# Chapter 9

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July 4, 2021

## Comments and Proofs

Another way to think of importance sampling is that we are trying to estimate $p$, but some regions of $p$ are more important than others (e.g. when $f(x)$ is large for equation 23.19). Thus sampling from $q$ lets us estimate $p$, but with a high resolution in regions where the probability density of $q$ is high.

## Exercises

### Exercise 2

The optimal M is given by

$$\begin{aligned} M &= \max\left[\frac{\text{Ga}(x|\alpha,\beta)}{\mathcal{T}(x|0,1,1)}\right] \\ &\propto \max\left[x^{\alpha-1}e^{-\beta x}\left(1+x^2\right)\right] \end{aligned}$$

Deriving the expression inside the max and setting to 0 tells us that

$$M = \left[\frac{\text{Ga}(x^*|\alpha,\beta)}{\mathcal{T}(x^*|0,1,1)}\right]$$

where $x^*$ is the solution to

$$-\beta x^3 + (\alpha+1)x^2, -\beta x + \alpha - 1 = 0$$

I'm not sure which of the roots to pick, but in the demo, there was only one real solution, so I just used that one.

Its pretty easy to see that rejection sampling of a gamma distribution with with a Cauchy proposal is fairly inefficient. One reason is that the gamma distribution has no support for negative numbers, thus at least half of the samples will be rejected. A better idea might be to use a student T distribution with $\mu = \frac{\alpha-1}{\beta}, \sigma^2 = \frac{\alpha}{\beta^2}$ and $\upsilon = 1$. The idea here is to have both distributions have the same mode and scale (note that the Cauchy distribution does not have a variance). An even better solution would be to sample as in section 23.2 since the gamma cdf has a closed form.

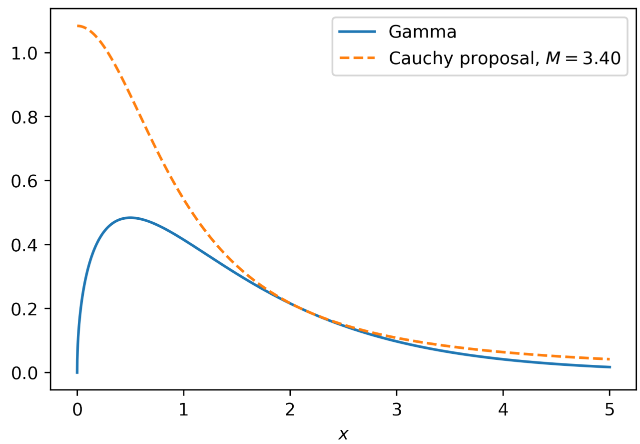


**Figure 1:** True gamma distribution vs Cauchy proposal with optimal $M$

## Exercise 3

When the transition dynamics of a model is non-linear, exact inference is intractable, even if the observation model is linear. We can see this when looking at the distribution for $\mathbf{z}_2$ given $\mathbf{y}_1, \mathbf{y}_2$:

$$p(\mathbf{z}_2|\mathbf{y}_1, \mathbf{y}_2) = \int p(\mathbf{z}_2|f(\mathbf{z}_1), \mathbf{y}_2)p(\mathbf{z}_1|\mathbf{y}_1)d\mathbf{z}_1$$

This is intractable because we have an $f(\mathbf{z}_1)$ in the integral. However, if we use particle filtering, we no long have to perform the calculate integral.

The optimal proposal distribution $q$ is given by equation 23.54. Given the form of our model, this is equivalent to having a prior of $\mathcal{N}(f(\mathbf{z}_{t-1}), \mathbf{Q}_{t-1})$ and a likelihood of $\mathcal{N}(\mathbf{H}_t\mathbf{z}_t, \mathbf{R}_t$. Plugging this into equation 4.125, we have

$$\begin{aligned} p(\mathbf{z}_t|\mathbf{z}_{t-1}, \mathbf{y}_t) &= \mathcal{N}(\mathbf{z}_t|\boldsymbol{\mu}, \boldsymbol{\Sigma}) \\ \boldsymbol{\Sigma}^{-1} &= \mathbf{Q}_{t-1}^{-1} + \mathbf{H}_t^T\mathbf{R}_t\mathbf{H} \\ \boldsymbol{\mu} &= \boldsymbol{\Sigma}\left[\mathbf{H}_t^T\mathbf{R}_{t-1}^{-1}\mathbf{y}_t + \mathbf{Q}_{t-1}^{-1}f(\mathbf{z}_{t-1})\right] \end{aligned}$$