

Stuff I Should Know for Bayesian Statistics

D. Aaron Hillegass
hillegass@gatech.edu

February 13, 2019

Normal Distribution

A normal distribution has two parameters: the mean (θ) and the variance (σ^2). x can go from $-\infty$ to ∞ . Its density is given by

$$p(x) \propto e^{-\frac{(x-\theta)^2}{2\sigma^2}}$$

For that to integrate to 1, the normalizing constant is

$$\frac{1}{\sqrt{2\pi\sigma^2}}$$

The conjugate prior of the mean of a normal distribution is another normal distribution. Specifically, if x_1, \dots, x_n , are identical and independent with a normal distribution $\mathcal{N}(\theta, \sigma^2)$ and the prior is $\theta \sim N(\theta_0, \sigma_0^2)$,

$$\theta|x_1, \dots, x_n \sim \mathcal{N}\left(\frac{\frac{\sigma^2}{n}\theta_0 + \sigma_0^2\bar{x}}{\frac{\sigma^2}{n} + \sigma_0^2}, \left(\frac{n}{\sigma^2} + \frac{1}{\sigma_0^2}\right)^{-1}\right)$$

The conjugate prior of the variance of a normal distribution is an inverse gamma distribution.

Gamma Distribution

The gamma distribution has two parameters: α and β . x can go from 0 to ∞ . Its density is given by

$$p(x) \propto x^{\alpha-1} e^{-\beta x} \quad \text{for } x > 0 \text{ and } \alpha, \beta > 0,$$

For that to integrate to 1, the normalizing constant is

$$\frac{\beta^\alpha}{\Gamma(\alpha)}$$

The mean of the distribution is

$$E[x] = \frac{\alpha}{\beta}$$

If $\alpha \geq 1$, the mode is

$$\frac{\alpha - 1}{\beta}$$

Inverse Gamma Distribution

An inverse gamma distribution has two parameters: α and β . x can go from 0 to ∞ . Its density is given by

$$p(x) \propto (1/x)^{\alpha+1} e^{(-\frac{\beta}{x})}$$

For that to integrate to 1, the normalizing constant is

$$\frac{\beta^\alpha}{\Gamma(\alpha)}$$

If $\alpha > 1$, the mean of the distribution is

$$E[x] = \frac{\beta}{\alpha - 1}$$

The mode is

$$\frac{\beta}{\alpha + 1}$$

Binomial Distribution

The binomial distribution is a discrete distribution that takes one parameter: π is the probability of one success in one try. The probability of getting exactly k successes in n trials is given by

$$p(k) = \binom{n}{k} \pi^k (1 - \pi)^{n-k}$$

The mean is $n\pi$.

The conjugate prior of π is the Beta distribution.

Beta Distribution

The beta distribution takes two parameters: α and β . Its density is given by

$$p(x) \propto x^{\alpha-1} (1-x)^{\beta-1}$$

For that to integrate to 1, the normalizing constant is

$$\frac{1}{Beta(\alpha, \beta)}$$

The mode is

$$\frac{\alpha - 1}{\alpha + \beta - 2}$$

Poisson Distribution

The Poisson Distribution is a discrete distribution that takes one parameter: λ . Its distribution is given by

$$p(x) = \frac{\lambda^x}{x!} \quad x \in \{0, 1, \dots\}$$

To normalize it, the constant is

$$e^{-\lambda}$$

λ is both its mean and its variance.

The conjugate prior for λ is the gamma distribution

Pareto Distribution

The Type 1 Pareto Distribution has two parameters α and x_m , where x_m is the minimum possible value. Both x_m and α must be positive. Its density is

$$p(x) = \begin{cases} \frac{\alpha x_m^\alpha}{x^{\alpha+1}} & x \geq x_m, \\ 0 & x < x_m. \end{cases}$$

The mean of the distribution is

$$E(X) = \begin{cases} \infty & \alpha \leq 1, \\ \frac{\alpha x_m}{\alpha - 1} & \alpha > 1. \end{cases}$$

Its cumulative distribution function is

$$F(x) = \begin{cases} 1 - \left(\frac{x_m}{x}\right)^\alpha & x \geq x_m, \\ 0 & x < x_m. \end{cases}$$

Gamma Function

The gamma function is a generalization of factorial. That is, if n is a positive integer

$$\Gamma(n) = (n - 1)!$$

But the gamma function is defined:

$$\Gamma(z) = \int_0^\infty x^{z-1} e^{-x} dx$$

Beta Function

The beta function is

$$\text{Beta}(x, y) = \int_0^1 t^{x-1} (1-t)^{y-1} dt = \frac{\Gamma(x) \Gamma(y)}{\Gamma(x+y)}$$

Choose Function

The choose function is:

$$\binom{n}{k} = \frac{n!}{k!(n-k)!}$$

Linear Regression

If you are trying to use p inputs (x_1, \dots, x_p) to predict an output y , you could create a vector of coefficients $(\beta_0, \dots, \beta_p)$ such that

$$y \approx \beta_0 + \beta_1 x_1 + \dots + \beta_p x_p$$

So how do you figure out what the β is? You use the n data points you have: The column vector $\mathbf{y} = (y_1, y_2, \dots, y_n)'$ is the outcomes. The matrix \mathbf{X} is the inputs. Row i of \mathbf{X} starts with 1 and has the inputs $(x_{i,1}, x_{i,2}, \dots, x_{i,p})$ that correspond to y_i . Thus \mathbf{X} has n rows and $p+1$ columns.

Given the data you have, the sum of the squares of the errors for a column vector β (of length $p+1$) is given by

$$\mathbf{y}^T \mathbf{y} - 2\beta^T \mathbf{X}^T \mathbf{y} + \beta^T \mathbf{X}^T \mathbf{X} \beta$$

To minimize that, you set β to be:

$$\beta = (\mathbf{X}^T \mathbf{X})^{-1} \mathbf{X}^T \mathbf{y}$$

Logarithmic Identities

$$\log(e^x) = x \qquad e^{\log x} = x$$

$$\log(ab) = \log a + \log b \qquad \log\left(\frac{a}{b}\right) = \log a - \log b$$

$$\log(a^b) = b \log a \qquad \log(\sqrt[b]{a}) = \frac{\log a}{b}$$

$$a^{\log b} = b^{\log a} \qquad x^{\frac{\log(a)}{\log(x)}} = a$$

$$\frac{d}{dx} \log x = \frac{1}{x} \qquad \log x = \int_1^x \frac{1}{t} dt$$