

$$\vec{w}_{t+1} \leftarrow \vec{w}_t \tag{11}$$

$$\vec{w}_2 \leftarrow \tag{12}$$

Update 2

$$\vec{w}_{t+1} \leftarrow \vec{w}_t \tag{11}$$

$$\vec{w}_2 \leftarrow \langle -2, 2 \rangle \tag{12}$$

$$\tag{13}$$

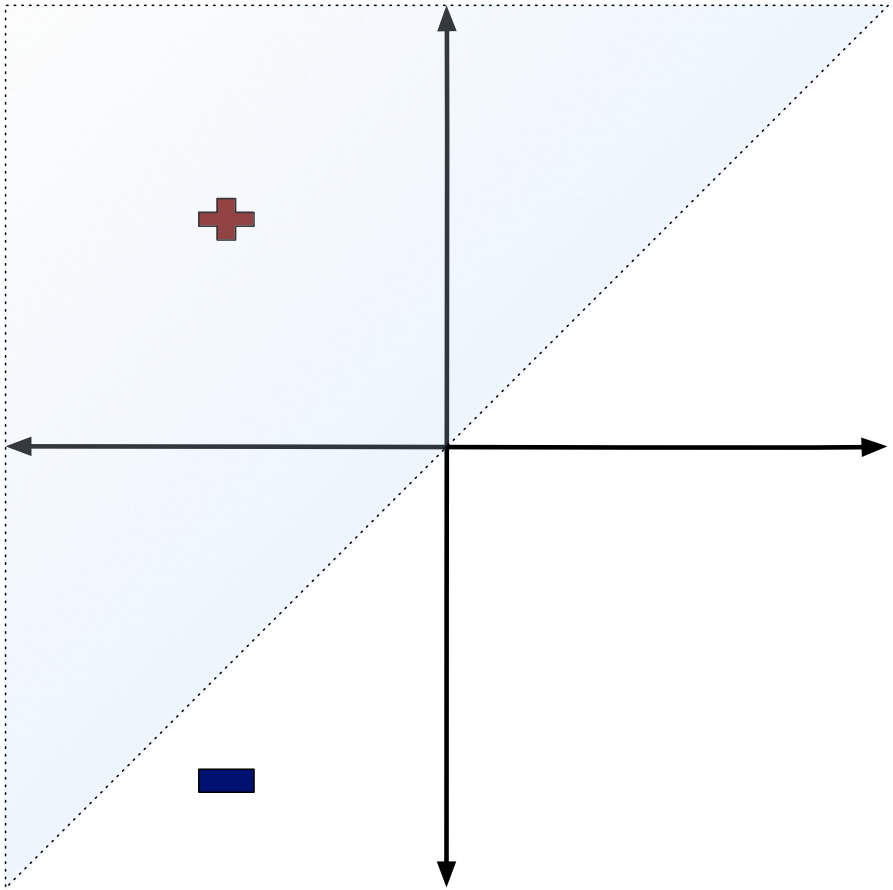
Update 2

$$\vec{w}_{t+1} \leftarrow \vec{w}_t \tag{11}$$

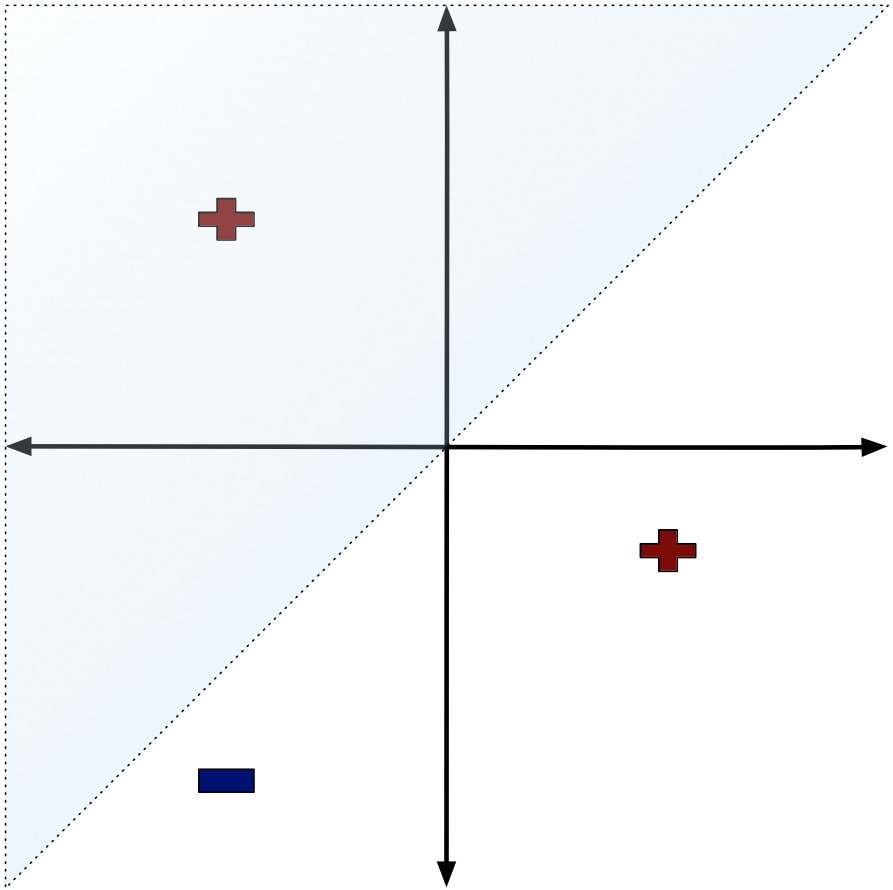
$$\vec{w}_2 \leftarrow \langle -2, 2 \rangle \tag{12}$$

$$\vec{w}_2 = \langle -2, 2 \rangle \tag{13}$$

Observation 3



Observation 3



$$x_3 = \langle 2, -1 \rangle \tag{14}$$

$$\hat{y}_3 = -4 + -2 = -6 \tag{15}$$

$$y_3 = +1 \tag{16}$$

Update 3

$$\vec{w}_{t+1} \leftarrow \vec{w}_t + y_t \vec{x}_t \tag{17}$$

$$\vec{w}_3 \leftarrow \tag{18}$$

Update 3

$$\vec{w}_{t+1} \leftarrow \vec{w}_t + y_t \vec{x}_t \tag{17}$$

$$\vec{w}_3 \leftarrow \langle -2, 2 \rangle + \langle 2, -1 \rangle \tag{18}$$

$$\tag{19}$$

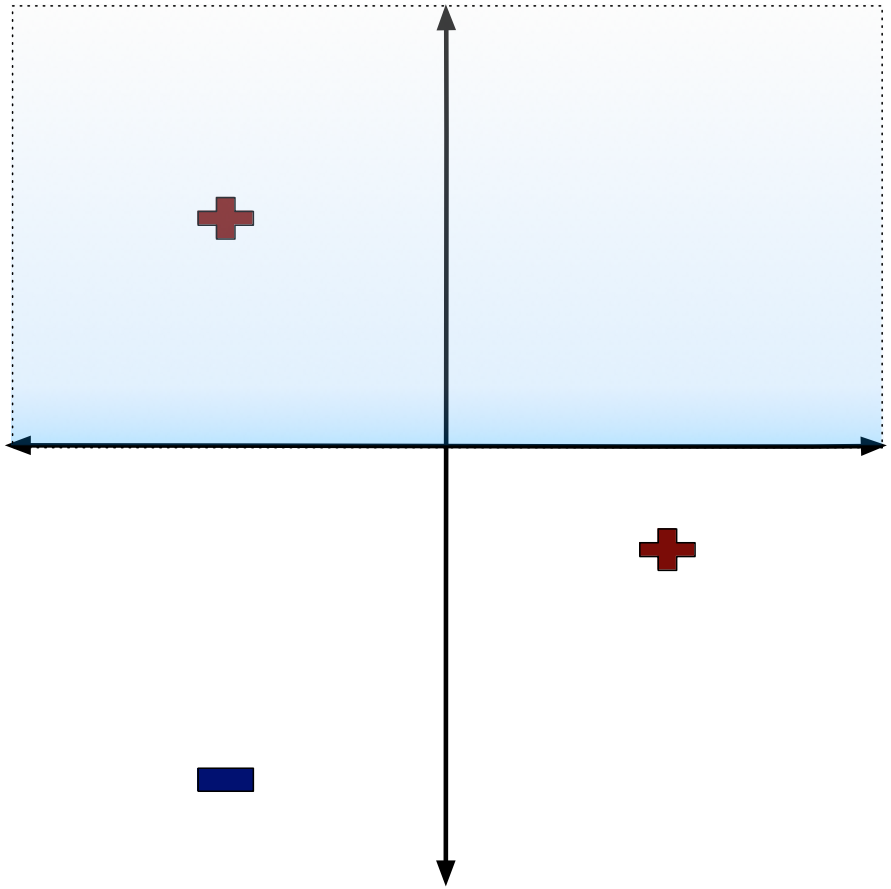
Update 3

$$\vec{w}_{t+1} \leftarrow \vec{w}_t + y_t \vec{x}_t \tag{17}$$

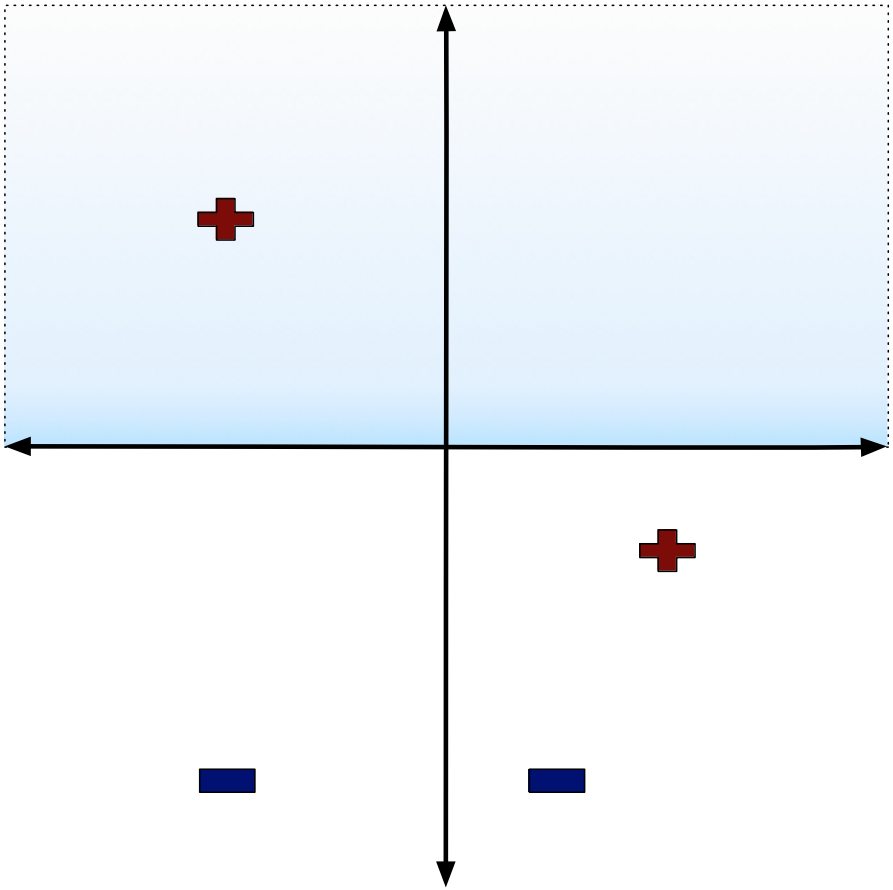
$$\vec{w}_3 \leftarrow \langle -2, 2 \rangle + \langle 2, -1 \rangle \tag{18}$$

$$\vec{w}_3 = \langle 0, 1 \rangle \tag{19}$$

Observation 4



Observation 4



$$x_4 = \langle 1, -4 \rangle \tag{20}$$

$$\hat{y}_4 = -4 \tag{21}$$

$$y_4 = -1 \tag{22}$$

Update 4

$$\vec{w}_4 \leftarrow \tag{23}$$

Update 4

$$\vec{w}_4 \leftarrow \vec{w}_3 \tag{23}$$

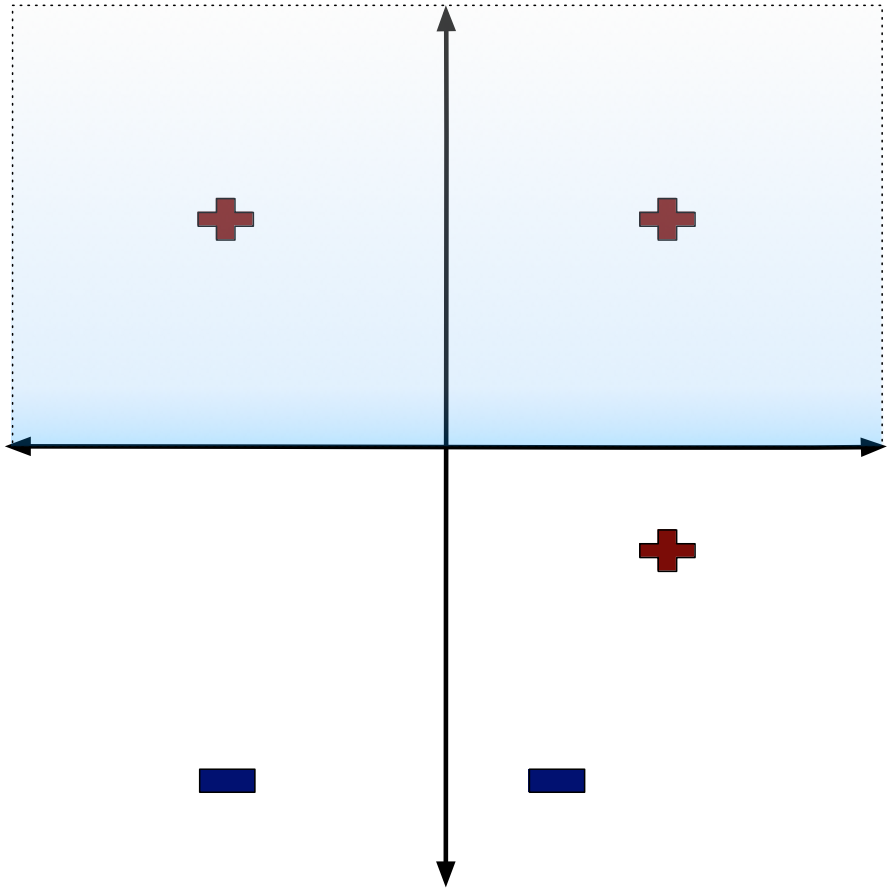
$$\tag{24}$$

Update 4

$$\vec{w}_4 \leftarrow \vec{w}_3 \tag{23}$$

$$\vec{w}_4 = \langle 0, 1 \rangle \tag{24}$$

Observation 5



$$x_5 = \langle 2, 2 \rangle \quad (25)$$

$$\hat{y}_5 = 2 \quad (26)$$

$$y_5 = +1 \quad (27)$$

Update 5

$$\vec{w}_5 \leftarrow \tag{28}$$

Update 5

$$\vec{w}_5 \leftarrow \vec{w}_4 \tag{28}$$

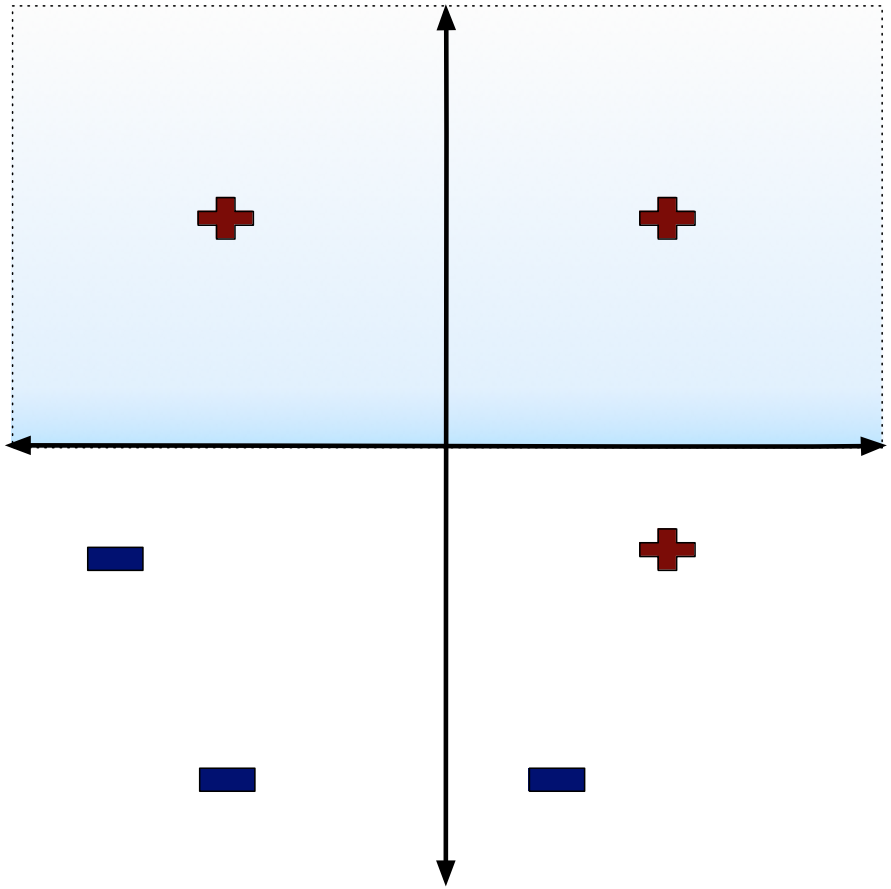
$$\tag{29}$$

Update 5

$$\vec{w}_5 \leftarrow \vec{w}_4 \tag{28}$$

$$\vec{w}_5 = \langle 0, 1 \rangle \tag{29}$$

Observation 6



$$x_6 = \langle 2, 2 \rangle \quad (30)$$

$$\hat{y}_6 = 2 \quad (31)$$

$$y_6 = +1 \quad (32)$$

Update 6

$$\vec{w}_6 \leftarrow \tag{33}$$

Update 6

$$\vec{w}_6 \leftarrow \vec{w}_5 \tag{33}$$

(34)

Update 6

$$\vec{w}_6 \leftarrow \vec{w}_5 \tag{33}$$

$$\vec{w}_6 = \langle 0, 1 \rangle \tag{34}$$

Decoding Sentence 1

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{answer}_0 & \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} & & \\ & & \\ & & \\ & & \end{pmatrix} \end{array} \tag{35}$$

Decoding Sentence 1

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{answer}_0 & \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} 0.00 & & \\ & & \\ & & \\ & & \end{pmatrix} \end{array} \tag{35}$$

Decoding Sentence 1

$$w_{\text{START, DET}} + w_{\text{DET, answer}} = 0.00 + 0.00 = 0.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{answer}_0 & \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} 0.00 & & \\ 0.00 & & \\ & & \\ & & \end{pmatrix} \end{array} \tag{35}$$

Decoding Sentence 1

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{answer}_0 & \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} 0.00 & & \\ 0.00 & & \\ 0.00 & & \\ & & \end{pmatrix} \end{array} \tag{35}$$

Decoding Sentence 1

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{answer}_0 & \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} 0.00 & & \\ 0.00 & & \\ 0.00 & & \\ 0.00 & & \end{pmatrix} \end{array} \tag{35}$$

Decoding Sentence 1

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{answer}_0 & \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} 0.00 & 0.00 & \\ 0.00 & & \\ 0.00 & & \\ 0.00 & & \end{pmatrix} \end{array} \tag{35}$$

Decoding Sentence 1

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cc} \text{answer}_0 & \text{the}_1 \quad \text{question}_2 \end{array} \\ \begin{pmatrix} 0.00 & 0.00 \\ 0.00 & 0.00 \\ 0.00 & \\ 0.00 & \end{pmatrix} \end{array} \tag{35}$$

Decoding Sentence 1

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{answer}_0 & \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} 0.00 & 0.00 & \\ 0.00 & 0.00 & \\ 0.00 & 0.00 & \\ 0.00 & & \end{pmatrix} \end{array} \tag{35}$$

Decoding Sentence 1

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cc} \text{answer}_0 & \text{the}_1 \quad \text{question}_2 \end{array} \\ \begin{pmatrix} 0.00 & 0.00 \\ 0.00 & 0.00 \\ 0.00 & 0.00 \\ 0.00 & 0.00 \end{pmatrix} \end{array} \tag{35}$$

Decoding Sentence 1

$$\delta_1(VB) + w_{\text{VB, VB}} + w_{\text{VB, question}} = 0.00 + 0.00 + 0.00 = 0.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{answer}_0 & \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & \\ 0.00 & 0.00 & \\ 0.00 & 0.00 & \end{pmatrix} \end{array} \tag{35}$$

Decoding Sentence 1

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{answer}_0 & \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & \\ 0.00 & 0.00 & \end{pmatrix} \end{array} \tag{35}$$

Decoding Sentence 1

$$\delta_1(VB) + w_{\text{VB, PRO}} + w_{\text{PRO, question}} = 0.00 + 0.00 + 0.00 = 0.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{answer}_0 & \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & \end{pmatrix} \end{array} \tag{35}$$

Decoding Sentence 1

$$\delta_1(VB) + w_{\text{VB, NN}} + w_{\text{NN, question}} = 0.00 + 0.00 + 0.00 = 0.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{answer}_0 & \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \end{pmatrix} \end{array} \tag{35}$$

Decoding Sentence 1

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{answer}_0 & \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \end{pmatrix} \end{array} \tag{35}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{cc} \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} VB & VB \\ VB & VB \\ VB & VB \\ VB & VB \end{pmatrix} \end{array} \tag{36}$$

Decoding Sentence 1

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{answer}_0 & \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \end{pmatrix} \end{array} \tag{35}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{cc} \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} VB & VB \\ VB & VB \\ VB & VB \\ VB & VB \end{pmatrix} \end{array} \tag{36}$$

Decoding Sentence 1

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{answer}_0 & \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \end{pmatrix} \end{array} \tag{35}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{cc} \text{the}_1 & \text{question}_2 \end{array} \\ \begin{pmatrix} VB & VB \\ VB & VB \\ VB & VB \\ VB & VB \end{pmatrix} \end{array} \tag{36}$$

- Reconstruction: VB VB VB

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

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

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

Gold Features

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

Shared Features

(START, VB)
(VB, answer)

Predicted Features

(VB, the)
(VB, question)
(VB, VB)

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

Gold Features

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

Shared Features

(START, VB)
(VB, answer)

Predicted Features

(VB, the)
(VB, question)
(VB, VB)

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

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

Gold Features

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

Shared Features

(START, VB)
(VB, answer)

Predicted Features

(VB, the)
(VB, question)
(VB, VB)

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

Decoding Sentence 2

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} & & \\ & & \\ & & \\ & & \end{pmatrix} \end{array} \tag{37}$$

Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & & \\ & & \\ & & \\ & & \end{pmatrix} \end{array} \tag{37}$$

Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & & \\ 0.00 & & \\ & & \\ & & \end{pmatrix} \end{array} \tag{37}$$

Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & & \\ 0.00 & & \\ 0.00 & & \\ & & \end{pmatrix} \end{array} \tag{37}$$

Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{c} \text{question}_0 \quad \text{the}_1 \quad \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & & \\ 0.00 & & \\ 0.00 & & \\ 1.00 & & \end{pmatrix} \end{array} \tag{37}$$

Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cc} \text{question}_0 & \text{the}_1 \quad \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 \\ 0.00 & \\ 0.00 & \\ 1.00 & \end{pmatrix} \end{array} \tag{37}$$

Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & \\ 0.00 & 2.00 & \\ 0.00 & & \\ 1.00 & & \end{pmatrix} \end{array} \tag{37}$$

Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & \\ 0.00 & 2.00 & \\ 0.00 & 1.00 & \\ 1.00 & & \end{pmatrix} \end{array} \tag{37}$$

Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cc} \text{question}_0 & \text{the}_1 \quad \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 \\ 0.00 & 2.00 \\ 0.00 & 1.00 \\ 1.00 & 1.00 \end{pmatrix} \end{array} \tag{37}$$

Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & 2.00 \\ 0.00 & 2.00 & \\ 0.00 & 1.00 & \\ 1.00 & 1.00 & \end{pmatrix} \end{array} \tag{37}$$

Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & 2.00 \\ 0.00 & 2.00 & 2.00 \\ 0.00 & 1.00 & \\ 1.00 & 1.00 & \end{pmatrix} \end{array} \tag{37}$$

Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & 2.00 \\ 0.00 & 2.00 & 2.00 \\ 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & \end{pmatrix} \end{array} \tag{37}$$

Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & 2.00 \\ 0.00 & 2.00 & 2.00 \\ 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & 3.00 \end{pmatrix} \end{array} \tag{37}$$

Decoding Sentence 2

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & 2.00 \\ 0.00 & 2.00 & 2.00 \\ 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & 3.00 \end{pmatrix} \end{array} \tag{37}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{cc} \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} NN & DET \\ NN & DET \\ NN & DET \\ DET & DET \end{pmatrix} \end{array} \tag{38}$$

Decoding Sentence 2

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & 2.00 \\ 0.00 & 2.00 & 2.00 \\ 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & 3.00 \end{pmatrix} \end{array} \tag{37}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{cc} \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} NN & DET \\ NN & DET \\ NN & DET \\ DET & DET \end{pmatrix} \end{array} \tag{38}$$

Decoding Sentence 2

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & 2.00 \\ 0.00 & 2.00 & 2.00 \\ 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & 3.00 \end{pmatrix} \end{array} \tag{37}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{cc} \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} NN & DET \\ NN & DET \\ NN & DET \\ DET & DET \end{pmatrix} \end{array} \tag{38}$$

- Reconstruction: NN DET NN

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

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

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

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

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

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

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

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

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

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

Decoding Sentence 3

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & & & \\ 0.00 & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & & & \\ 0.00 & & & \\ 0.00 & & & \\ & & & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & & & \\ 0.00 & & & \\ 0.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & & \\ 0.00 & & & \\ 0.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

$$\delta_0(VB) + w_{\text{VB, DET}} + w_{\text{DET, demand}} = 1.00 + 2.00 + 0.00 = 3.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & & \\ 0.00 & 3.00 & & \\ 0.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & & \\ 0.00 & 3.00 & & \\ 0.00 & 1.00 & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & & \\ 0.00 & 3.00 & & \\ 0.00 & 1.00 & & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & \\ 0.00 & 3.00 & & \\ 0.00 & 1.00 & & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

$$\delta_1(DET) + w_{\text{DET, DET}} + w_{\text{DET, the}} = 3.00 + 0.00 + 1.00 = 4.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & \\ 0.00 & 3.00 & 4.00 & \\ 0.00 & 1.00 & & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & \\ 0.00 & 3.00 & 4.00 & \\ 0.00 & 1.00 & 3.00 & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

$$\delta_1(DET) + w_{\text{DET, NN}} + w_{\text{NN, the}} = 3.00 + 1.00 + 0.00 = 4.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & \\ 0.00 & 3.00 & 4.00 & \\ 0.00 & 1.00 & 3.00 & \\ -1.00 & 1.00 & 4.00 & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

$$\delta_2(DET) + w_{\text{DET, VB}} + w_{\text{VB, delay}} = 4.00 + 0.00 + 0.00 = 4.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & 4.00 \\ 0.00 & 3.00 & 4.00 & \\ 0.00 & 1.00 & 3.00 & \\ -1.00 & 1.00 & 4.00 & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

$$\delta_2(VB) + w_{\text{VB, DET}} + w_{\text{DET, delay}} = 2.00 + 2.00 + 0.00 = 4.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & 4.00 \\ 0.00 & 3.00 & 4.00 & 4.00 \\ 0.00 & 1.00 & 3.00 & \\ -1.00 & 1.00 & 4.00 & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

$$\delta_2(DET) + w_{\text{DET, PRO}} + w_{\text{PRO, delay}} = 4.00 + 0.00 + 0.00 = 4.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & 4.00 \\ 0.00 & 3.00 & 4.00 & 4.00 \\ 0.00 & 1.00 & 3.00 & 4.00 \\ -1.00 & 1.00 & 4.00 & \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

$$\delta_2(DET) + w_{\text{DET, NN}} + w_{\text{NN, delay}} = 4.00 + 1.00 + 0.00 = 5.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & 4.00 \\ 0.00 & 3.00 & 4.00 & 4.00 \\ 0.00 & 1.00 & 3.00 & 4.00 \\ -1.00 & 1.00 & 4.00 & 5.00 \end{pmatrix} \end{array} \tag{39}$$

Decoding Sentence 3

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & 4.00 \\ 0.00 & 3.00 & 4.00 & 4.00 \\ 0.00 & 1.00 & 3.00 & 4.00 \\ -1.00 & 1.00 & 4.00 & 5.00 \end{pmatrix} \end{array} \tag{39}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} DET & DET & DET \\ VB & DET & VB \\ VB & DET & DET \\ VB & DET & DET \end{pmatrix} \end{array} \tag{40}$$

Decoding Sentence 3

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & 4.00 \\ 0.00 & 3.00 & 4.00 & 4.00 \\ 0.00 & 1.00 & 3.00 & 4.00 \\ -1.00 & 1.00 & 4.00 & 5.00 \end{pmatrix} \end{array} \tag{39}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} DET & DET & DET \\ VB & DET & VB \\ VB & DET & DET \\ VB & DET & DET \end{pmatrix} \end{array} \tag{40}$$

Decoding Sentence 3

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & 4.00 \\ 0.00 & 3.00 & 4.00 & 4.00 \\ 0.00 & 1.00 & 3.00 & 4.00 \\ -1.00 & 1.00 & 4.00 & 5.00 \end{pmatrix} \end{array} \tag{39}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} DET & DET & DET \\ VB & DET & VB \\ VB & DET & DET \\ VB & DET & DET \end{pmatrix} \end{array} \tag{40}$$

- Reconstruction: VB DET DET NN

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

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

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

Gold Features	Shared Features	Predicted Features
(VB, demand)	(DET, the)	(DET, DET)
(PRO, you)	(DET, NN)	(START, VB)
(START, PRO)	(VB, DET)	(DET, demand)
(PRO, VB)	(NN, delay)	(VB, you)

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

Gold Features	Shared Features	Predicted Features
(VB, demand)	(DET, the)	(DET, DET)
(PRO, you)	(DET, NN)	(START, VB)
(START, PRO)	(VB, DET)	(DET, demand)
(PRO, VB)	(NN, delay)	(VB, you)

- New feature vector: (DET, DET): -1.00; (DET, NN): 1.00; (DET, demand): -1.00; (DET, the): 1.00; (NN, DET): -1.00; (PRO, VB): 1.00; (PRO, you): 1.00; (VB, DET): 2.00; (VB, VB): -2.00; (VB, demand): 1.00; (VB, the): -1.00; (VB, you): -1.00; (START, NN): -1.00; (START, PRO): 1.00

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

Gold Features	Shared Features	Predicted Features
(VB, demand)	(DET, the)	(DET, DET)
(PRO, you)	(DET, NN)	(START, VB)
(START, PRO)	(VB, DET)	(DET, demand)
(PRO, VB)	(NN, delay)	(VB, you)

- New feature vector: (DET, DET): -1.00; (DET, NN): 1.00; (DET, demand): -1.00; (DET, the): 1.00; (NN, DET): -1.00; (PRO, VB): 1.00; (PRO, you): 1.00; (VB, DET): 2.00; (VB, VB): -2.00; (VB, demand): 1.00; (VB, the): -1.00; (VB, you): -1.00; (START, NN): -1.00; (START, PRO): 1.00

Decoding Sentence 4

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & & & \\ 0.00 & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

$$w_{\text{START, PRO}} + w_{\text{PRO, you}} = 1.00 + 1.00 = 2.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & & & \\ 0.00 & & & \\ 2.00 & & & \\ & & & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & & & \\ 0.00 & & & \\ 2.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

$$\delta_0(PRO) + w_{\text{PRO, VB}} + w_{\text{VB, delay}} = 2.00 + 1.00 + 0.00 = 3.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & & \\ 0.00 & & & \\ 2.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

$$\delta_0(PRO) + w_{\text{PRO, DET}} + w_{\text{DET, delay}} = 2.00 + 0.00 + 0.00 = 2.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & & \\ 0.00 & 2.00 & & \\ 2.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

$$\delta_0(PRO) + w_{\text{PRO, PRO}} + w_{\text{PRO, delay}} = 2.00 + 0.00 + 0.00 = 2.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & & \\ 0.00 & 2.00 & & \\ 2.00 & 2.00 & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

$$\delta_0(PRO) + w_{\text{PRO, NN}} + w_{\text{NN, delay}} = 2.00 + 0.00 + 0.00 = 2.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & & \\ 0.00 & 2.00 & & \\ 2.00 & 2.00 & & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & \\ 0.00 & 2.00 & & \\ 2.00 & 2.00 & & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

$$\delta_1(VB) + w_{\text{VB, DET}} + w_{\text{DET, the}} = 3.00 + 2.00 + 1.00 = 6.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & \\ 0.00 & 2.00 & 6.00 & \\ 2.00 & 2.00 & & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

$$\delta_1(VB) + w_{\text{VB, PRO}} + w_{\text{PRO, the}} = 3.00 + 0.00 + 0.00 = 3.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & \\ 0.00 & 2.00 & 6.00 & \\ 2.00 & 2.00 & 3.00 & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & \\ 0.00 & 2.00 & 6.00 & \\ 2.00 & 2.00 & 3.00 & \\ -1.00 & 2.00 & 3.00 & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

$$\delta_2(DET) + w_{\text{DET, VB}} + w_{\text{VB, demand}} = 6.00 + 0.00 + 1.00 = 7.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & 7.00 \\ 0.00 & 2.00 & 6.00 & \\ 2.00 & 2.00 & 3.00 & \\ -1.00 & 2.00 & 3.00 & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

$\delta_2(DET) + w_{\text{DET, DET}} + w_{\text{DET, demand}} =$
$6.00 + -1.00 + -1.00 = 4.00$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & 7.00 \\ 0.00 & 2.00 & 6.00 & 4.00 \\ 2.00 & 2.00 & 3.00 & \\ -1.00 & 2.00 & 3.00 & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

$$\delta_2(DET) + w_{\text{DET, PRO}} + w_{\text{PRO, demand}} = 6.00 + 0.00 + 0.00 = 6.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & 7.00 \\ 0.00 & 2.00 & 6.00 & 4.00 \\ 2.00 & 2.00 & 3.00 & 6.00 \\ -1.00 & 2.00 & 3.00 & \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

$$\delta_2(DET) + w_{\text{DET, NN}} + w_{\text{NN, demand}} = 6.00 + 1.00 + 0.00 = 7.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & 7.00 \\ 0.00 & 2.00 & 6.00 & 4.00 \\ 2.00 & 2.00 & 3.00 & 6.00 \\ -1.00 & 2.00 & 3.00 & 7.00 \end{pmatrix} \end{array} \tag{41}$$

Decoding Sentence 4

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & 7.00 \\ 0.00 & 2.00 & 6.00 & 4.00 \\ 2.00 & 2.00 & 3.00 & 6.00 \\ -1.00 & 2.00 & 3.00 & 7.00 \end{pmatrix} \end{array} \tag{41}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} PRO & PRO & DET \\ PRO & VB & DET \\ PRO & VB & DET \\ PRO & VB & DET \end{pmatrix} \end{array} \tag{42}$$

Decoding Sentence 4

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & 7.00 \\ 0.00 & 2.00 & 6.00 & 4.00 \\ 2.00 & 2.00 & 3.00 & 6.00 \\ -1.00 & 2.00 & 3.00 & 7.00 \end{pmatrix} \end{array} \tag{41}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} PRO & PRO & DET \\ PRO & VB & DET \\ PRO & VB & DET \\ PRO & VB & DET \end{pmatrix} \end{array} \tag{42}$$

Decoding Sentence 4

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & 7.00 \\ 0.00 & 2.00 & 6.00 & 4.00 \\ 2.00 & 2.00 & 3.00 & 6.00 \\ -1.00 & 2.00 & 3.00 & 7.00 \end{pmatrix} \end{array} \tag{41}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} PRO & PRO & DET \\ PRO & VB & DET \\ PRO & VB & DET \\ PRO & VB & DET \end{pmatrix} \end{array} \tag{42}$$

- Reconstruction: PRO VB DET VB

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

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

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

Gold Features

(DET, NN)
(NN, demand)

Shared Features

(VB, delay)
(DET, the)
(VB, DET)
(PRO, you)
(START, PRO)
(PRO, VB)

Predicted Features

(DET, VB)
(VB, demand)

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

Gold Features

(DET, NN)
(NN, demand)

Shared Features

(VB, delay)
(DET, the)
(VB, DET)
(PRO, you)
(START, PRO)
(PRO, VB)

Predicted Features

(DET, VB)
(VB, demand)

- New feature vector: (DET, DET): -1.00; (DET, NN): 2.00; (DET, VB): -1.00; (DET, demand): -1.00; (DET, the): 1.00; (NN, DET): -1.00; (NN, demand): 1.00; (PRO, VB): 1.00; (PRO, you): 1.00; (VB, DET): 2.00; (VB, VB): -2.00; (VB, the): -1.00; (VB, you): -1.00; (START, NN): -1.00; (START, PRO): 1.00

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

Gold Features

(DET, NN)
(NN, demand)

Shared Features

(VB, delay)
(DET, the)
(VB, DET)
(PRO, you)
(START, PRO)
(PRO, VB)

Predicted Features

(DET, VB)
(VB, demand)

- New feature vector: (DET, DET): -1.00; (DET, NN): 2.00; (DET, VB): -1.00; (DET, demand): -1.00; (DET, the): 1.00; (NN, DET): -1.00; (NN, demand): 1.00; (PRO, VB): 1.00; (PRO, you): 1.00; (VB, DET): 2.00; (VB, VB): -2.00; (VB, the): -1.00; (VB, you): -1.00; (START, NN): -1.00; (START, PRO): 1.00

Decoding Sentence 5

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

$$w_{\text{START, DET}} + w_{\text{DET, what}} = 0.00 + 0.00 = 0.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.00 & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

$$w_{\text{START, PRO}} + w_{\text{PRO, what}} = 1.00 + 0.00 = 1.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.00 & & & \\ 1.00 & & & \\ & & & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.00 & & & \\ 1.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & & & \\ 1.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & 2.00 & & \\ 1.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & 2.00 & & \\ 1.00 & 1.00 & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

$$\delta_0(DET) + w_{\text{DET, NN}} + w_{\text{NN, silence}} = 0.00 + 2.00 + 0.00 = 2.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & 2.00 & & \\ 1.00 & 1.00 & & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & \\ 0.00 & 2.00 & & \\ 1.00 & 1.00 & & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

$$\delta_1(VB) + w_{\text{VB, DET}} + w_{\text{DET, can}} = 2.00 + 2.00 + 0.00 = 4.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & \\ 0.00 & 2.00 & 4.00 & \\ 1.00 & 1.00 & & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

$$\delta_1(VB) + w_{\text{VB, PRO}} + w_{\text{PRO, can}} = 2.00 + 0.00 + 0.00 = 2.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & \\ 0.00 & 2.00 & 4.00 & \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

$$\delta_1(DET) + w_{\text{DET, NN}} + w_{\text{NN, can}} = 2.00 + 2.00 + 0.00 = 4.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & \\ 0.00 & 2.00 & 4.00 & \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 2.00 & 4.00 & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

$$\delta_2(NN) + w_{\text{NN, VB}} + w_{\text{VB, show}} = 4.00 + 0.00 + 0.00 = 4.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & 4.00 \\ 0.00 & 2.00 & 4.00 & \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 2.00 & 4.00 & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

$$\delta_2(VB) + w_{\text{VB, DET}} + w_{\text{DET, show}} = 2.00 + 2.00 + 0.00 = 4.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & 4.00 \\ 0.00 & 2.00 & 4.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 2.00 & 4.00 & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

$$\delta_2(DET) + w_{\text{DET, PRO}} + w_{\text{PRO, show}} = 4.00 + 0.00 + 0.00 = 4.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & 4.00 \\ 0.00 & 2.00 & 4.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 4.00 \\ -1.00 & 2.00 & 4.00 & \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

$$\delta_2(DET) + w_{\text{DET, NN}} + w_{\text{NN, show}} = 4.00 + 2.00 + 0.00 = 6.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & 4.00 \\ 0.00 & 2.00 & 4.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 4.00 \\ -1.00 & 2.00 & 4.00 & 6.00 \end{pmatrix} \end{array} \tag{43}$$

Decoding Sentence 5

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & 4.00 \\ 0.00 & 2.00 & 4.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 4.00 \\ -1.00 & 2.00 & 4.00 & 6.00 \end{pmatrix} \end{array} \tag{43}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} PRO & PRO & NN \\ VB & VB & VB \\ PRO & VB & DET \\ DET & DET & DET \end{pmatrix} \end{array} \tag{44}$$

Decoding Sentence 5

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & 4.00 \\ 0.00 & 2.00 & 4.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 4.00 \\ -1.00 & 2.00 & 4.00 & 6.00 \end{pmatrix} \end{array} \tag{43}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} PRO & PRO & NN \\ VB & VB & VB \\ PRO & VB & DET \\ DET & DET & DET \end{pmatrix} \end{array} \tag{44}$$

Decoding Sentence 5

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & 4.00 \\ 0.00 & 2.00 & 4.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 4.00 \\ -1.00 & 2.00 & 4.00 & 6.00 \end{pmatrix} \end{array} \tag{43}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} PRO & PRO & NN \\ VB & VB & VB \\ PRO & VB & DET \\ DET & DET & DET \end{pmatrix} \end{array} \tag{44}$$

- Reconstruction: PRO VB DET NN

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

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

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

Gold Features

(VB, show)
(VB, can)
(PRO, NN)
(NN, silence)
(NN, VB) (VB, VB)

Shared Features

(START, PRO)
(PRO, what)

Predicted Features

(DET, can)
(NN, show)
(VB, silence)
(DET, NN)
(VB, DET)
(PRO, VB)

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

Gold Features

(VB, show)
(VB, can)
(PRO, NN)
(NN, silence)
(NN, VB) (VB, VB)

Shared Features

(START, PRO)
(PRO, what)

Predicted Features

(DET, can)
(NN, show)
(VB, silence)
(DET, NN)
(VB, DET)
(PRO, VB)

- New feature vector: (DET, DET): -1.00; (DET, NN): 1.00; (DET, VB): -1.00; (DET, can): -1.00; (DET, demand): -1.00; (DET, the): 1.00; (NN, DET): -1.00; (NN, VB): 1.00; (NN, demand): 1.00; (NN, show): -1.00; (NN, silence): 1.00; (PRO, NN): 1.00; (PRO, you): 1.00; (VB, DET): 1.00; (VB, VB): -1.00; (VB, can): 1.00; (VB, show): 1.00; (VB, silence): -1.00; (VB, the): -1.00; (VB, you): -1.00; (START, NN): -1.00; (START, PRO): 1.00

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

Gold Features

(VB, show)
(VB, can)
(PRO, NN)
(NN, silence)
(NN, VB) (VB, VB)

Shared Features

(START, PRO)
(PRO, what)

Predicted Features

(DET, can)
(NN, show)
(VB, silence)
(DET, NN)
(VB, DET)
(PRO, VB)

- New feature vector: (DET, DET): -1.00; (DET, NN): 1.00; (DET, VB): -1.00; (DET, can): -1.00; (DET, demand): -1.00; (DET, the): 1.00; (NN, DET): -1.00; (NN, VB): 1.00; (NN, demand): 1.00; (NN, show): -1.00; (NN, silence): 1.00; (PRO, NN): 1.00; (PRO, you): 1.00; (VB, DET): 1.00; (VB, VB): -1.00; (VB, can): 1.00; (VB, show): 1.00; (VB, silence): -1.00; (VB, the): -1.00; (VB, you): -1.00; (START, NN): -1.00; (START, PRO): 1.00

Decoding Sentence 6

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

$$w_{\text{START, DET}} + w_{\text{DET, what}} = 0.00 + 0.00 = 0.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.00 & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

$$w_{\text{START, PRO}} + w_{\text{PRO, what}} = 1.00 + 0.00 = 1.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.00 & & & \\ 1.00 & & & \\ & & & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.00 & & & \\ 1.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & & & \\ 1.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & 1.00 & & \\ 1.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & 1.00 & & \\ 1.00 & 1.00 & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

$$\delta_0(PRO) + w_{\text{PRO, NN}} + w_{\text{NN, show}} = 1.00 + 1.00 + -1.00 = 1.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & 1.00 & & \\ 1.00 & 1.00 & & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

$$\delta_1(NN) + w_{\text{NN, VB}} + w_{\text{VB, can}} = 1.00 + 1.00 + 1.00 = 3.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & \\ 0.00 & 1.00 & & \\ 1.00 & 1.00 & & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & \\ 0.00 & 1.00 & 2.00 & \\ 1.00 & 1.00 & & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

$$\delta_1(VB) + w_{\text{VB, PRO}} + w_{\text{PRO, can}} = 2.00 + 0.00 + 0.00 = 2.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & \\ 0.00 & 1.00 & 2.00 & \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

$$\delta_1(VB) + w_{\text{VB, NN}} + w_{\text{NN, can}} = 2.00 + 0.00 + 0.00 = 2.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & \\ 0.00 & 1.00 & 2.00 & \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 1.00 & 2.00 & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

$$\delta_2(NN) + w_{\text{NN, VB}} + w_{\text{VB, silence}} = 2.00 + 1.00 + -1.00 = 2.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & 2.00 \\ 0.00 & 1.00 & 2.00 & \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 1.00 & 2.00 & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

$$\delta_2(VB) + w_{\text{VB, DET}} + w_{\text{DET, silence}} = 3.00 + 1.00 + 0.00 = 4.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & 2.00 \\ 0.00 & 1.00 & 2.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 1.00 & 2.00 & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

$$\delta_2(VB) + w_{\text{VB, PRO}} + w_{\text{PRO, silence}} = 3.00 + 0.00 + 0.00 = 3.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & 2.00 \\ 0.00 & 1.00 & 2.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 3.00 \\ -1.00 & 1.00 & 2.00 & \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

$$\delta_2(VB) + w_{\text{VB, NN}} + w_{\text{NN, silence}} = 3.00 + 0.00 + 1.00 = 4.00$$

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & 2.00 \\ 0.00 & 1.00 & 2.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 3.00 \\ -1.00 & 1.00 & 2.00 & 4.00 \end{pmatrix} \end{array} \tag{45}$$

Decoding Sentence 6

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & 2.00 \\ 0.00 & 1.00 & 2.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 3.00 \\ -1.00 & 1.00 & 2.00 & 4.00 \end{pmatrix} \end{array} \tag{45}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} PRO & NN & NN \\ VB & VB & VB \\ PRO & VB & VB \\ PRO & VB & VB \end{pmatrix} \end{array} \tag{46}$$

Decoding Sentence 6

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & 2.00 \\ 0.00 & 1.00 & 2.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 3.00 \\ -1.00 & 1.00 & 2.00 & 4.00 \end{pmatrix} \end{array} \tag{45}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} PRO & NN & NN \\ VB & VB & VB \\ PRO & VB & VB \\ PRO & VB & VB \end{pmatrix} \end{array} \tag{46}$$

Decoding Sentence 6

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & 2.00 \\ 0.00 & 1.00 & 2.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 3.00 \\ -1.00 & 1.00 & 2.00 & 4.00 \end{pmatrix} \end{array} \tag{45}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} PRO & NN & NN \\ VB & VB & VB \\ PRO & VB & VB \\ PRO & VB & VB \end{pmatrix} \end{array} \tag{46}$$

- Reconstruction: PRO NN VB DET

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

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

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

Gold Features

(VB, silence)
(VB, VB)

Shared Features

(NN, show)
(VB, can)
(PRO, NN)
(NN, VB)
(START, PRO)
(PRO, what)

Predicted Features

(DET, silence)
(VB, DET)

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

Gold Features

(VB, silence)
(VB, VB)

Shared Features

(NN, show)
(VB, can)
(PRO, NN)
(NN, VB)
(START, PRO)
(PRO, what)

Predicted Features

(DET, silence)
(VB, DET)

- New feature vector: (DET, DET): -1.00; (DET, NN): 1.00; (DET, VB): -1.00; (DET, can): -1.00; (DET, demand): -1.00; (DET, silence): -1.00; (DET, the): 1.00; (NN, DET): -1.00; (NN, VB): 1.00; (NN, demand): 1.00; (NN, show): -1.00; (NN, silence): 1.00; (PRO, NN): 1.00; (PRO, you): 1.00; (VB, can): 1.00; (VB, show): 1.00; (VB, the): -1.00; (VB, you): -1.00; (START, NN): -1.00; (START, PRO): 1.00

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

Gold Features

(VB, silence)
(VB, VB)

Shared Features

(NN, show)
(VB, can)
(PRO, NN)
(NN, VB)
(START, PRO)
(PRO, what)

Predicted Features

(DET, silence)
(VB, DET)

- New feature vector: (DET, DET): -1.00; (DET, NN): 1.00; (DET, VB): -1.00; (DET, can): -1.00; (DET, demand): -1.00; (DET, silence): -1.00; (DET, the): 1.00; (NN, DET): -1.00; (NN, VB): 1.00; (NN, demand): 1.00; (NN, show): -1.00; (NN, silence): 1.00; (PRO, NN): 1.00; (PRO, you): 1.00; (VB, can): 1.00; (VB, show): 1.00; (VB, the): -1.00; (VB, you): -1.00; (START, NN): -1.00; (START, PRO): 1.00