# Why Language is Hard: Structure and Predictions

Introduction to Data Science Algorithms

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STRUCTURED PREDICTION EXAMPLE

## Decoding Sentence 1

- Scores

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

## Decoding Sentence 1

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

- Scores

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

## Decoding Sentence 1

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

- Scores

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

## Decoding Sentence 1

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

- Scores

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

## Decoding Sentence 1

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

- Scores

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

## Decoding Sentence 1

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

- Scores

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

## Decoding Sentence 1

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

- Scores

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

## Decoding Sentence 1

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

- Scores

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

## Decoding Sentence 1

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

- Scores

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

## Decoding Sentence 1

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

- Scores

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

## Decoding Sentence 1

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

- Scores

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

## Decoding Sentence 1

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

- Scores

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

## Decoding Sentence 1

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

- Scores

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

## Decoding Sentence 1

- Scores

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

- Backpointers

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

## Decoding Sentence 1

- Scores

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

- Backpointers

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

## Decoding Sentence 1

- Scores

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

- Backpointers

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

- 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

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} & & \\ & & \\ & & \\ & & \end{pmatrix} \end{array} \tag{3}$$

## Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & & \\ & & \\ & & \\ & & \end{pmatrix} \end{array} \tag{3}$$

## Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & & \\ 0.00 & & \\ & & \\ & & \end{pmatrix} \end{array} \tag{3}$$

## Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & & \\ 0.00 & & \\ 0.00 & & \\ & & \end{pmatrix} \end{array} \tag{3}$$

## Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & & \\ 0.00 & & \\ 0.00 & & \\ 1.00 & & \end{pmatrix} \end{array} \tag{3}$$

## Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cc} \text{question}_0 & \text{the}_1 \quad \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 \\ 0.00 & \\ 0.00 & \\ 1.00 & \end{pmatrix} \end{array} \tag{3}$$

## Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cc} \text{question}_0 & \text{the}_1 \quad \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 \\ 0.00 & 2.00 \\ 0.00 & \\ 1.00 & \end{pmatrix} \end{array} \tag{3}$$

## Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & \\ 0.00 & 2.00 & \\ 0.00 & 1.00 & \\ 1.00 & & \end{pmatrix} \end{array} \tag{3}$$

## Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cc} \text{question}_0 & \text{the}_1 \quad \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 \\ 0.00 & 2.00 \\ 0.00 & 1.00 \\ 1.00 & 1.00 \end{pmatrix} \end{array} \tag{3}$$

## Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & 2.00 \\ 0.00 & 2.00 & \\ 0.00 & 1.00 & \\ 1.00 & 1.00 & \end{pmatrix} \end{array} \tag{3}$$

## Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & 2.00 \\ 0.00 & 2.00 & 2.00 \\ 0.00 & 1.00 & \\ 1.00 & 1.00 & \end{pmatrix} \end{array} \tag{3}$$

## Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & 2.00 \\ 0.00 & 2.00 & 2.00 \\ 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & \end{pmatrix} \end{array} \tag{3}$$

## Decoding Sentence 2

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & 2.00 \\ 0.00 & 2.00 & 2.00 \\ 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & 3.00 \end{pmatrix} \end{array} \tag{3}$$

## Decoding Sentence 2

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & 2.00 \\ 0.00 & 2.00 & 2.00 \\ 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & 3.00 \end{pmatrix} \end{array} \tag{3}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{cc} \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} NN & DET \\ NN & DET \\ NN & DET \\ DET & DET \end{pmatrix} \end{array} \tag{4}$$

## Decoding Sentence 2

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & 2.00 \\ 0.00 & 2.00 & 2.00 \\ 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & 3.00 \end{pmatrix} \end{array} \tag{3}$$

- Backpointers

$$\beta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cc} \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} NN & DET \\ NN & DET \\ NN & DET \\ DET & DET \end{pmatrix} \end{array} \tag{4}$$

## Decoding Sentence 2

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{question}_0 & \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} -1.00 & 0.00 & 2.00 \\ 0.00 & 2.00 & 2.00 \\ 0.00 & 1.00 & 2.00 \\ 1.00 & 1.00 & 3.00 \end{pmatrix} \end{array} \tag{3}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{cc} \text{the}_1 & \text{answer}_2 \end{array} \\ \begin{pmatrix} NN & DET \\ NN & DET \\ NN & DET \\ DET & DET \end{pmatrix} \end{array} \tag{4}$$

- 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**

(VB, DET)
(START, VB)
(VB, question)

**Shared Features**

(DET, the) (DET, NN)
(NN, answer)

**Predicted Features**

(START, NN)
(NN, question)
(NN, DET)

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

**Gold Features**

(VB, DET)
(START, VB)
(VB, question)

**Shared Features**

(DET, the) (DET, NN)
(NN, answer)

**Predicted Features**

(START, NN)
(NN, question)
(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**

(VB, DET)
(START, VB)
(VB, question)

**Shared Features**

(DET, the) (DET, NN)
(NN, answer)

**Predicted Features**

(START, NN)
(NN, question)
(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

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & & & \\ 0.00 & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & & & \\ 0.00 & & & \\ 0.00 & & & \\ & & & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & & & \\ 0.00 & & & \\ 0.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & & \\ 0.00 & & & \\ 0.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & & \\ 0.00 & 3.00 & & \\ 0.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & & \\ 0.00 & 3.00 & & \\ 0.00 & 1.00 & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & & \\ 0.00 & 3.00 & & \\ 0.00 & 1.00 & & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & \\ 0.00 & 3.00 & & \\ 0.00 & 1.00 & & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & \\ 0.00 & 3.00 & 4.00 & \\ 0.00 & 1.00 & & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & \\ 0.00 & 3.00 & 4.00 & \\ 0.00 & 1.00 & 3.00 & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & \\ 0.00 & 3.00 & 4.00 & \\ 0.00 & 1.00 & 3.00 & \\ -1.00 & 1.00 & 4.00 & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & 4.00 \\ 0.00 & 3.00 & 4.00 & \\ 0.00 & 1.00 & 3.00 & \\ -1.00 & 1.00 & 4.00 & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & 4.00 \\ 0.00 & 3.00 & 4.00 & 4.00 \\ 0.00 & 1.00 & 3.00 & \\ -1.00 & 1.00 & 4.00 & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & 4.00 \\ 0.00 & 3.00 & 4.00 & 4.00 \\ 0.00 & 1.00 & 3.00 & 4.00 \\ -1.00 & 1.00 & 4.00 & \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & 4.00 \\ 0.00 & 3.00 & 4.00 & 4.00 \\ 0.00 & 1.00 & 3.00 & 4.00 \\ -1.00 & 1.00 & 4.00 & 5.00 \end{pmatrix} \end{array} \tag{5}$$

## Decoding Sentence 3

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & 4.00 \\ 0.00 & 3.00 & 4.00 & 4.00 \\ 0.00 & 1.00 & 3.00 & 4.00 \\ -1.00 & 1.00 & 4.00 & 5.00 \end{pmatrix} \end{array} \tag{5}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} DET & DET & DET \\ VB & DET & VB \\ VB & DET & DET \\ VB & DET & DET \end{pmatrix} \end{array} \tag{6}$$

## Decoding Sentence 3

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & 4.00 \\ 0.00 & 3.00 & 4.00 & 4.00 \\ 0.00 & 1.00 & 3.00 & 4.00 \\ -1.00 & 1.00 & 4.00 & 5.00 \end{pmatrix} \end{array} \tag{5}$$

- Backpointers

$$\beta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} DET & DET & DET \\ VB & DET & VB \\ VB & DET & DET \\ VB & DET & DET \end{pmatrix} \end{array} \tag{6}$$

## Decoding Sentence 3

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} 1.00 & 0.00 & 2.00 & 4.00 \\ 0.00 & 3.00 & 4.00 & 4.00 \\ 0.00 & 1.00 & 3.00 & 4.00 \\ -1.00 & 1.00 & 4.00 & 5.00 \end{pmatrix} \end{array} \tag{5}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{demand}_1 & \text{the}_2 & \text{delay}_3 \end{array} \\ \begin{pmatrix} DET & DET & DET \\ VB & DET & VB \\ VB & DET & DET \\ VB & DET & DET \end{pmatrix} \end{array} \tag{6}$$

- 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

(VB, demand)
(PRO, you)
(START, PRO)
(PRO, VB)

### Shared Features

(DET, the) (DET, NN)
(VB, DET)
(NN, delay)

### Predicted Features

(DET, DET)
(START, VB)
(DET, demand)
(VB, you)

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

**Gold Features**

(VB, demand)
(PRO, you)
(START, PRO)
(PRO, VB)

**Shared Features**

(DET, the) (DET, NN)
(VB, DET)
(NN, delay)

**Predicted Features**

(DET, DET)
(START, VB)
(DET, demand)
(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**

(VB, demand)
(PRO, you)
(START, PRO)
(PRO, VB)

**Shared Features**

(DET, the) (DET, NN)
(VB, DET)
(NN, delay)

**Predicted Features**

(DET, DET)
(START, VB)
(DET, demand)
(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

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \left( \begin{array}{cccc} & & & \\ & & & \\ & & & \\ & & & \end{array} \right) \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & & & \\ 0.00 & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & & & \\ 0.00 & & & \\ 2.00 & & & \\ & & & \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & & & \\ 0.00 & & & \\ 2.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & & \\ 0.00 & & & \\ 2.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & & \\ 0.00 & 2.00 & & \\ 2.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & & \\ 0.00 & 2.00 & & \\ 2.00 & 2.00 & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & & \\ 0.00 & 2.00 & & \\ 2.00 & 2.00 & & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & \\ 0.00 & 2.00 & & \\ 2.00 & 2.00 & & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & \\ 0.00 & 2.00 & 6.00 & \\ 2.00 & 2.00 & & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & \\ 0.00 & 2.00 & 6.00 & \\ 2.00 & 2.00 & 3.00 & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & \\ 0.00 & 2.00 & 6.00 & \\ 2.00 & 2.00 & 3.00 & \\ -1.00 & 2.00 & 3.00 & \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & 7.00 \\ 0.00 & 2.00 & 6.00 & \\ 2.00 & 2.00 & 3.00 & \\ -1.00 & 2.00 & 3.00 & \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & 7.00 \\ 0.00 & 2.00 & 6.00 & 4.00 \\ 2.00 & 2.00 & 3.00 & \\ -1.00 & 2.00 & 3.00 & \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & 7.00 \\ 0.00 & 2.00 & 6.00 & 4.00 \\ 2.00 & 2.00 & 3.00 & 6.00 \\ -1.00 & 2.00 & 3.00 & \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & 7.00 \\ 0.00 & 2.00 & 6.00 & 4.00 \\ 2.00 & 2.00 & 3.00 & 6.00 \\ -1.00 & 2.00 & 3.00 & 7.00 \end{pmatrix} \end{array} \tag{7}$$

## Decoding Sentence 4

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & 7.00 \\ 0.00 & 2.00 & 6.00 & 4.00 \\ 2.00 & 2.00 & 3.00 & 6.00 \\ -1.00 & 2.00 & 3.00 & 7.00 \end{pmatrix} \end{array} \tag{7}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} PRO & PRO & DET \\ PRO & VB & DET \\ PRO & VB & DET \\ PRO & VB & DET \end{pmatrix} \end{array} \tag{8}$$

## Decoding Sentence 4

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & 7.00 \\ 0.00 & 2.00 & 6.00 & 4.00 \\ 2.00 & 2.00 & 3.00 & 6.00 \\ -1.00 & 2.00 & 3.00 & 7.00 \end{pmatrix} \end{array} \tag{7}$$

- Backpointers

$$\beta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{ccc} \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} PRO & PRO & DET \\ PRO & VB & DET \\ PRO & VB & DET \\ PRO & VB & DET \end{pmatrix} \end{array} \tag{8}$$

## Decoding Sentence 4

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{you}_0 & \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} -1.00 & 3.00 & 2.00 & 7.00 \\ 0.00 & 2.00 & 6.00 & 4.00 \\ 2.00 & 2.00 & 3.00 & 6.00 \\ -1.00 & 2.00 & 3.00 & 7.00 \end{pmatrix} \end{array} \tag{7}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{delay}_1 & \text{the}_2 & \text{demand}_3 \end{array} \\ \begin{pmatrix} PRO & PRO & DET \\ PRO & VB & DET \\ PRO & VB & DET \\ PRO & VB & DET \end{pmatrix} \end{array} \tag{8}$$

- 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

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.00 & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.00 & & & \\ 1.00 & & & \\ & & & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.00 & & & \\ 1.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & & & \\ 1.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & 2.00 & & \\ 1.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & 2.00 & & \\ 1.00 & 1.00 & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & 2.00 & & \\ 1.00 & 1.00 & & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & \\ 0.00 & 2.00 & & \\ 1.00 & 1.00 & & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & \\ 0.00 & 2.00 & 4.00 & \\ 1.00 & 1.00 & & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & \\ 0.00 & 2.00 & 4.00 & \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 2.00 & & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & \\ 0.00 & 2.00 & 4.00 & \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 2.00 & 4.00 & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & 4.00 \\ 0.00 & 2.00 & 4.00 & \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 2.00 & 4.00 & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & 4.00 \\ 0.00 & 2.00 & 4.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 2.00 & 4.00 & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & 4.00 \\ 0.00 & 2.00 & 4.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 4.00 \\ -1.00 & 2.00 & 4.00 & \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & 4.00 \\ 0.00 & 2.00 & 4.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 4.00 \\ -1.00 & 2.00 & 4.00 & 6.00 \end{pmatrix} \end{array} \tag{9}$$

## Decoding Sentence 5

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & 4.00 \\ 0.00 & 2.00 & 4.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 4.00 \\ -1.00 & 2.00 & 4.00 & 6.00 \end{pmatrix} \end{array} \tag{9}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} PRO & PRO & NN \\ VB & VB & VB \\ PRO & VB & DET \\ DET & DET & DET \end{pmatrix} \end{array} \tag{10}$$

## Decoding Sentence 5

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & 4.00 \\ 0.00 & 2.00 & 4.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 4.00 \\ -1.00 & 2.00 & 4.00 & 6.00 \end{pmatrix} \end{array} \tag{9}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} PRO & PRO & NN \\ VB & VB & VB \\ PRO & VB & DET \\ DET & DET & DET \end{pmatrix} \end{array} \tag{10}$$

## Decoding Sentence 5

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 2.00 & 4.00 \\ 0.00 & 2.00 & 4.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 4.00 \\ -1.00 & 2.00 & 4.00 & 6.00 \end{pmatrix} \end{array} \tag{9}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{silence}_1 & \text{can}_2 & \text{show}_3 \end{array} \\ \begin{pmatrix} PRO & PRO & NN \\ VB & VB & VB \\ PRO & VB & DET \\ DET & DET & DET \end{pmatrix} \end{array} \tag{10}$$

- 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

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.00 & & & \\ & & & \\ & & & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.00 & & & \\ 1.00 & & & \\ & & & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.00 & & & \\ 1.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & & & \\ 1.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & 1.00 & & \\ 1.00 & & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & 1.00 & & \\ 1.00 & 1.00 & & \\ -1.00 & & & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & & \\ 0.00 & 1.00 & & \\ 1.00 & 1.00 & & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & \\ 0.00 & 1.00 & & \\ 1.00 & 1.00 & & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & \\ 0.00 & 1.00 & 2.00 & \\ 1.00 & 1.00 & & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & \\ 0.00 & 1.00 & 2.00 & \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 1.00 & & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & \\ 0.00 & 1.00 & 2.00 & \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 1.00 & 2.00 & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & 2.00 \\ 0.00 & 1.00 & 2.00 & \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 1.00 & 2.00 & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & 2.00 \\ 0.00 & 1.00 & 2.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & \\ -1.00 & 1.00 & 2.00 & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & 2.00 \\ 0.00 & 1.00 & 2.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 3.00 \\ -1.00 & 1.00 & 2.00 & \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

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

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & 2.00 \\ 0.00 & 1.00 & 2.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 3.00 \\ -1.00 & 1.00 & 2.00 & 4.00 \end{pmatrix} \end{array} \tag{11}$$

## Decoding Sentence 6

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & 2.00 \\ 0.00 & 1.00 & 2.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 3.00 \\ -1.00 & 1.00 & 2.00 & 4.00 \end{pmatrix} \end{array} \tag{11}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} PRO & NN & NN \\ VB & VB & VB \\ PRO & VB & VB \\ PRO & VB & VB \end{pmatrix} \end{array} \tag{12}$$

## Decoding Sentence 6

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & 2.00 \\ 0.00 & 1.00 & 2.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 3.00 \\ -1.00 & 1.00 & 2.00 & 4.00 \end{pmatrix} \end{array} \tag{11}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} PRO & NN & NN \\ VB & VB & VB \\ PRO & VB & VB \\ PRO & VB & VB \end{pmatrix} \end{array} \tag{12}$$

## Decoding Sentence 6

- Scores

$$\delta = \begin{array}{c} \\ VB \\ DET \\ PRO \\ NN \end{array} \begin{array}{c} \begin{array}{cccc} \text{what}_0 & \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} 0.00 & 2.00 & 3.00 & 2.00 \\ 0.00 & 1.00 & 2.00 & 4.00 \\ 1.00 & 1.00 & 2.00 & 3.00 \\ -1.00 & 1.00 & 2.00 & 4.00 \end{pmatrix} \end{array} \tag{11}$$

- Backpointers

$$\beta = \begin{array}{c} \\ \text{VB} \\ \text{DET} \\ \text{PRO} \\ \text{NN} \end{array} \begin{array}{c} \begin{array}{ccc} \text{show}_1 & \text{can}_2 & \text{silence}_3 \end{array} \\ \begin{pmatrix} PRO & NN & NN \\ VB & VB & VB \\ PRO & VB & VB \\ PRO & VB & VB \end{pmatrix} \end{array} \tag{12}$$

- 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