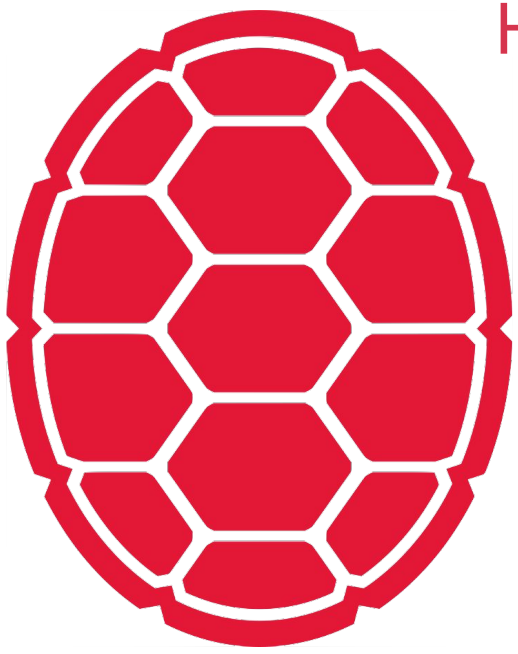

Hidden Markov Models

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Examples

Warning about next homework(s)

- Kaggle competition
- Thus, late days not very useful
- Following homework is not computational

Garden Pathing

What is the probability of the sequence “a/`Det` blue/`Adj` boat/`N`”?

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$$0.3 * 0.2 * 0.4 * 0.3 * 0.5 * 0.3 = 0.00108 \tag{2}$$

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Example . . .

Base case

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1. $\delta_1(a) = -4.6$

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1. $\delta_1(a) = -4.6$
2. $\delta_1(v) = -5.7$

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Base case

1. $\delta_1(a) = -4.6$
2. $\delta_1(v) = -5.7$
3. $\delta_1(d) = -1.7$
4. $\delta_1(n) = -4.6$

Example . . .

Second position

1. $\delta_2(a) = \max\left(\underbrace{-5.8}_{\text{a}}, \underbrace{-7.3}_{\text{v}}, \underbrace{-2.6}_{\mathbf{d}}, \underbrace{-7.6}_{\text{n}}\right) + -1.2 = -2.6 + -1.2 = -3.8$

Example . . .

Second position

1. $\delta_2(a) = \max\left(\underbrace{-5.8}_{\text{a}}, \underbrace{-7.3}_{\text{v}}, \underbrace{-2.6}_{\textbf{d}}, \underbrace{-7.6}_{\text{n}}\right) + -1.2 = -2.6 + -1.2 = -3.8$
2. $\delta_2(v) = \max\left(\underbrace{-6.9}_{\text{a}}, \underbrace{-7.3}_{\text{v}}, \underbrace{-4.7}_{\textbf{d}}, \underbrace{-4.8}_{\text{n}}\right) + -2.3 = -4.7 + -2.3 = -7.0$

Example . . .

Second position

1. $\delta_2(a) = \max\left(\underbrace{-5.8}_{\text{a}}, \underbrace{-7.3}_{\text{v}}, \underbrace{-2.6}_{\textbf{d}}, \underbrace{-7.6}_{\text{n}}\right) + -1.2 = -2.6 + -1.2 = -3.8$
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3. $\delta_2(d) = \max\left(\underbrace{-6.9}_{\text{a}}, \underbrace{-6.9}_{\text{v}}, \underbrace{-4.0}_{\textbf{d}}, \underbrace{-7.6}_{\text{n}}\right) + -3.7 = -4.0 + -3.7 = -7.7$

Example . . .

Second position

1. $\delta_2(a) = \max\left(\underbrace{-5.8}_{\text{a}}, \underbrace{-7.3}_{\text{v}}, \underbrace{-2.6}_{\textbf{d}}, \underbrace{-7.6}_{\text{n}}\right) + -1.2 = -2.6 + -1.2 = -3.8$
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3. $\delta_2(d) = \max\left(\underbrace{-6.9}_{\text{a}}, \underbrace{-6.9}_{\text{v}}, \underbrace{-4.0}_{\textbf{d}}, \underbrace{-7.6}_{\text{n}}\right) + -3.7 = -4.0 + -3.7 = -7.7$
4. $\delta_2(n) = \max\left(\underbrace{-5.3}_{\text{a}}, \underbrace{-6.9}_{\text{v}}, \underbrace{-2.5}_{\textbf{d}}, \underbrace{-6.9}_{\text{n}}\right) + -1.9 = -2.5 + -1.9 = -4.4$

Example . . .

Third position

1. $\delta_3(a) = \max\left(\underbrace{-5.0}_{\mathbf{a}}, \underbrace{-8.6}_{\text{v}}, \underbrace{-8.6}_{\text{d}}, \underbrace{-7.4}_{\text{n}}\right) + -2.3 = -5.0 + -2.3 = -7.3$

Example . . .

Third position

1. $\delta_3(a) = \max\left(\underbrace{-5.0}_{\mathbf{a}}, \underbrace{-8.6}_{\text{v}}, \underbrace{-8.6}_{\text{d}}, \underbrace{-7.4}_{\text{n}}\right) + -2.3 = -5.0 + -2.3 = -7.3$
2. $\delta_3(v) = \max\left(\underbrace{-6.1}_{\text{a}}, \underbrace{-8.6}_{\text{v}}, \underbrace{-10.7}_{\text{d}}, \underbrace{-4.6}_{\mathbf{n}}\right) + -0.9 = -4.6 + -0.9 = -5.5$

Example . . .

Third position

1. $\delta_3(a) = \max\left(\underbrace{-5.0}_{\mathbf{a}}, \underbrace{-8.6}_{\text{v}}, \underbrace{-8.6}_{\text{d}}, \underbrace{-7.4}_{\text{n}}\right) + -2.3 = -5.0 + -2.3 = -7.3$
2. $\delta_3(v) = \max\left(\underbrace{-6.1}_{\text{a}}, \underbrace{-8.6}_{\text{v}}, \underbrace{-10.7}_{\text{d}}, \underbrace{-4.6}_{\mathbf{n}}\right) + -0.9 = -4.6 + -0.9 = -5.5$
3. $\delta_3(d) = \max\left(\underbrace{-6.1}_{\mathbf{a}}, \underbrace{-8.2}_{\text{v}}, \underbrace{-10.0}_{\text{d}}, \underbrace{-7.4}_{\text{n}}\right) + -3.7 = -6.1 + -3.7 = -9.8$

Example ...

Third position

1. $\delta_3(a) = \max\left(\underbrace{-5.0}_{\mathbf{a}}, \underbrace{-8.6}_{\text{v}}, \underbrace{-8.6}_{\text{d}}, \underbrace{-7.4}_{\text{n}}\right) + -2.3 = -5.0 + -2.3 = -7.3$
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3. $\delta_3(d) = \max\left(\underbrace{-6.1}_{\mathbf{a}}, \underbrace{-8.2}_{\text{v}}, \underbrace{-10.0}_{\text{d}}, \underbrace{-7.4}_{\text{n}}\right) + -3.7 = -6.1 + -3.7 = -9.8$
4. $\delta_3(n) = \max\left(\underbrace{-4.5}_{\mathbf{a}}, \underbrace{-8.2}_{\text{v}}, \underbrace{-8.5}_{\text{d}}, \underbrace{-6.7}_{\text{n}}\right) + -0.9 = -4.5 + -0.9 = -5.4$

Example . . .

Fourth position

1. $\delta_4(a) = \max\left(\underbrace{-8.5}_{\text{a}}, \underbrace{-7.2}_{\textbf{v}}, \underbrace{-10.7}_{\text{d}}, \underbrace{-8.4}_{\text{n}}\right) + -3.4 = -7.2 + -3.4 = -10.6$

Example ...

Fourth position

1. $\delta_4(a) = \max\left(\underbrace{-8.5}_{\text{a}}, \underbrace{-7.2}_{\mathbf{v}}, \underbrace{-10.7}_{\text{d}}, \underbrace{-8.4}_{\text{n}}\right) + -3.4 = -7.2 + -3.4 = -10.6$
2. $\delta_4(v) = \max\left(\underbrace{-9.6}_{\text{a}}, \underbrace{-7.2}_{\text{v}}, \underbrace{-12.8}_{\text{d}}, \underbrace{-5.7}_{\mathbf{n}}\right) + -3.4 = -5.7 + -3.4 = -9.1$

Example ...

Fourth position

1. $\delta_4(a) = \max\left(\underbrace{-8.5}_{\text{a}}, \underbrace{-7.2}_{\mathbf{v}}, \underbrace{-10.7}_{\text{d}}, \underbrace{-8.4}_{\text{n}}\right) + -3.4 = -7.2 + -3.4 = -10.6$
2. $\delta_4(v) = \max\left(\underbrace{-9.6}_{\text{a}}, \underbrace{-7.2}_{\text{v}}, \underbrace{-12.8}_{\text{d}}, \underbrace{-5.7}_{\mathbf{n}}\right) + -3.4 = -5.7 + -3.4 = -9.1$
3. $\delta_4(d) = \max\left(\underbrace{-9.6}_{\text{a}}, \underbrace{-6.8}_{\mathbf{v}}, \underbrace{-12.1}_{\text{d}}, \underbrace{-8.4}_{\text{n}}\right) + -0.5 = -6.8 + -0.5 = -7.3$

Example ...

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1. $\delta_4(a) = \max\left(\underbrace{-8.5}_{\text{a}}, \underbrace{-7.2}_{\mathbf{v}}, \underbrace{-10.7}_{\text{d}}, \underbrace{-8.4}_{\text{n}}\right) + -3.4 = -7.2 + -3.4 = -10.6$
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3. $\delta_4(d) = \max\left(\underbrace{-9.6}_{\text{a}}, \underbrace{-6.8}_{\mathbf{v}}, \underbrace{-12.1}_{\text{d}}, \underbrace{-8.4}_{\text{n}}\right) + -0.5 = -6.8 + -0.5 = -7.3$
4. $\delta_4(n) = \max\left(\underbrace{-8.0}_{\text{a}}, \underbrace{-6.8}_{\mathbf{v}}, \underbrace{-10.6}_{\text{d}}, \underbrace{-7.7}_{\text{n}}\right) + -3.4 = -6.8 + -3.4 = -10.2$

Example . . .

Fifth position

1. $\delta_5(a) = \max\left(\underbrace{-11.8}_{\text{a}}, \underbrace{-10.7}_{\text{v}}, \underbrace{-8.2}_{\mathbf{d}}, \underbrace{-13.2}_{\text{n}}\right) + -2.3 = -8.2 + -2.3 = -11$

Example . . .

Fifth position

1. $\delta_5(a) = \max\left(\underbrace{-11.8}_{\text{a}}, \underbrace{-10.7}_{\text{v}}, \underbrace{-8.2}_{\textbf{d}}, \underbrace{-13.2}_{\text{n}}\right) + -2.3 = -8.2 + -2.3 = -11$
2. $\delta_5(v) = \max\left(\underbrace{-12.9}_{\text{a}}, \underbrace{-10.7}_{\text{v}}, \underbrace{-10.3}_{\textbf{d}}, \underbrace{-10.4}_{\text{n}}\right) + -1.6 = -10.3 + -1.6 = -12$

Example . . .

Fifth position

1. $\delta_5(a) = \max\left(\underbrace{-11.8}_{\text{a}}, \underbrace{-10.7}_{\text{v}}, \underbrace{-8.2}_{\textbf{d}}, \underbrace{-13.2}_{\text{n}}\right) + -2.3 = -8.2 + -2.3 = -11$
2. $\delta_5(v) = \max\left(\underbrace{-12.9}_{\text{a}}, \underbrace{-10.7}_{\text{v}}, \underbrace{-10.3}_{\textbf{d}}, \underbrace{-10.4}_{\text{n}}\right) + -1.6 = -10.3 + -1.6 = -12$
3. $\delta_5(d) = \max\left(\underbrace{-12.9}_{\text{a}}, \underbrace{-10.3}_{\text{v}}, \underbrace{-9.6}_{\textbf{d}}, \underbrace{-13.2}_{\text{n}}\right) + -3.7 = -9.6 + -3.7 = -13$

Example ...

Fifth position

1. $\delta_5(a) = \max\left(\underbrace{-11.8}_{\text{a}}, \underbrace{-10.7}_{\text{v}}, \underbrace{-8.2}_{\textbf{d}}, \underbrace{-13.2}_{\text{n}}\right) + -2.3 = -8.2 + -2.3 = -11$
2. $\delta_5(v) = \max\left(\underbrace{-12.9}_{\text{a}}, \underbrace{-10.7}_{\text{v}}, \underbrace{-10.3}_{\textbf{d}}, \underbrace{-10.4}_{\text{n}}\right) + -1.6 = -10.3 + -1.6 = -12$
3. $\delta_5(d) = \max\left(\underbrace{-12.9}_{\text{a}}, \underbrace{-10.3}_{\text{v}}, \underbrace{-9.6}_{\textbf{d}}, \underbrace{-13.2}_{\text{n}}\right) + -3.7 = -9.6 + -3.7 = -13$
4. $\delta_5(n) = \max\left(\underbrace{-11.3}_{\text{a}}, \underbrace{-10.3}_{\text{v}}, \underbrace{-8.1}_{\textbf{d}}, \underbrace{-12.5}_{\text{n}}\right) + -1.2 = -8.1 + -1.2 = -9.3$

Example . . .

Reconstruction

Example . . .

Reconstruction

For “the old man”, the reconstruction starts with the best part of speech at Position 3, which is noun (-5.4), which has an adjective back pointer, which as a back pointer to determiner. The overall sequence is “The/det old/adj man/n”.

Example . . .

Reconstruction

For “the old man”, the reconstruction starts with the best part of speech at Position 3, which is noun (-5.4), which has an adjective back pointer, which as a back pointer to determiner. The overall sequence is “The/det old/adj man/n”.

For “the old man the boats”, the reconstruction starts with the best part of speech at Position 5, which is a noun (-9.3), which leads to the sequence “The/det old/n man/v the/det boats/n”.