

Log-linear Models

Jon Dehdari

December 7, 2015

Good Morning!

Some Preliminaries

Vector : In this context, a sequence of numbers. Eg.:

$$\mathbf{x} = \vec{x} = \langle 2.1, -8.5, 0.1 \rangle$$

$$\mathbf{y} = \vec{y} = \langle 1.1, 5.0, -4.4 \rangle$$

Some Preliminaries

Vector : In this context, a sequence of numbers. Eg.:

$$\mathbf{x} = \vec{x} = \langle 2.1, -8.5, 0.1 \rangle$$

$$\mathbf{y} = \vec{y} = \langle 1.1, 5.0, -4.4 \rangle$$

Dot Product : Multiplying corresponding elements of two vectors, then adding them all up (here, a.k.a. 'inner product')

$$\begin{aligned}\mathbf{x} \cdot \mathbf{y} &= \mathbf{x}^T \mathbf{y} = \sum_{i=1}^n x_i \times y_i = x_1 y_1 + x_2 y_2 + x_3 y_3 \dots \\ &= (2.1 \times 1.1) + (-8.5 \times 5.0) + (0.1 \times -4.4) \\ &= 2.31 + -42.5 + -0.44 = -\mathbf{40.63}\end{aligned}$$

Some Preliminaries

Matrix : A 2-dimensional vector

$$\mathbf{A} = \begin{bmatrix} 2.1 & -8.5 & 0.1 \\ 1.1 & 5.0 & -4.4 \end{bmatrix}$$

Some Preliminaries

Matrix : A 2-dimensional vector

$$\mathbf{A} = \begin{bmatrix} 2.1 & -8.5 & 0.1 \\ 1.1 & 5.0 & -4.4 \end{bmatrix}$$

Tensor : In this context, an n -dimensional vector

Some Preliminaries

Matrix : A 2-dimensional vector

$$\mathbf{A} = \begin{bmatrix} 2.1 & -8.5 & 0.1 \\ 1.1 & 5.0 & -4.4 \end{bmatrix}$$

Tensor : In this context, an n -dimensional vector

Euler's Number : $e = 1 + \frac{1}{1} + \frac{1}{1 \cdot 2} + \frac{1}{1 \cdot 2 \cdot 3} + \cdots \approx \mathbf{2.71828}$

Some Preliminaries

Matrix : A 2-dimensional vector

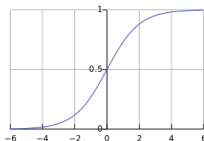
$$\mathbf{A} = \begin{bmatrix} 2.1 & -8.5 & 0.1 \\ 1.1 & 5.0 & -4.4 \end{bmatrix}$$

Tensor : In this context, an n -dimensional vector

Euler's Number : $e = 1 + \frac{1}{1} + \frac{1}{1 \cdot 2} + \frac{1}{1 \cdot 2 \cdot 3} + \cdots \approx \mathbf{2.71828}$

Logistic function : An S-shaped ('sigmoid') curve, defined as:

$$\sigma(x) = \frac{e^x}{1+e^x} = \frac{1}{1+e^{-x}}$$



Log-linear Models

$$P(y|\mathbf{x}) = \frac{e^{\mathbf{W}_y \cdot \mathbf{x}}}{Z}$$

← exponentiation helps ensure scores are positive

← **normalization constant**, to ensure the score of all possible outcomes sums to 1

$$= \frac{e^{\mathbf{W}_y \cdot \mathbf{x}}}{\sum_h e^{\mathbf{W}_h \cdot \mathbf{x}}}$$

← to get Z, we just add up scores from all possible outcomes

$$= \text{softmax}(\mathbf{W}_y \cdot \mathbf{x})$$

Log-linear Models

$$\begin{aligned} P(y|\mathbf{x}) &= \frac{e^{\mathbf{W}_y \cdot \mathbf{x}}}{Z} \quad \leftarrow \text{exponentiation helps ensure scores are positive} \\ &\quad \leftarrow \text{normalization constant, to ensure the score of all possible outcomes sums to 1} \\ &= \frac{e^{\mathbf{W}_y \cdot \mathbf{x}}}{\sum_h e^{\mathbf{W}_h \cdot \mathbf{x}}} \quad \leftarrow \text{to get } Z, \text{ we just add up scores from all possible outcomes} \\ &= \text{softmax}(\mathbf{W}_y \cdot \mathbf{x}) \end{aligned}$$

The input vector \mathbf{x} includes an additional dummy value of 1.0, called a **bias term**. This helps determine the offset of the linear separator.

Visualization

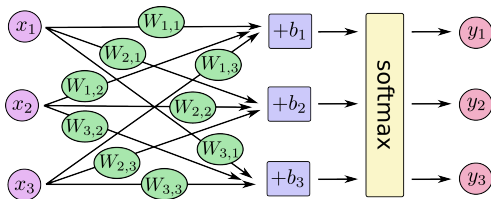
$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \text{softmax} \left(\begin{bmatrix} W_{1,1}x_1 + W_{1,2}x_2 + W_{1,3}x_3 + b_1 \\ W_{2,1}x_1 + W_{2,2}x_2 + W_{2,3}x_3 + b_2 \\ W_{3,1}x_1 + W_{3,2}x_2 + W_{3,3}x_3 + b_3 \end{bmatrix} \right)$$

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \text{softmax} \left(\begin{bmatrix} W_{1,1} & W_{1,2} & W_{1,3} \\ W_{2,1} & W_{2,2} & W_{2,3} \\ W_{3,1} & W_{3,2} & W_{3,3} \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} \right)$$

Visualization

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \text{softmax} \begin{bmatrix} W_{1,1}x_1 + W_{1,2}x_2 + W_{1,3}x_3 + b_1 \\ W_{2,1}x_1 + W_{2,2}x_2 + W_{2,3}x_3 + b_2 \\ W_{3,1}x_1 + W_{3,2}x_2 + W_{3,3}x_3 + b_3 \end{bmatrix}$$

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \text{softmax} \left(\begin{bmatrix} W_{1,1} & W_{1,2} & W_{1,3} \\ W_{2,1} & W_{2,2} & W_{2,3} \\ W_{3,1} & W_{3,2} & W_{3,3} \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} \right)$$



Finding Good Values for \mathbf{W}



- The weight matrix \mathbf{W} constitutes the **parameters** of the model
- Then the main task is to find good values for the weight matrix \mathbf{W}
- This is done by common **optimization** techniques, like L-BFGS for logistic regression

Terminology

- Logistic regression is over 50 years old

Terminology

- Logistic regression is over 50 years old
- It's sometimes also called a **maximum entropy** classifier (MaxEnt) and softmax regression, *inter alia*
- It also can be viewed as a **neural network** without any hidden layers

Terminology

- Logistic regression is over 50 years old
- It's sometimes also called a **maximum entropy** classifier (MaxEnt) and softmax regression, *inter alia*
- It also can be viewed as a **neural network** without any hidden layers
- The model is called a **log-linear model**. The following all have a log-linear model, but are trained differently:
 - **Logistic regression / MaxEnt / Softmax regression**
 - **Perceptron**
 - **Support vector machines (SVMs)**
 - **Conditional random fields (CRFs)**
 - **Linear discriminant analysis (LDA)**