

# Evidence lower bounds with built-in baselines

Justin

December 26, 2022

## 1 Problem setup

The goal is to maximize the log marginal likelihood,

$$\log p(x) = \log \sum_z p(x, z), \quad (1)$$

for a latent variable model. The derivative of the above is

$$\nabla \log \sum_z p(x, z) = \frac{p(x, z)}{p(x)} \nabla \log p(x, z) = p(z | x) \nabla \log p(x, z), \quad (2)$$

the expected gradient under the posterior. When exact marginalization is intractable, a common approach is to introduce a variational approximation to the posterior  $q(z | x)$  and optimize the lower bound

$$\log p(x) = \log \sum_z q(z | x) \frac{p(x, z)}{q(z | x)} \geq \sum_z q(z | x) \log \frac{p(x, z)}{q(z | x)}, \quad (3)$$

which allows for tractable Monte Carlo approximation.<sup>1</sup>

Empirically, we find directly optimizing this lower bound (3) to be more difficult than optimizing the marginal likelihood (1), often requiring a baseline:

$$\begin{aligned} & \nabla_q \sum_z q(z | x) \log \frac{p(x, z)}{q(z | x)} \\ &= \nabla_q \sum_z q(z | x) \log p(x | z) - KL[q(z | x) || p(z)] \\ &= \nabla_q \sum_z q(z | x) (\log p(x | z) - B) - KL[q(z | x) || p(z)], \end{aligned} \quad (4)$$

where the baseline  $B$  is not a function of  $z$ .<sup>2</sup> Computing this baseline  $B$  can be expensive, potentially requiring multiple evaluations of  $p(x | z)$ . A common choice of baseline is the sample-average baseline, where  $B = \sum_{z' \in Z} \log p(x | z')$  and  $Z$  is a set of iid samples.<sup>3</sup> Additionally, even in scenarios where exact marginalization is tractable, prior work has included a baseline. This begs the questions: Is a baseline necessary, and why does optimizing the marginal likelihood not require a baseline?

We show that the gradient of the marginal likelihood (2) already contains a built-in baseline, and use that to derive a simple and computable lower bound of the marginal likelihood (1) whose gradient does not require the manual engineering of a baseline.

<sup>1</sup>The gap between the two is given by  $KL[q(z | x) || p(z | x)]$ .

<sup>2</sup>The derivative is a linear operator, and  $\nabla \sum_z q(z | x) B = B \nabla \sum_z q(z | x) = B \cdot 0$ .

<sup>3</sup>A more efficient alternative is the leave-one-out baseline, which is efficient if the results of  $p(x | z)$  are already available for a set of iid  $z$ .

## 2 The gradient of logsumexp approximates the exponentiated regret

The key component of the marginal likelihood is the logsumexp operation, a smooth version of max:  $\log \sum_z \exp f(z)$ . Similar to the gradient of the marginal likelihood, the gradient of logsumexp is given by

$$\nabla \log \sum_{z' \in Z} \exp f(z') = \frac{e^{f(z)}}{\sum_{z' \in Z} e^{f(z')}} \nabla f(z) = e^{f(z) - \log \sum_{z' \in Z} e^{f(z')}} \nabla f(z) \approx \underbrace{e^{f(z) - \max_{z' \in Z} f(z')}}_R \nabla f(z).$$

The last approximation holds because logsumexp is a smooth approximation of max. We can therefore think of  $\log \sum_{z' \in Z} \exp f(z') \approx \max_{z' \in Z} f(z)$  as a built-in baseline.  $R$  is also the exponentiated regret, the difference between a given  $f(z)$  and the best  $f(z)$ . Since the regret is non-positive, the exponentiated regret is always between 0 and 1.

## 3 Variance analysis

TBD