

EE-559 – Deep learning

## 5.2. Stochastic gradient descent

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To minimize a loss of the form

$$\mathcal{L}(w) = \sum_{n=1}^N \underbrace{\ell(f(x_n; w), y_n)}_{\ell_n(w)}$$

the standard gradient-descent algorithm update has the form

$$w_{t+1} = w_t - \eta \nabla \mathcal{L}(w_t).$$

A straight-forward implementation would be

```
for e in range(nb_epochs):
    output = model(train_input)
    loss = criterion(output, train_target)

    model.zero_grad()
    loss.backward()
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However, the memory footprint is proportional to the full set size. This can be mitigated by summing the gradient through “mini-batches”:

```
for e in range(nb_epochs):
    model.zero_grad()

    for b in range(0, train_input.size(0), batch_size):
        output = model(train_input[b:b+batch_size])
        loss = criterion(output, train_target[b:b+batch_size])
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- It takes time to compute (more exactly **all our time!**).
- It is an empirical estimation of an hidden quantity, and any partial sum is also an unbiased estimate, although of greater variance.
- It is computed incrementally

$$\nabla \mathcal{L}(w_t) = \sum_{n=1}^N \nabla \ell_n(w_t),$$

and when we compute  $\ell_n$ , we have already computed  $\ell_1, \dots, \ell_{n-1}$ , and we could have a better estimate of  $w^*$  than  $w_t$ .



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So instead of summing over all the samples and moving by  $\eta$ , we can visit only  $M = N/K$  samples and move by  $K\eta$ , which would cut the computation by  $K$ .

Although this is an ideal case, there is redundancy in practice that results in similar behaviors.

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**The stochastic behavior of this procedure helps evade local minima.**



So our exact gradient descent with mini-batches

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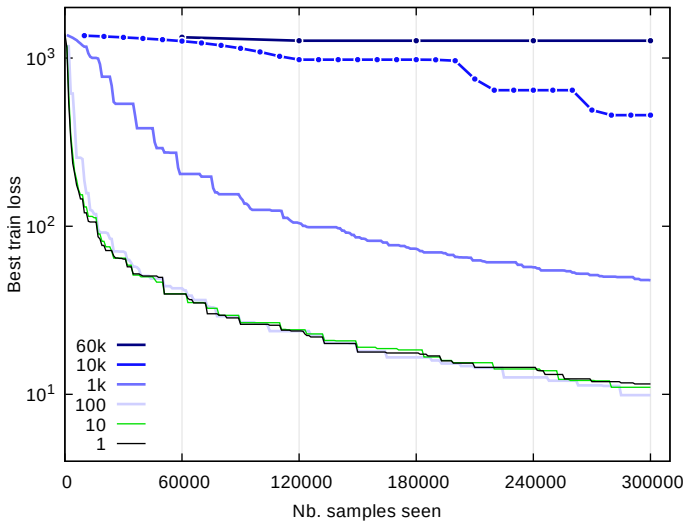
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can be modified into the mini-batch stochastic gradient descent as follows:

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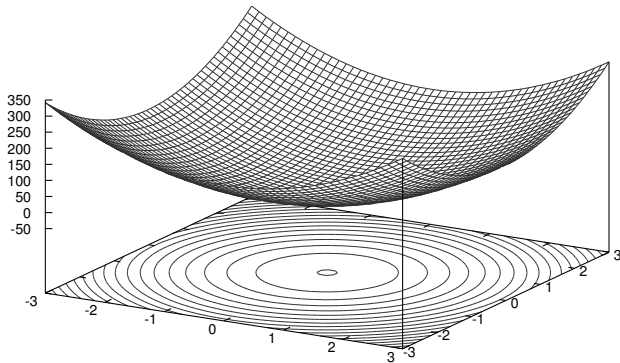
Mini-batch size and loss reduction (MNIST)



## Limitation of the gradient descent

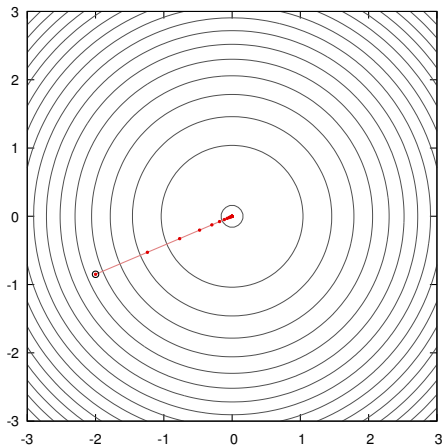
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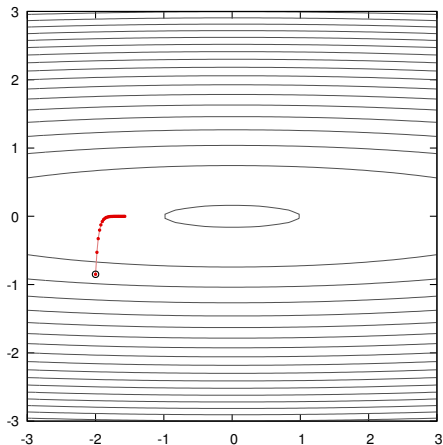
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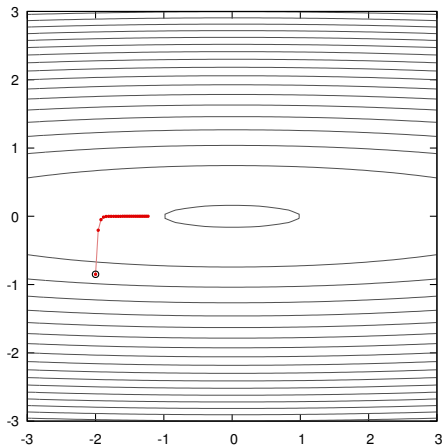
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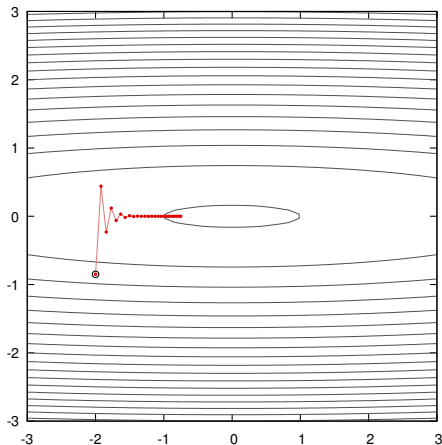
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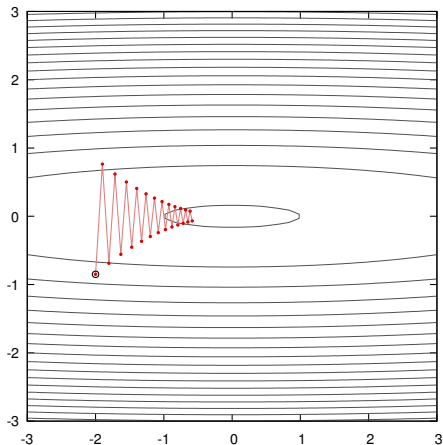
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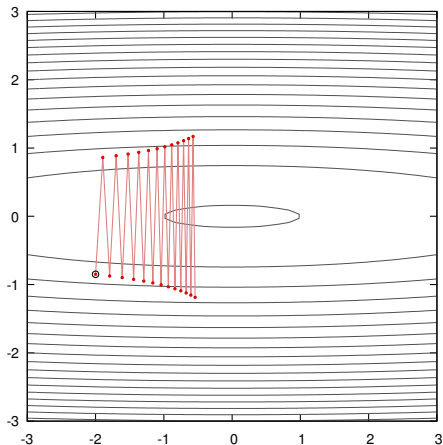
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Deep-learning generally relies on a smarter use of the gradient, using statistics over its past values to make a “smarter step” with the current one.

## Momentum and moment estimation



The “vanilla” mini-batch stochastic gradient descent (SGD) consists of

$$w_{t+1} = w_t - \eta g_t,$$

where

$$g_t = \sum_{b=1}^B \nabla \ell_{n(t,b)}(w_t)$$

is the gradient summed over a mini-batch.

The first improvement is the use of a “momentum” to add inertia in the choice of the step direction

$$u_t = \gamma u_{t-1} + \eta g_t$$
$$w_{t+1} = w_t - u_t.$$

(Rumelhart et al., 1986)

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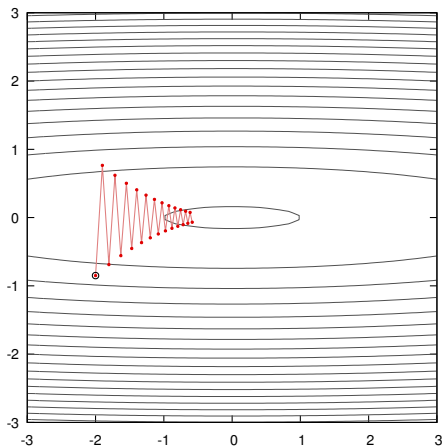
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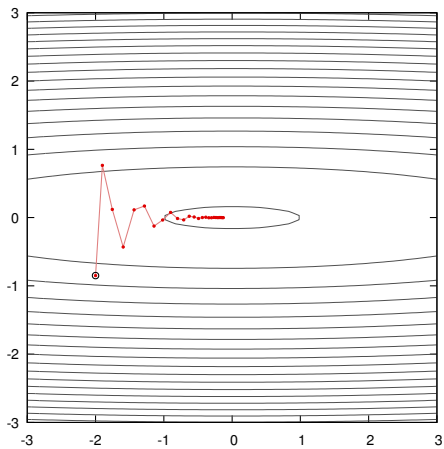
$$(u = \gamma u + \eta g) \Rightarrow \left( u = \frac{\eta}{1 - \gamma} g \right),$$

- it dampens oscillations in narrow valleys.

$$\eta = 5.0e - 2, \gamma = 0$$



$$\eta = 5.0e - 2, \gamma = 0.5$$



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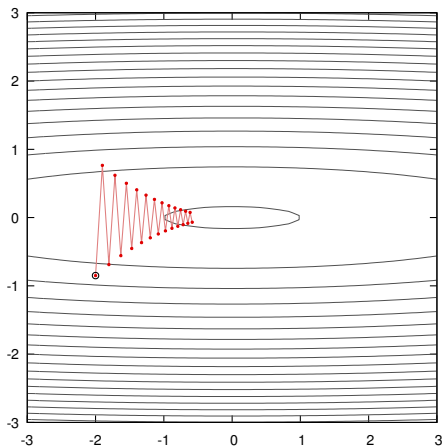
The update rule is, **on each coordinate separately**

$$\begin{aligned}m_t &= \beta_1 m_{t-1} + (1 - \beta_1) g_t \\ \hat{m}_t &= \frac{m_t}{1 - \beta_1} \\ v_t &= \beta_2 v_{t-1} + (1 - \beta_2) g_t^2 \\ \hat{v}_t &= \frac{v_t}{1 - \beta_2} \\ w_{t+1} &= w_t - \frac{\eta}{\sqrt{\hat{v}_t} + \epsilon} \hat{m}_t\end{aligned}$$

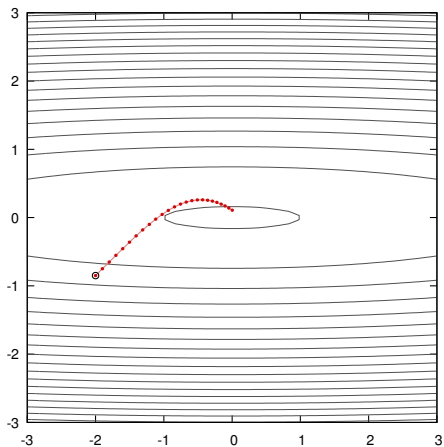
(Kingma and Ba, 2014)

This can be seen as a combination of momentum, with  $\hat{m}_t$ , and a per-coordinate re-scaling with  $\hat{v}_t$ .

$$\eta = 5.0e - 2$$



Adam,  $\beta_1 = 0.9, \beta_2 = 0.999, \epsilon = 1e - 8, \eta = 1.0e - 1$



These two core strategies have been used in multiple incarnations:

- Nesterov's accelerated gradient,
- Adagrad,
- Adadelta,
- RMSprop,
- AdaMax,
- Nadam ...

The end

## References

- D. Kingma and J. Ba. Adam: A method for stochastic optimization. CoRR, abs/1412.6980, 2014.
- D. E. Rumelhart, G. E. Hinton, and R. J. Williams. Learning representations by back-propagating errors. Nature, 323(9):533–536, 1986.