Importance Sampling

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Normal distribution

For the normal distribution $\mathcal{N}(\mu, \Sigma)$ to look like the one from exponential family, let's make a change of variables: $S = \Sigma^{-1}$ and $m = \Sigma^{-1}\mu$. Then the density of distribution will look like the following:

$$g_{m,S}(x) = \frac{1}{2\pi} \exp\Big(m^T x - \frac{1}{2}\operatorname{tr}(Sxx^T)\Big) \exp\Big(-\frac{1}{2}\big(m^T S^{-1} m - \log|S|\big)\Big).$$

So in this case $A(m, S) = \frac{1}{2} m^T S^{-1} m - \frac{1}{2}\log|S|$, $T(x) = (x, -\frac{1}{2}xx^T)$ and $h(x) = \frac{1}{2\pi}$

Strong convexity

It is a well-known fact that if $f(x)$ is strong convex with a coefficient β, then $e^{f(x)}$ is a strongly convex function on some compact and if $x \in [-C, C]$ for some $C > 0$, then the coefficient of strong convexity is equal to βe^{-C}. In our case if $\lambda(\Sigma) \in [\lambda_{min}, \lambda_{max}]$, then

$$\frac{1}{2}x^T Sx - m^T x + \frac{1}{2}m^T S^{-1} m - \frac{1}{2}\log|S| \geq -\frac{1}{2}\log|S| \geq \frac{n}{2}\log\lambda_{min}$$

Therefore, $e^{-C} = \lambda_{min}^{\frac{n}{2}}$. Now we need to find β.

Strong convexity

It is quite obvious that $\frac{1}{2}x^T Sx - m^T x$ is convex w.r.t. distribution parameters m, S. One can easily check the convexity of $f(x) = \frac{1}{2}m^T S^{-1} m$ using the following criterion:

$$\langle \nabla f(x) - \nabla f(y), x - y \rangle \geq 0$$

Indeed, here $\nabla f(x) = (S^{-1}m, -\frac{1}{2}S^{-1}mm^T S^{-1})$, so

$$\frac{1}{2}\operatorname{tr}\left(\left(S_1^{-1}m_1 m_1^T S_1^{-1} - S_2^{-1}m_2 m_2^T S_2^{-1}\right)^T \left(S_2 - S_1\right)\right) +$$
$$+\left(S_1^{-1}m_1 - S_2^{-1}m_2\right)^T \left(m_1 - m_2\right) = \frac{1}{2}(x_1 - x_2)^T (S_1 + S_2)(x_1 - x_2) > 0$$

where $x_i = S_i^{-1}m_i$ and last inequality holds due to S_i is positive-definite for any $i \in \{1, 2\}$

Strong convexity

Let's prove the strong convexity of the function $f(S) = -\frac{1}{2}\log|S|$, using the criterion:

$$\langle \nabla f(x) - \nabla f(y), x - y \rangle \geq \beta \|x - y\|^2$$

Here, as $\nabla f(S) = -\frac{1}{2}S^{-1}$, then

$$\frac{1}{2}\operatorname{tr}((S_1^{-1} - S_2^{-1})^T(S_2 - S_1)) = \frac{1}{2}(S_1^{-1}(S_2 - S_1)^T S_2^{-1}(S_2 - S_1)) \geq$$
$$\geq \frac{\lambda_{min}^2}{2}\operatorname{tr}((S_2 - S_1)^T(S_2 - S_1))$$

Therefore $\beta = \dfrac{\lambda_{min}^2}{2}$

Finally, $\alpha = \dfrac{\lambda_{min}^{\frac{n}{2}+2}}{2}$

Closing remark

If we have a proper $\alpha(x)$ (here $\alpha(x) = \frac{\lambda_{min}^{\frac{n}{2}+2}}{2}$) and a set $\mathbf{\Theta}$, then for all $\theta_1, \theta_2 \in \mathbf{\Theta}$ we will have:

$$\int \exp(A(t(\theta_1) + (1-t)\theta_2) - (t\theta_1 + (1-t)\theta_2)^T T(x)) f^2(x)\phi^2(x)h(x)\,dx \leq$$

$$\leq t \int \exp(A(\theta_1) - \theta_1^T T(x)) f^2(x)\phi^2(x)h(x)\,dx +$$

$$+ (1-t) \int \exp(A(\theta_2) - \theta_2^T T(x)) f^2(x)\phi^2(x)h(x)\,dx -$$

$$- t(1-t)\frac{\lambda_{min}^{\frac{n}{2}+2}}{4\pi} \int f^2(x)\phi^2(x)\,dx \|\theta_1 - \theta_2\|_2^2$$

The coefficient will depend on the value of $\int\limits_{\mathbb{R}^n} f^2(x)\phi^2(x)\,dx$, but we can also take $\alpha(x) = \frac{\lambda_{min}^{\frac{n}{2}+2}}{2}\mathbb{I}(x \in X)$ for some X and then it is enough to know the value $\int\limits_X f^2(x)\phi^2(x)\,dx$