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# Regularization

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April 25, 2023



## Tasks in this exercise

1. Optimization Constraints: Augmenting the loss function
2. Dropout **Layer**
3. Batch Normalization **Layer**
4. LeNet: Put everything together (**optional**)
5. RNN layer: Elman Unit
6. LSTM layer: Backpropagation at its best! (**optional**)



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# Optimization Constraints: Loss function augmentation



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- **Independent** of loss function
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- Add constraint objects in the optimizer
- Since constraints generate part of the loss:
- Change Neural Network container class (and associated classes) to “channel” and gather **regularization loss** for **all layers**

## Workflow

- Forward pass
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  - Add regularization loss to the final loss
- Backward pass
  - In each trainable layer, include **the gradient of norm** when calculating update

## $L_2$ regularization

- Forward pass:

$$\tilde{L}(\mathbf{w}) = L(\mathbf{w}) + \lambda \|\mathbf{w}\|_2^2$$

- Backward pass:

$$\mathbf{w}^{(k+1)} = \underbrace{(1 - \eta \lambda) \mathbf{w}^{(k)}}_{\text{Shrinkage}} - \eta \frac{\partial L}{\partial \mathbf{w}^{(k)}}$$

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- Notice for matrices we compute here the Frobenius norm, not the Spectral norm.
- The influence of constraints is controlled via  $\lambda$ . Because `lambda` is a python keyword, you want to use e.g. `alpha` instead.

## $L_1$ regularization

- Forward pass:

$$\tilde{L}(\mathbf{w}) = L(\mathbf{w}) + \lambda \|\mathbf{w}\|_1$$

- Backward pass:

$$\mathbf{w}^{(k+1)} = \underbrace{\mathbf{w}^{(k)} - \eta \lambda \text{sign}(\mathbf{w}^{(k)})}_{\text{Other shrinkage}} - \eta \frac{\partial L}{\partial \mathbf{w}^{(k)}}$$



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# Dropout



## Method

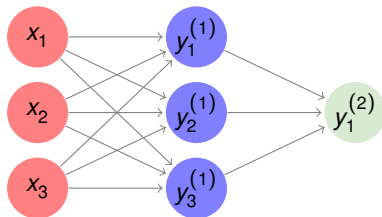


Figure: Dropout

- Implement this as a **fixed-function layer**



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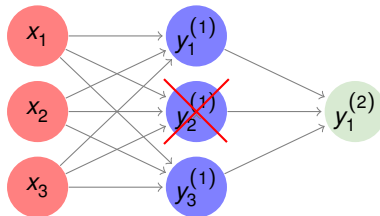


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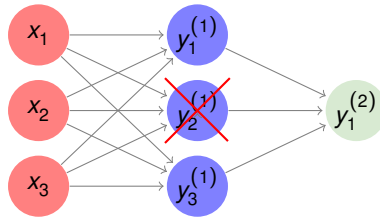


Figure: Dropout

- Implement this as a **fixed-function layer**
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- Can we get rid of the dropout layer at test-time?
- Change the behavior during training
- Multiply activations in forward-pass **only during training** by  $\frac{1}{p}$  (increases signal strength)
- Note: the backward pass has to be adapted as well!



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# Batch normalization



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$$\tilde{\mathbf{X}} = \frac{\mathbf{X} - \mu_B}{\sqrt{\sigma_B^2 + \epsilon}} \rightarrow \text{always +ve}$$

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gamma and beta are trained in BN

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- Notice that  $\beta$  is a **bias**

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- Therefore a **moving average** is common:

$$\begin{aligned}\tilde{\mu}^{(k)} &\approx \alpha \tilde{\mu}^{(k-1)} + (1 - \alpha) \mu_B^{(k)} \\ \tilde{\sigma}^{2(k)} &\approx \alpha \tilde{\sigma}^{2(k-1)} + (1 - \alpha) \sigma_B^{2(k)}\end{aligned}$$

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- Moving average **decay**  $\alpha$  (e.g. 0.8)
- The exponent (k) and (k-1) are iteration-indices!

## Backward pass

- Gradient **with respect to weights** is simply:

$$\frac{\partial L}{\partial \gamma} = \sum_{b=1}^B \frac{\partial L}{\partial \hat{\mathbf{Y}}_b} \tilde{\mathbf{X}}_b = \sum_{b=1}^B \mathbf{E}_b \tilde{\mathbf{X}}_b$$

- For the **bias** likewise we have:

$$\frac{\partial L}{\partial \beta} = \sum_{b=1}^B \frac{\partial L}{\partial \hat{\mathbf{Y}}_b} = \sum_{b=1}^B \mathbf{E}_b$$



## Backward pass

The **gradient with respect to the input** is more complicated, but here it is:

$$\begin{aligned}
 \frac{\partial L}{\partial \tilde{\mathbf{X}}} &= \frac{\partial L}{\partial \hat{\mathbf{Y}}} \odot \gamma \\
 \frac{\partial L}{\partial \sigma_B^2} &= \sum_{b=1}^B \frac{\partial L}{\partial \tilde{\mathbf{X}}_b} \odot (\mathbf{x}_b - \mu_B) \odot \frac{-1}{2} (\sigma_B^2 + \epsilon)^{\frac{-3}{2}} \\
 \frac{\partial L}{\partial \mu_B} &= \left( \sum_{b=1}^B \frac{\partial L}{\partial \tilde{\mathbf{X}}_b} \odot \frac{-1}{\sqrt{\sigma_B^2 + \epsilon}} \right) + \underbrace{\frac{\partial L}{\partial \sigma_B^2} \odot \frac{\sum_{b=1}^B -2(\mathbf{x}_b - \mu_B)}{B}}_0 \\
 \frac{\partial L}{\partial \mathbf{X}} &= \frac{\partial L}{\partial \tilde{\mathbf{X}}} \odot \frac{1}{\sqrt{\sigma_B^2 + \epsilon}} + \frac{\partial L}{\partial \sigma_B^2} \odot \frac{2(\mathbf{X} - \mu_B)}{B} + \frac{\partial L}{\partial \mu_B} \odot \frac{1}{B}
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- `compute_bn_gradients`

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  - because of our format we have to **transpose** from  $B \times H \times M \cdot N$  to  $B \times M \cdot N \times H$
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- ... and do the **same** in the **backward pass**



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## LeNet (optional)



# LeNet architecture

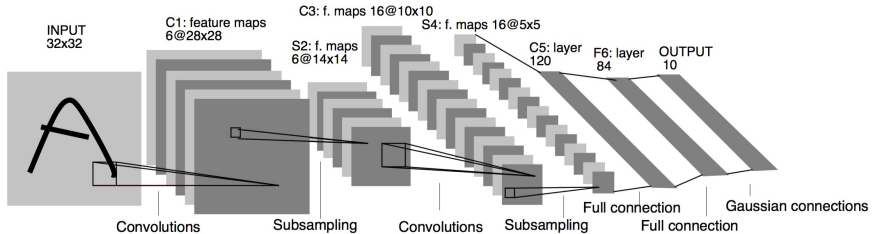


Figure: LeNet

# Modified LeNet architecture

## Deviations

- Input is  $28 \times 28$
- Our conv only supports “same” padding - so C3 has **larger activation maps**
- Input to **C5** is also **larger**
- We only implemented ReLUs, so **no** TanH
- We also use the implemented SoftMax **instead of** RBF units

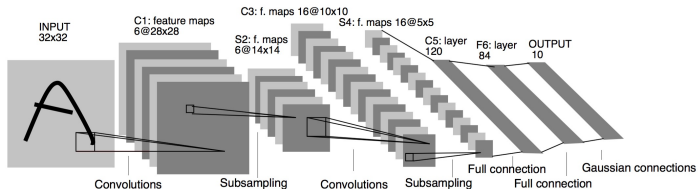


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Thanks for listening.  
**Any questions?**