

# Evidence lower bounds with built-in baselines

Justin

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## 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 equation 1 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 and exact computation of the posterior is intractable,<sup>1</sup> a common approach is to introduce a variational approximation the the posterior  $q(z | x)$  and optimize the following lower bound

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

Empirically, we find that directly optimizing equation 3 to be more difficult than optimizing the marginal likelihood (equation 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>3</sup> Computing this baseline  $B$  can be relatively expensive, 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>4</sup>

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

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<sup>1</sup>Marginalization and computation of the posterior take the same amount of computation.

<sup>2</sup>The gap between the two is given by  $KL[q(z | x) || p(z | x)]$ .

<sup>3</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>4</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 gives the scaled regret

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

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

The last approximation holds because logsumexp is a smooth approximation of  $\max$ . We can therefore think of  $R$  as a built-in baseline.  $R$  is also known as the regret, e.g. difference between a given  $f(z)$  and the best  $f(z)$ . The gradient has another nice property: it is always scaled between 0 and 1.