

# Maximum Likelihood and Classification

## Maximum Likelihood:

Maximum Likelihood fundamentally uses a probability distribution over a dataset.

$$P(x_i|\theta) \quad P(x_i, \dots, x_N|\theta) = \prod_{i=1}^N (P(x_i|\theta)) \quad L(\theta) = \sum_{i=1}^N \log(P(x_i|\theta))$$

The idea is to change theta in order to increase the value outputted by the probability distribution. The function is all wrapped in a log since it's easier to do calculus with. The maximum log-likelihood = maximum likelihood.

Example - Biased coin toss:

1 = heads, 0 = tails

$$P(x = 1|p) = p \quad P(x = 0|p) = 1 - p$$

$$P(x|p) = p^x (1 - p)^{1-x}$$

$$L(p) = \sum_{i=1}^N \log(p^{x_i} (1 - p)^{1-x_i})$$

$$L(p) = \sum_{i=1}^N (x_i \log(p) + (1 - x_i) \log(1 - p))$$

$$L(p) = \left( \sum_{i=1}^N x_i \right) \log(p) + \left( N - \sum_{i=1}^N x_i \right) \log(1 - p)$$

From this function, we can differentiate with respect to L(p) to find the value of p that gives the highest likelihood value.

$$0 = \frac{\delta L(p)}{\delta p} \quad \frac{\delta \log(p)}{\delta p} = \frac{1}{p} \quad \frac{\delta \log(p)}{\delta p} = -\frac{1}{1-p}$$

$$0 = \left( \sum_{i=1}^N x_i \right) \frac{1}{p} - \left( N - \sum_{i=1}^N x_i \right) \frac{1}{1-p}$$

$$0 = (\sum_{i=1}^N x_i)(1-p) - (N - \sum_{i=1}^N x_i)p$$

$$0 = (\sum_{i=1}^N x_i) - Np \quad Np = \sum_{i=1}^N x_i \quad p = \frac{1}{N} \sum_{i=1}^N x_i$$

### Classification:

The data is in the form of N input vectors that contain scalar values representing its feature points and N binary targets which label each scalar into either class.

$L(w)$  = Number of wrong classifications (loss function)

$$f_w(x_i) = \theta(w^T x_i) = \theta(\sum_{j=1}^n w_j X_{ij})$$

$$\theta(a < 0) = 0 \quad \theta(a \geq 0) = 1$$

Since this loss function is discrete we cannot use it to perform calculus to find the minimum point. We can use a probability function instead.

$$P = (y_i = 1|x_i) = \sigma(w^T x) = \sigma(\sum_{j=1}^n X_{ij} w_j)$$

Where sigma represents a continuous sigmoid function:

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

$y_i = 1$  is more likely if  $w^T x > 0$

$y_i = 0$  is more likely if  $w^T x < 0$

### Gaussian:

$$p(x|m, v) = \frac{1}{\sqrt{2\pi v}} e^{-\frac{(x-m)^2}{2v}}$$

$$\log(p(x|m, v)) = \log\left(\frac{1}{2\pi}\right) + \log\left(\frac{1}{\sqrt{v}}\right) - \frac{(x-m)^2}{2v}$$

$$= -\frac{1}{2}\log(2\pi) - \frac{1}{2}\log(v) - \frac{1}{2v}(x - m)^2$$

$$\log(p(x_1, \dots, x_n)) = \sum_{i=1}^N (\log(p(x_i|m, v)))$$

$$= \sum_{i=1}^N \left( \log\left(\frac{1}{2\pi}\right) + \log\left(\frac{1}{\sqrt{v}}\right) - \frac{(x_i - m)^2}{2v} \right)$$

$$= -\frac{N}{2}\log(2\pi) - \frac{N}{2}\log(v) - \frac{1}{2v} \sum_{i=1}^N (x_i - m)^2$$

$$\frac{\delta \log(P(x_1, \dots, x_N|m, v))}{\delta m} = 0 \quad \frac{\delta \log(P(x_1, \dots, x_N|m, v))}{\delta v} = 0$$

$$0 = \frac{\delta \log(p(\dots))}{\delta m} = -\frac{1}{2v} \frac{\delta}{\delta m} \sum_{i=1}^N (x_i - m)^2 = \frac{\delta}{\delta m} \sum_{i=1}^N (x_i - m)^2$$

The above function is differentiating the squared distance between  $X$  and some parameter  $m$  which is a constant representing the mean, therefore this problem is the same as “yconst”.

$$m = \frac{1}{N} \sum_{i=1}^N x_i = \text{Mean}$$

$$0 = \frac{\delta \log(p(\dots))}{\delta v} = -\frac{N}{2v} + \frac{1}{2v^2} \sum_{i=1}^N (x_i - m)^2$$

$$\frac{Nv}{2} = \frac{1}{2} \sum_{i=1}^N (x_i - m)^2 \quad \frac{1}{N} \sum_{i=1}^N (x_i - m)^2 = \text{Variance}$$