

gaussian identities

0.1 multidimensional gaussian

a d -dimensional multidimensional gaussian (normal) density for \mathbf{x} is:

$$\mathcal{N}(\boldsymbol{\mu}, \boldsymbol{\Sigma}) = (2\pi)^{-d/2} |\boldsymbol{\Sigma}|^{-1/2} \exp \left[-\frac{1}{2} (\mathbf{x} - \boldsymbol{\mu})^T \boldsymbol{\Sigma}^{-1} (\mathbf{x} - \boldsymbol{\mu}) \right] \quad (1)$$

it has entropy:

$$S = \frac{1}{2} \log_2 \left[(2\pi e)^d |\boldsymbol{\Sigma}| \right] - \text{const bits} \quad (2)$$

where $\boldsymbol{\Sigma}$ is a symmetric positive semi-definite covariance matrix and the (unfortunate) constant is the log of the units in which \mathbf{x} is measured over the "natural units"

0.2 linear functions of a normal vector

no matter how \mathbf{x} is distributed,

$$\mathbf{E}[\mathbf{Ax} + \mathbf{y}] = \mathbf{A}(\mathbf{E}[\mathbf{x}]) + \mathbf{y} \quad (3a)$$

$$\text{Covar}[\mathbf{Ax} + \mathbf{y}] = \mathbf{A}(\text{Covar}[\mathbf{x}])\mathbf{A}^T \quad (3b)$$

in particular this means that for normal distributed quantities:

$$\mathbf{x} \sim \mathcal{N}(\boldsymbol{\mu}, \boldsymbol{\Sigma}) \Rightarrow (\mathbf{Ax} + \mathbf{y}) \sim \mathcal{N}(\mathbf{A}\boldsymbol{\mu} + \mathbf{y}, \mathbf{A}\boldsymbol{\Sigma}\mathbf{A}^T) \quad (4a)$$

$$\mathbf{x} \sim \mathcal{N}(\boldsymbol{\mu}, \boldsymbol{\Sigma}) \Rightarrow \boldsymbol{\Sigma}^{-1/2}(\mathbf{x} - \boldsymbol{\mu}) \sim \mathcal{N}(\mathbf{0}, \mathbf{I}) \quad (4b)$$

$$\mathbf{x} \sim \mathcal{N}(\boldsymbol{\mu}, \boldsymbol{\Sigma}) \Rightarrow (\mathbf{x} - \boldsymbol{\mu})^T \boldsymbol{\Sigma}^{-1} (\mathbf{x} - \boldsymbol{\mu}) \sim \chi_n^2 \quad (4c)$$

0.3 marginal and conditional distributions

let the vector $\mathbf{z} = [\mathbf{x}^T \mathbf{y}^T]^T$ be normally distributed according to:

$$\mathbf{z} = \begin{bmatrix} \mathbf{x} \\ \mathbf{y} \end{bmatrix} \sim \mathcal{N} \left(\begin{bmatrix} \mathbf{a} \\ \mathbf{b} \end{bmatrix}, \begin{bmatrix} \mathbf{A} & \mathbf{C} \\ \mathbf{C}^T & \mathbf{B} \end{bmatrix} \right) \quad (5a)$$

where \mathbf{C} is the (non-symmetric) cross-covariance matrix between \mathbf{x} and \mathbf{y} which has as many rows as the size of \mathbf{x} and as many columns as the size of \mathbf{y} . then the marginal distributions are:

$$\mathbf{x} \sim \mathcal{N}(\mathbf{a}, \mathbf{A}) \quad (5b)$$

$$\mathbf{y} \sim \mathcal{N}(\mathbf{b}, \mathbf{B}) \quad (5c)$$

and the conditional distributions are:

$$\mathbf{x}|\mathbf{y} \sim \mathcal{N}(\mathbf{a} + \mathbf{C}\mathbf{B}^{-1}(\mathbf{y} - \mathbf{b}), \mathbf{A} - \mathbf{C}\mathbf{B}^{-1}\mathbf{C}^T) \quad (5d)$$

$$\mathbf{y}|\mathbf{x} \sim \mathcal{N}(\mathbf{b} + \mathbf{C}^T\mathbf{A}^{-1}(\mathbf{x} - \mathbf{a}), \mathbf{B} - \mathbf{C}^T\mathbf{A}^{-1}\mathbf{C}) \quad (5e)$$

0.4 multiplication

the multiplication of two gaussian functions is another gaussian function (although no longer normalized). in particular,

$$\mathcal{N}(\mathbf{a}, \mathbf{A}) \cdot \mathcal{N}(\mathbf{b}, \mathbf{B}) \propto \mathcal{N}(\mathbf{c}, \mathbf{C}) \quad (6a)$$

where

$$\mathbf{C} = (\mathbf{A}^{-1} + \mathbf{B}^{-1})^{-1} \quad (6b)$$

$$\mathbf{c} = \mathbf{C}\mathbf{A}^{-1}\mathbf{a} + \mathbf{C}\mathbf{B}^{-1}\mathbf{b} \quad (6c)$$

amazingly, the normalization constant z_c is Gaussian in either \mathbf{a} or \mathbf{b} :

$$z_c = (2\pi)^{-d/2} |\mathbf{C}|^{+1/2} |\mathbf{A}|^{-1/2} |\mathbf{B}|^{-1/2} \exp \left[-\frac{1}{2} (\mathbf{a}^T \mathbf{A}^{-1} \mathbf{a} + \mathbf{b}^T \mathbf{B}^{-1} \mathbf{b} - \mathbf{c}^T \mathbf{C}^{-1} \mathbf{c}) \right] \quad (6d)$$

$$z_c(\mathbf{a}) \sim \mathcal{N}((\mathbf{A}^{-1}\mathbf{C}\mathbf{A}^{-1})^{-1}(\mathbf{A}^{-1}\mathbf{C}\mathbf{B}^{-1})\mathbf{b}, (\mathbf{A}^{-1}\mathbf{C}\mathbf{A}^{-1})^{-1}) \quad (6e)$$

$$z_c(\mathbf{b}) \sim \mathcal{N}((\mathbf{B}^{-1}\mathbf{C}\mathbf{B}^{-1})^{-1}(\mathbf{B}^{-1}\mathbf{C}\mathbf{A}^{-1})\mathbf{a}, (\mathbf{B}^{-1}\mathbf{C}\mathbf{B}^{-1})^{-1}) \quad (6f)$$

0.5 quadratic forms

the expectation of a quadratic form under a gaussian is another quadratic form (plus an annoying constant). in particular, if \mathbf{x} is gaussian distributed with mean \mathbf{m} and variance \mathbf{S} then,

$$\int_{\mathbf{x}} (\mathbf{x} - \boldsymbol{\mu})^T \boldsymbol{\Sigma}^{-1} (\mathbf{x} - \boldsymbol{\mu}) \mathcal{N}(\mathbf{m}, \mathbf{S}) d\mathbf{x} \\ = (\boldsymbol{\mu} - \mathbf{m})^T \boldsymbol{\Sigma}^{-1} (\boldsymbol{\mu} - \mathbf{m}) + \text{Tr} [\boldsymbol{\Sigma}^{-1} \mathbf{S}] \quad (7a)$$

if the original quadratic form has a linear function of \mathbf{x} the result is still simple:

$$\int_{\mathbf{x}} (\mathbf{W}\mathbf{x} - \boldsymbol{\mu})^T \boldsymbol{\Sigma}^{-1} (\mathbf{W}\mathbf{x} - \boldsymbol{\mu}) \mathcal{N}(\mathbf{m}, \mathbf{S}) d\mathbf{x} \\ = (\boldsymbol{\mu} - \mathbf{W}\mathbf{m})^T \boldsymbol{\Sigma}^{-1} (\boldsymbol{\mu} - \mathbf{W}\mathbf{m}) + \text{Tr} [\mathbf{W}^T \boldsymbol{\Sigma}^{-1} \mathbf{W} \mathbf{S}] \quad (7b)$$

0.6 convolution

the convolution of two gaussian functions is another gaussian function (although no longer normalized). in particular,

$$\mathcal{N}(\mathbf{a}, \mathbf{A}) * \mathcal{N}(\mathbf{b}, \mathbf{B}) \propto \mathcal{N}(\mathbf{a} + \mathbf{b}, \mathbf{A} + \mathbf{B}) \quad (8)$$

this is a direct consequence of the fact that the Fourier transform of a gaussian is another gaussian and that the multiplication of two gaussians is still gaussian.

0.7 Fourier transform

the (inverse) Fourier transform of a gaussian function is another gaussian function (although no longer normalized). in particular,

$$\mathcal{F}[\mathcal{N}(\mathbf{a}, \mathbf{A})] \propto \mathcal{N}(j\mathbf{A}^{-1}\mathbf{a}, \mathbf{A}^{-1}) \quad (9a)$$

$$\mathcal{F}^{-1}[\mathcal{N}(\mathbf{b}, \mathbf{B})] \propto \mathcal{N}(-j\mathbf{B}^{-1}\mathbf{b}, \mathbf{B}^{-1}) \quad (9b)$$

where $j = \sqrt{-1}$

0.8 constrained maximization

the maximum over \mathbf{x} of the quadratic form:

$$\boldsymbol{\mu}^T \mathbf{x} - \frac{1}{2} \mathbf{x}^T \mathbf{A}^{-1} \mathbf{x} \quad (10a)$$

subject to the J conditions $c_j(\mathbf{x}) = 0$ is given by:

$$\mathbf{A}\boldsymbol{\mu} + \mathbf{A}\mathbf{C}\boldsymbol{\Lambda}, \quad \boldsymbol{\Lambda} = -4(\mathbf{C}^T \mathbf{A}\mathbf{C})\mathbf{C}^T \mathbf{A}\boldsymbol{\mu} \quad (10b)$$

where the j th column of \mathbf{C} is $\partial c_j(\mathbf{x})/\partial \mathbf{x}$