A

Common Distributions

This thesis makes use of a number of common distributions. The notation $z \sim \mathrm{P}(\theta)$ means that the random variable z is sampled from (or distributed according to) the distribution P, which is parameterized by θ. When we write $\mathrm{P}(z \mid \theta)$ we refer to the density (assuming it exists) of P evaluated at z. Here, we provide a summary of common distributions and their parametric densities or mass functions.

Bernoulli

For a binary random variable $x \in \{0, 1\}$ with $\rho \in [0, 1]$,

$$\mathrm{Bern}(x \mid \rho) = \rho^x (1 - \rho)^{1-x}.$$

Beta

For a continuous random variable $\rho \in [0, 1]$ with $a > 0$ and $b > 0$,

$$\mathrm{Beta}(\rho \mid a, b) = \frac{\Gamma(a + b)}{\Gamma(a)\Gamma(b)} \rho^{a-1} (1 - \rho)^{b-1}.$$

The beta distribution is a conjugate prior for the Bernoulli, binomial, and negative binomial distributions.

Binomial

For an integer-valued random variable $x \in \{1, \ldots, N\}$ with $N \in \mathbb{N}$ and $\rho \in [0, 1]$,

$$\mathrm{Bin}(x \mid N, \rho) = \binom{N}{x} \rho^x (1-\rho)^{N-x}.$$

Dirichlet

For a probability vector $\boldsymbol{\pi} \in [0, 1]^K$ such that $\pi_k \geq 0$ and $\sum_k \pi_k = 1$, and parameter $\boldsymbol{\alpha} \in \mathbb{R}_+^K$,

$$\mathrm{Dir}(\boldsymbol{\pi} \mid \boldsymbol{\alpha}) = \frac{\Gamma\left(\sum_{k=1}^K \alpha_k\right)}{\prod_{k=1}^K \Gamma(\alpha_k)} \prod_{k=1}^K \pi_k^{\alpha_k - 1}.$$

The Dirichlet distribution is a conjugate prior to the discrete and multinomial distributions.

Discrete

For a discrete random variable $x \in \{1, \ldots, K\}$ with K distinct outcomes, and a probability vector $\boldsymbol{\pi} \in [0, 1]^K$ that is nonnegative and sums to one,

$$\mathrm{Discrete}(x \mid \boldsymbol{\pi}) = \prod_{k=1}^K \pi_k^{\mathbb{I}[x=k]}.$$

Gamma

For a nonnegative random variable $\lambda \in \mathbb{R}_+$ with shape parameter $a > 0$ and rate parameter $b > 0$,

$$\mathrm{Gamma}(\lambda \,|\, a, b) = \frac{b^a}{\Gamma(a)} \lambda^{a-1} e^{-b\lambda}.$$

The gamma distribution is the conjugate prior to the Poisson distribution, as well as to the rate parameter of the gamma distribution. The gamma distribution may also be parameterized in terms of a scale parameter, $\theta = b^{-1}$, but we do not use that parameterization in this thesis.

Gaussian

For a random variable $\boldsymbol{x} \in \mathbb{R}^D$ with mean $\boldsymbol{\mu} \in \mathbb{R}^D$ and positive semidefinite covariance matrix $\boldsymbol{\Sigma} \in \mathbb{R}^{D \times D}$,

$$\mathcal{N}(\boldsymbol{x} \,|\, \boldsymbol{\mu}, \boldsymbol{\Sigma}) = (2\pi)^{-D/2} |\boldsymbol{\Sigma}|^{-1/2} \exp\left\{ -\frac{1}{2} (\boldsymbol{x} - \boldsymbol{\mu})^\mathsf{T} \boldsymbol{\Sigma}^{-1} (\boldsymbol{x} - \boldsymbol{\mu}) \right\}.$$

Multinomial

For a vector of discrete counts $\boldsymbol{x} \in \mathbb{N}^K$ with $\sum_k x_k = N$ and a probability vector $\boldsymbol{\pi} \in [0,1]^K$,

$$\mathrm{Mult}(\boldsymbol{x} \,|\, N, \boldsymbol{\pi}) = \binom{N}{x_1, x_2, \ldots x_K} \prod_{k=1}^{K} \pi_k^{x_k},$$

where

$$\binom{N}{x_1, x_2, \ldots x_K} = \frac{N!}{x_1! \ldots x_K!}.$$

Negative Binomial

For an integer-valued random variable $x \in \mathbb{N}$ with shape parameters $\nu \in \mathbb{R}_+$ and probability $\rho \in [0, 1]$,

$$\mathrm{NB}(x \mid \nu, \rho) = \binom{x + \nu - 1}{x} \rho^x (1 - \rho)^\nu.$$

Poisson

For an integer random variable $x \in \mathbb{N}$ and a nonnegative rate parameters $\lambda \in \mathbb{R}_+$,

$$\mathrm{Poisson}(x \mid \lambda) = \frac{1}{x!} \lambda^x e^{-\lambda}.$$

Uniform

For a continuous random variable $x \in \mathbb{R}$,

$$\mathrm{Unif}(x \mid a, b) = \begin{cases} \frac{1}{b-a} & \text{if } a < x < b, \\ 0 & \text{o.w..} \end{cases}$$

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