

Computer Vision

CNN Training 2

Dr. Mrinmoy Ghorai

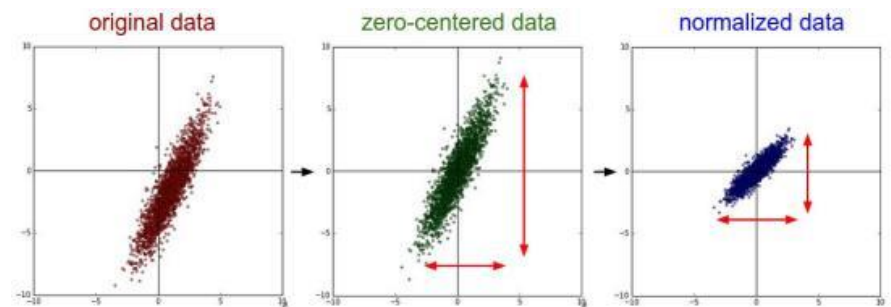
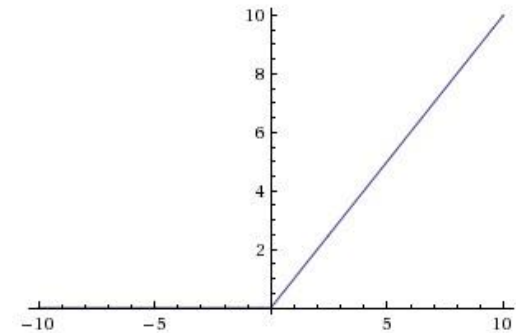
**Indian Institute of Information Technology
Sri City, Chittoor**



Previous Class

Training Aspects of CNN

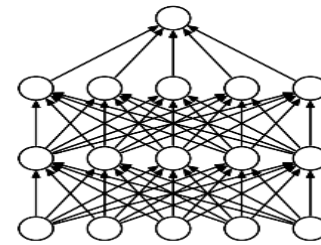
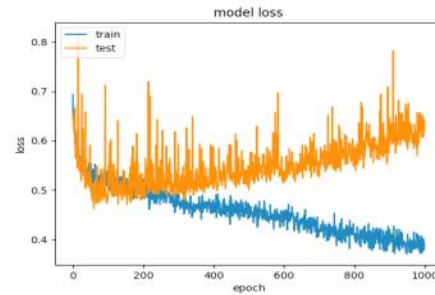
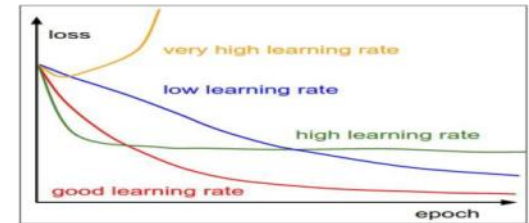
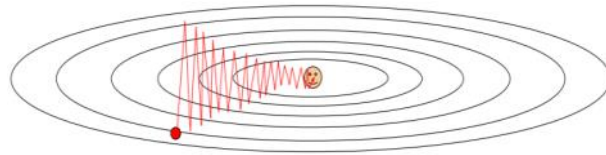
- Activation Functions
- Dataset Preparation
- Data Preprocessing
- Weight Initialization



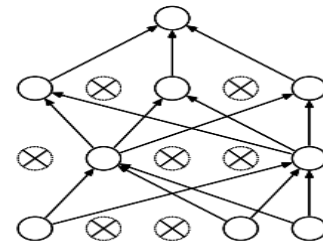
This Class

Training Aspects of CNN

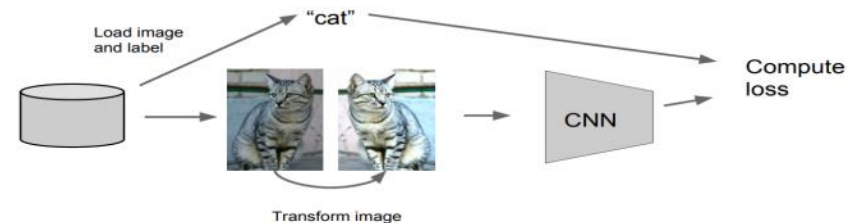
- Optimization
- Learning Rate
- Regularization
- Dropout
- Batch Normalization
- Data Augmentation
- Transfer Learning
- Interpreting Loss Curve



(a) Standard Neural Net



(b) After applying dropout.



Optimization



Mini-batch SGD

Loop:

1. **Sample** a batch of data
2. **Forward** prop it through the graph (network), get loss
3. **Backprop** to calculate the gradients
4. **Update** the parameters using the gradient

Stochastic Gradient Descent (SGD)

The procedure of repeatedly evaluating the **gradient of loss function** and then performing a **parameter update**.

Vanilla (Original) Gradient Descent:

```
while True:
    dx = compute_gradient(x)
    x += learning_rate * dx
```

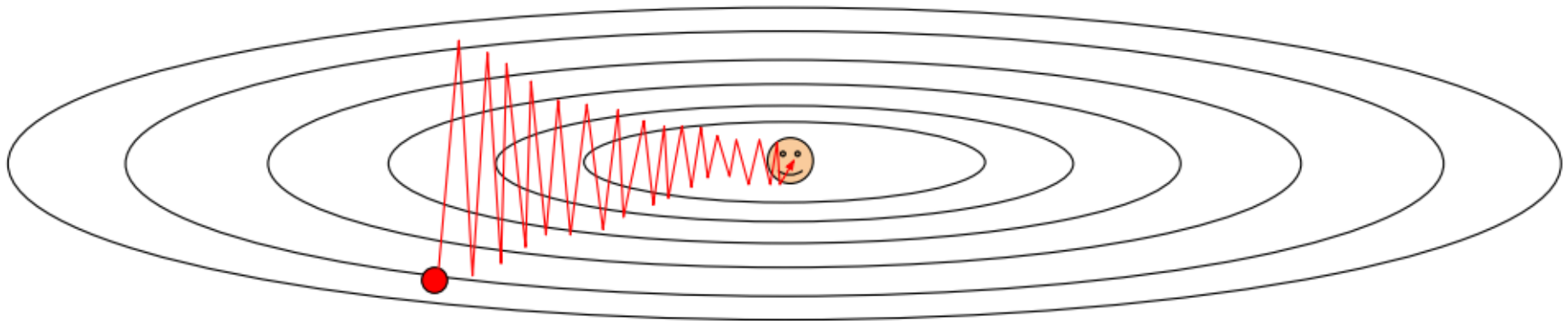
SGD: Problems

What if loss changes quickly in one direction and slowly in another?

SGD: Problems

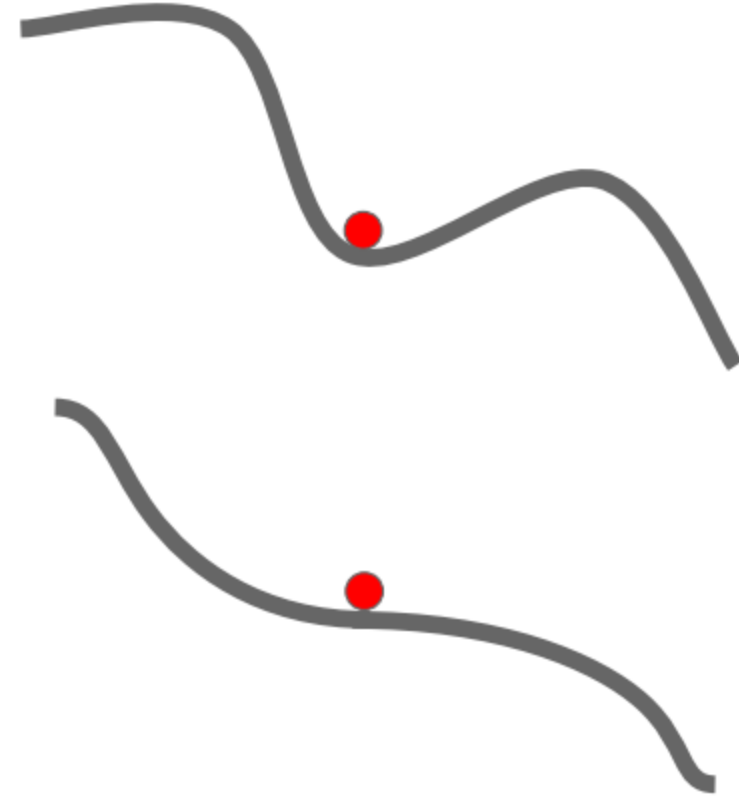
What if loss changes quickly in one direction and slowly in another?

Very slow progress along shallow dimension, jitter along steep direction



SGD: Problems

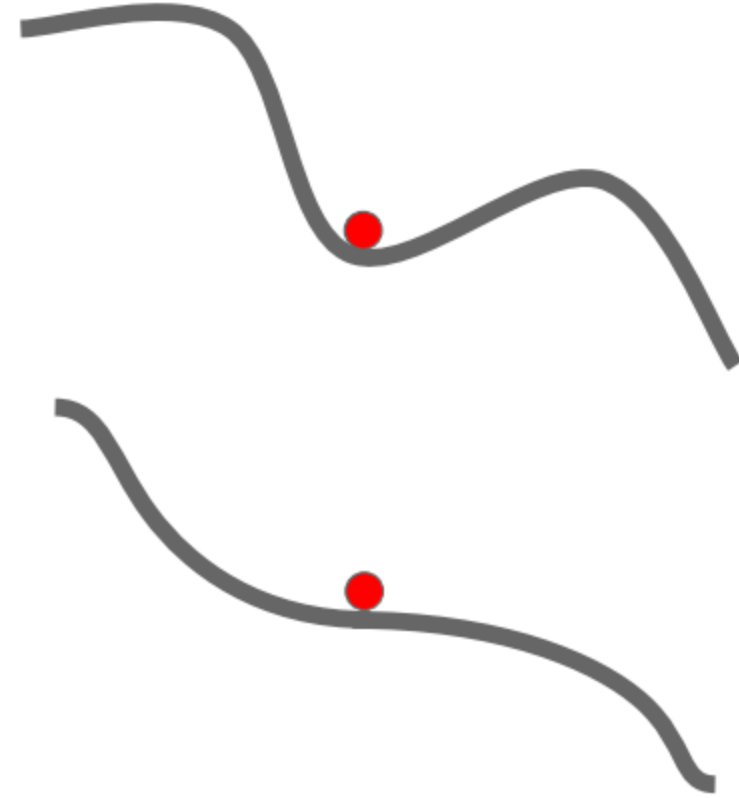
What if the loss function has a **local minima** or **saddle point**?



SGD: Problems

What if the loss function has a **local minima** or **saddle point**?

Zero gradient,
gradient descent
gets stuck



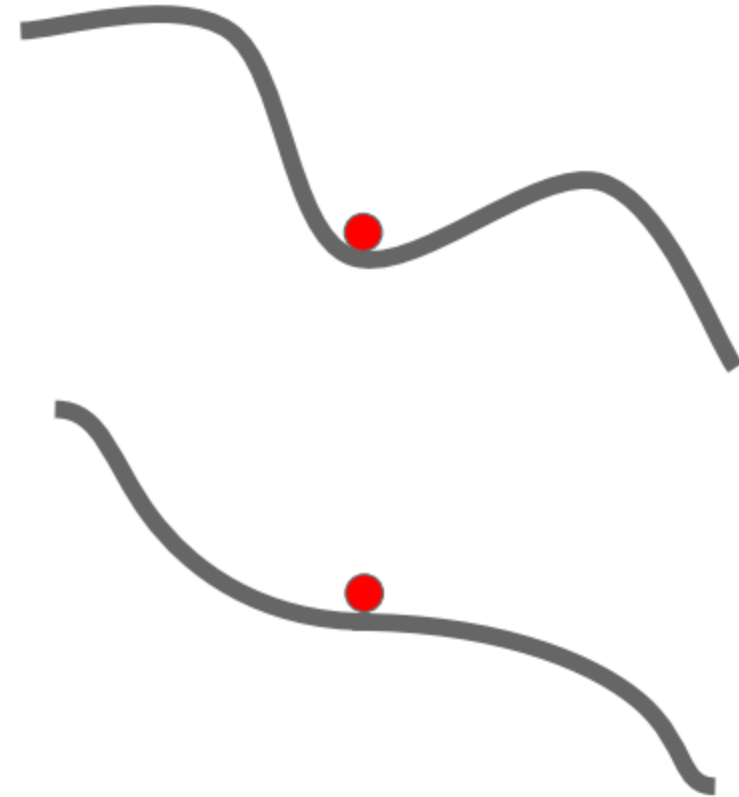
SGD: Problems

What if the loss function has a **local minima** or **saddle point**?

Zero gradient,
gradient descent
gets stuck

Saddle points much more
common in high
dimension

Dauphin et al, "Identifying and attacking the saddle point problem in high-dimensional non-convex optimization", NIPS 2014

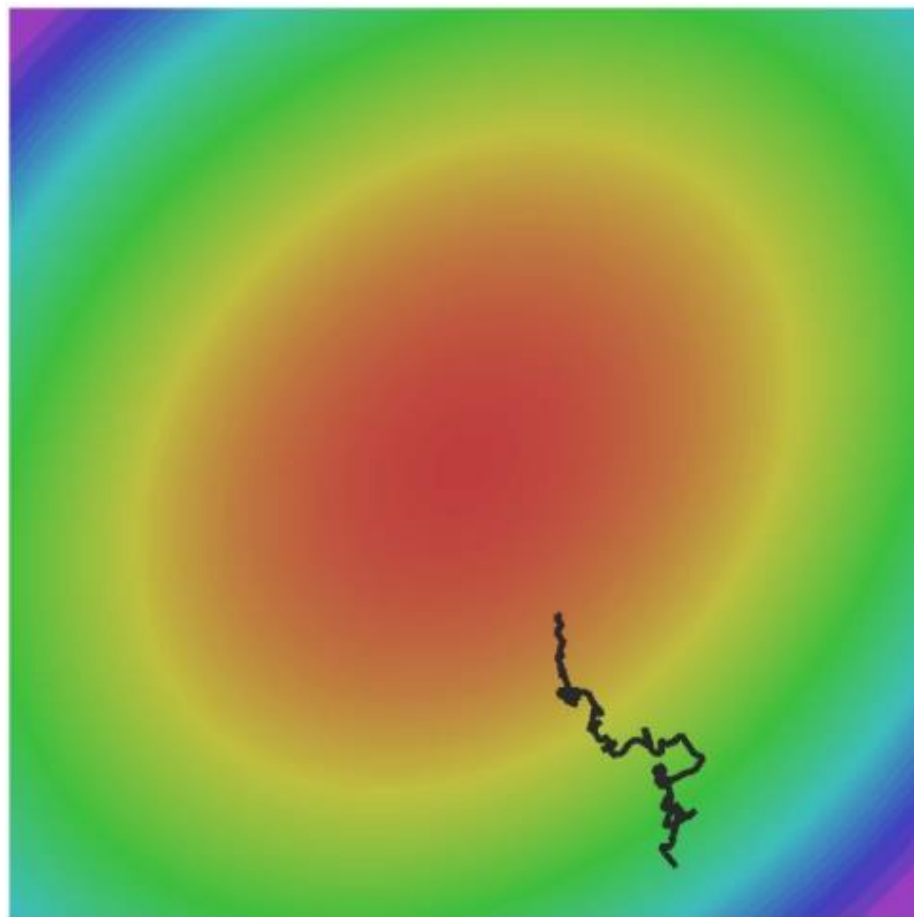


SGD: Problems

Our gradients come from **minibatches** so they can be **noisy!**

$$L(W) = \frac{1}{N} \sum_{i=1}^N L_i(x_i, y_i, W)$$

$$\nabla_W L(W) = \frac{1}{N} \sum_{i=1}^N \nabla_W L_i(x_i, y_i, W)$$



SGD + Momentum

SGD

$$x_{t+1} = x_t - \alpha \nabla f(x_t)$$

```
while True:  
    dx = compute_gradient(x)  
    x += learning_rate * dx
```


SGD + Momentum

SGD

$$x_{t+1} = x_t - \alpha \nabla f(x_t)$$

```
while True:
```

```
    dx = compute_gradient(x)
```

```
    x += learning_rate * dx
```

SGD+Momentum

$$v_{t+1} = \rho v_t + \nabla f(x_t)$$

$$x_{t+1} = x_t - \alpha v_{t+1}$$

SGD + Momentum

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    x += learning_rate * dx
```

SGD+Momentum

$$v_{t+1} = \rho v_t + \nabla f(x_t)$$

$$x_{t+1} = x_t - \alpha v_{t+1}$$

```
vx = 0
```

```
while True:
```

```
    dx = compute_gradient(x)
```

```
    vx = rho * vx + dx
```

```
    x += learning_rate * vx
```

SGD + Momentum

SGD

$$x_{t+1} = x_t - \alpha \nabla f(x_t)$$

```
while True:
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```
while True:
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```
    dx = compute_gradient(x)
```

```
    vx = rho * vx + dx
```

```
    x += learning_rate * vx
```

- Build up “velocity” in any direction that has consistent gradient
- Rho gives “friction”; typically rho=0.9 or 0.99

SGD + Momentum

SGD

$$x_{t+1} = x_t - \alpha \nabla f(x_t)$$

```
while True:
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    dx = compute_gradient(x)
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    x += learning_rate * dx
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SGD+Momentum

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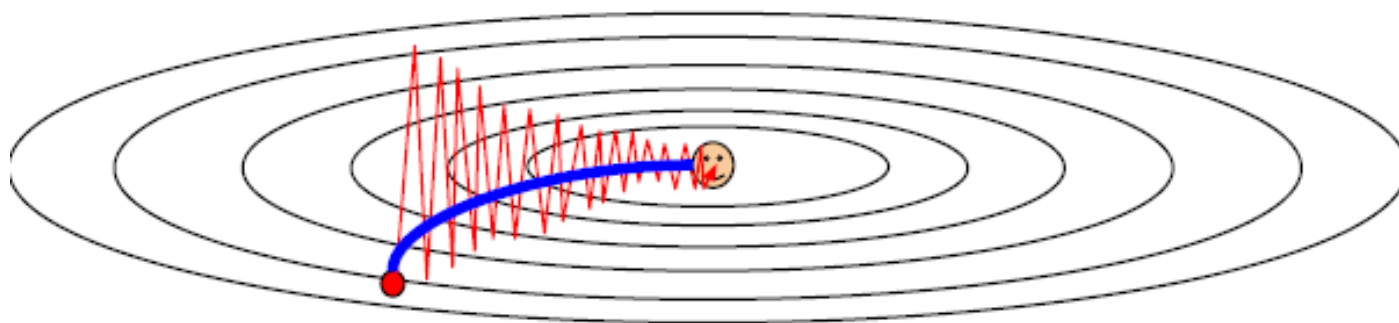
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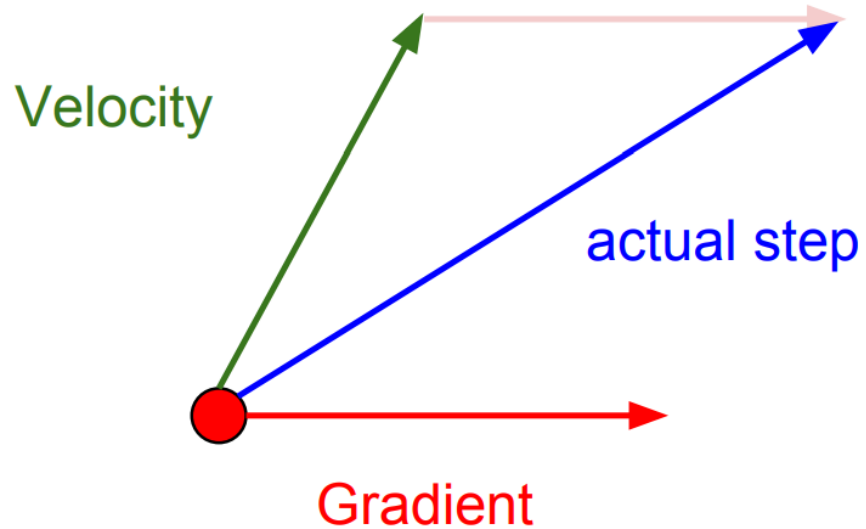
```
    vx = rho * vx + dx
```

```
    x += learning_rate * vx
```



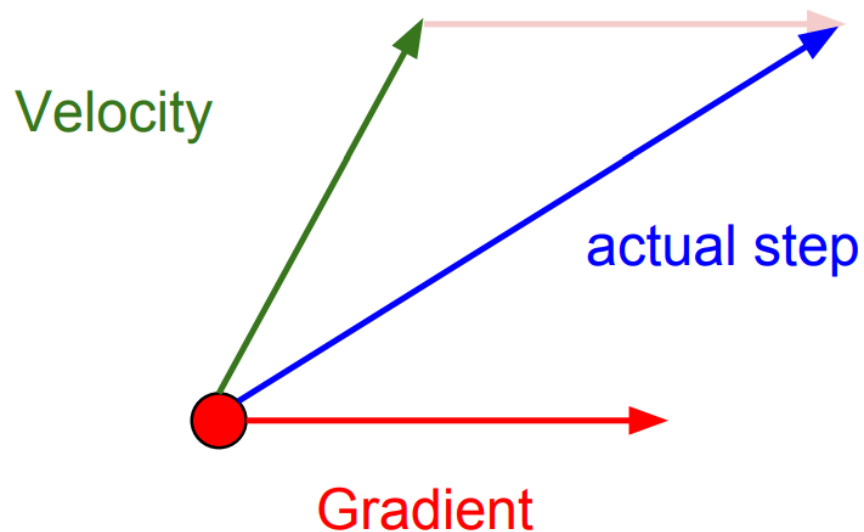
SGD + Momentum

Momentum update:

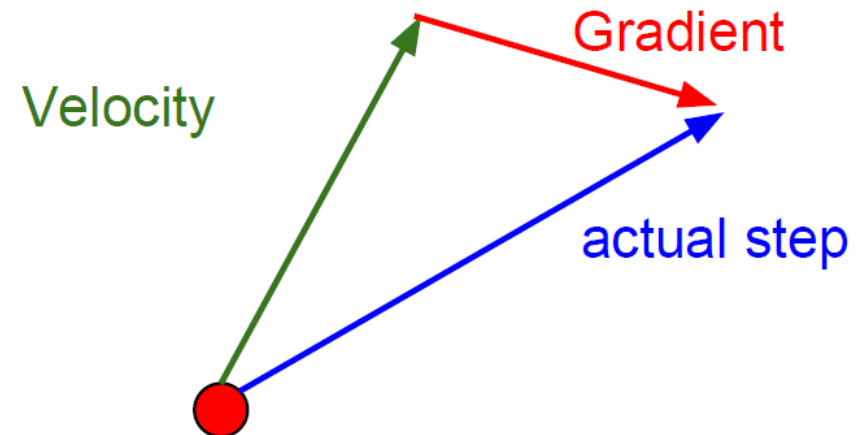


Nesterov Momentum

Momentum update:



Nesterov Momentum



Nesterov Momentum

$$v_{t+1} = \rho v_t - \alpha \nabla f(x_t + \rho v_t)$$

$$x_{t+1} = x_t + v_{t+1}$$

Nesterov Momentum

$$v_{t+1} = \rho v_t - \alpha \nabla f(x_t + \rho v_t)$$

$$x_{t+1} = x_t + v_{t+1}$$

Change of variables $\tilde{x}_t = x_t + \rho v_t$ and rearrange:

$$v_{t+1} = \rho v_t - \alpha \nabla f(\tilde{x}_t)$$

$$\tilde{x}_{t+1} = \tilde{x}_t - \rho v_t + (1 + \rho)v_{t+1}$$

Nesterov Momentum

$$v_{t+1} = \rho v_t - \alpha \nabla f(x_t + \rho v_t)$$

$$x_{t+1} = x_t + v_{t+1}$$

Change of variables $\tilde{x}_t = x_t + \rho v_t$ and rearrange:

$$v_{t+1} = \rho v_t - \alpha \nabla f(\tilde{x}_t)$$

$$\tilde{x}_{t+1} = \tilde{x}_t - \rho v_t + (1 + \rho)v_{t+1}$$

```
dx = compute_gradient(x)
old_v = v
v = rho * v - learning_rate * dx
x += -rho * old_v + (1 + rho) * v
```

Sutskever et al, “On the importance of initialization and momentum in deep learning”, ICML 2013

Source: cs231n

AdaGrad

```
grad_squared = 0
while True:
    dx = compute_gradient(x)
    grad_squared += dx * dx
    x -= learning_rate * dx / (np.sqrt(grad_squared) + 1e-7)
```

Added element-wise scaling of the gradient based on the historical sum of squares in each dimension

AdaGrad

```
grad_squared = 0
while True:
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    grad_squared += dx * dx
    x -= learning_rate * dx / (np.sqrt(grad_squared) + 1e-7)
```

What happens to the step size over long time?

AdaGrad

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grad_squared = 0
while True:
    dx = compute_gradient(x)
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```

What happens to the step size over long time?

Effective learning rate diminishing problem

RMSProp

```
grad_squared = 0
while True:
    dx = compute_gradient(x)
    grad_squared += dx * dx
    x -= learning_rate * dx / (np.sqrt(grad_squared) + 1e-7)
```

AdaGrad



RMSProp

```
grad_squared = 0
while True:
    dx = compute_gradient(x)
    grad_squared = decay_rate * grad_squared + (1 - decay_rate) * dx * dx
    x -= learning_rate * dx / (np.sqrt(grad_squared) + 1e-7)
```

Adam

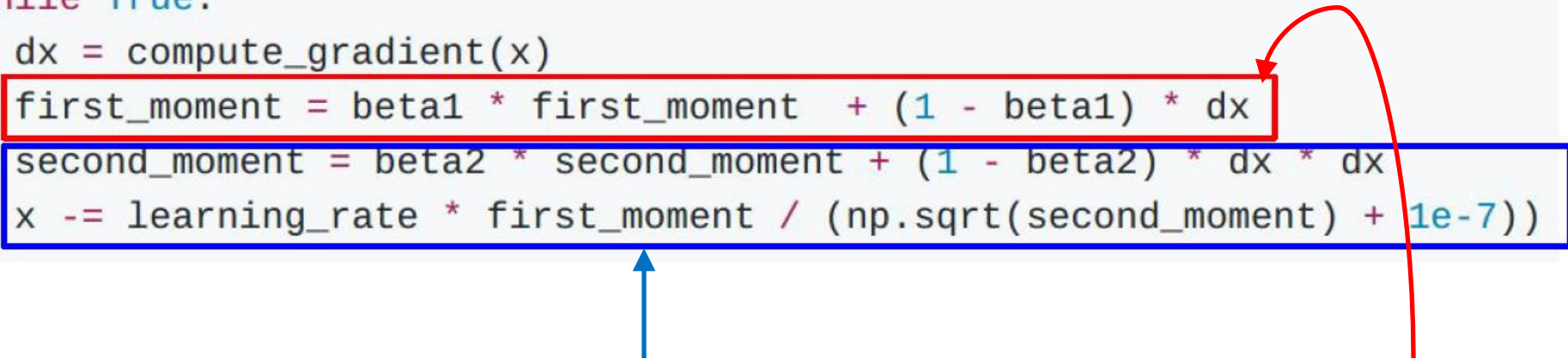
Kingma and Ba, “Adam:
A method for stochastic
optimization”, ICLR 2015

```
first_moment = 0
second_moment = 0
while True:
    dx = compute_gradient(x)
    first_moment = beta1 * first_moment + (1 - beta1) * dx
    second_moment = beta2 * second_moment + (1 - beta2) * dx * dx
    x -= learning_rate * first_moment / (np.sqrt(second_moment) + 1e-7))
```

Adam

Kingma and Ba, "Adam:
A method for stochastic
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```
first_moment = 0
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while True:
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```

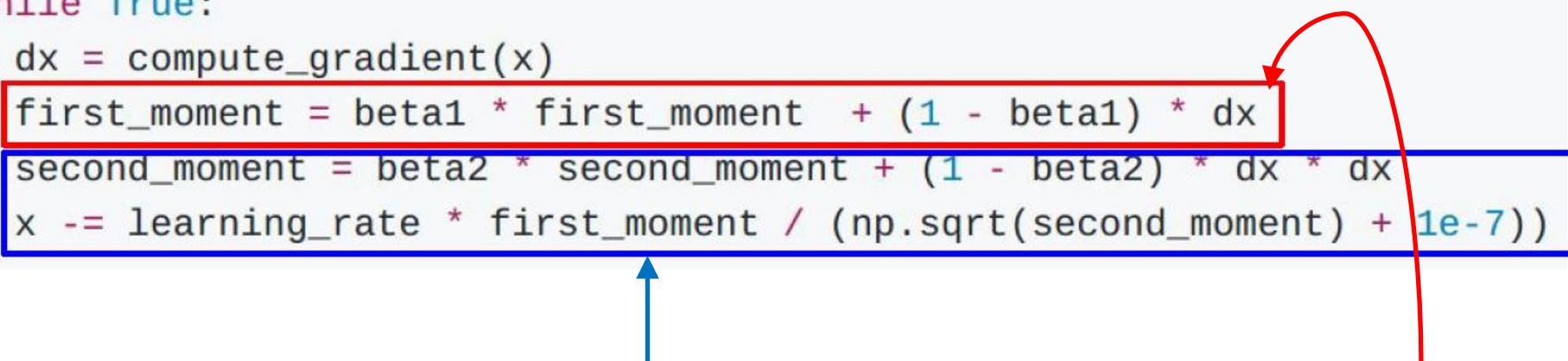


Sort of like RMSProp with Momentum

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Kingma and Ba, "Adam: A method for stochastic optimization", ICLR 2015

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first_moment = 0
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    x -= learning_rate * first_moment / (np.sqrt(second_moment) + 1e-7))
```



Sort of like **RMSProp** with **Momentum**

Problem:

Initially, second_moment=0 and beta2=0.999

After 1st iteration, second_moment -> close to zero

So, very large step for update of x

Adam (with Bias correction)

```
first_moment = 0
second_moment = 0
for t in range(num_iterations):
    dx = compute_gradient(x)
    first_moment = beta1 * first_moment + (1 - beta1) * dx
    second_moment = beta2 * second_moment + (1 - beta2) * dx * dx
    first_unbias = first_moment / (1 - beta1 ** t)
    second_unbias = second_moment / (1 - beta2 ** t)
    x -= learning_rate * first_unbias / (np.sqrt(second_unbias) + 1e-7))
```

AdaGrad/
RMSProp

Bias Correction

Bias correction for the fact that first and second
moment estimates start at zero

Momentum

Adam (with Bias correction)

```
first_moment = 0
second_moment = 0
for t in range(num_iterations):
    dx = compute_gradient(x)
    first_moment = beta1 * first_moment + (1 - beta1) * dx
    second_moment = beta2 * second_moment + (1 - beta2) * dx * dx
    first_unbias = first_moment / (1 - beta1 ** t)
    second_unbias = second_moment / (1 - beta2 ** t)
    x -= learning_rate * first_unbias / (np.sqrt(second_unbias) + 1e-7))
```

AdaGrad/
RMSProp

Bias Correction

Momentum

Bias correction for the fact that first and second
moment estimates start at zero

**Adam with $\text{beta1} = 0.9$,
 $\text{beta2} = 0.999$, and $\text{learning_rate} = 1\text{e-}3$ or $5\text{e-}4$
is a great starting point for many models!**

AMSGrad

Some minibatches (rarely occur) provide large and informative gradients, exponential averaging diminishes their influence, which leads to poor convergence.

AMSGrad

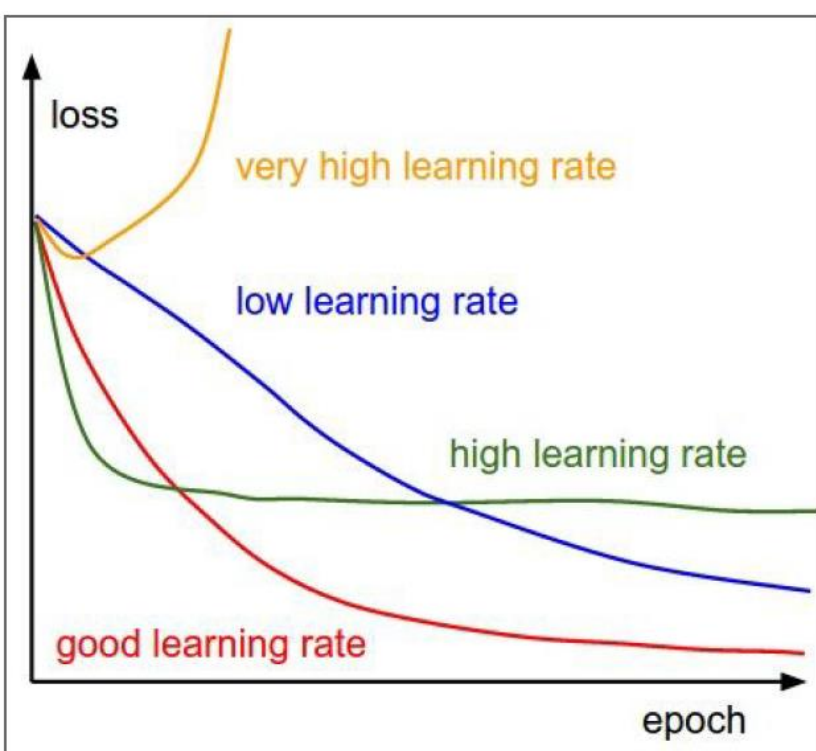
Some minibatches (rarely occur) provide large and informative gradients, exponential averaging diminishes their influence, which leads to poor convergence.

AMSGrad that uses the maximum of past squared gradients v_t

$$\begin{aligned}m_t &= \beta_1 m_{t-1} + (1 - \beta_1) g_t \\v_t &= \beta_2 v_{t-1} + (1 - \beta_2) g_t^2 \\\hat{v}_t &= \max(\hat{v}_{t-1}, v_t) \\\theta_{t+1} &= \theta_t - \frac{\eta}{\sqrt{\hat{v}_t} + \epsilon} m_t\end{aligned}$$

Learning Rate

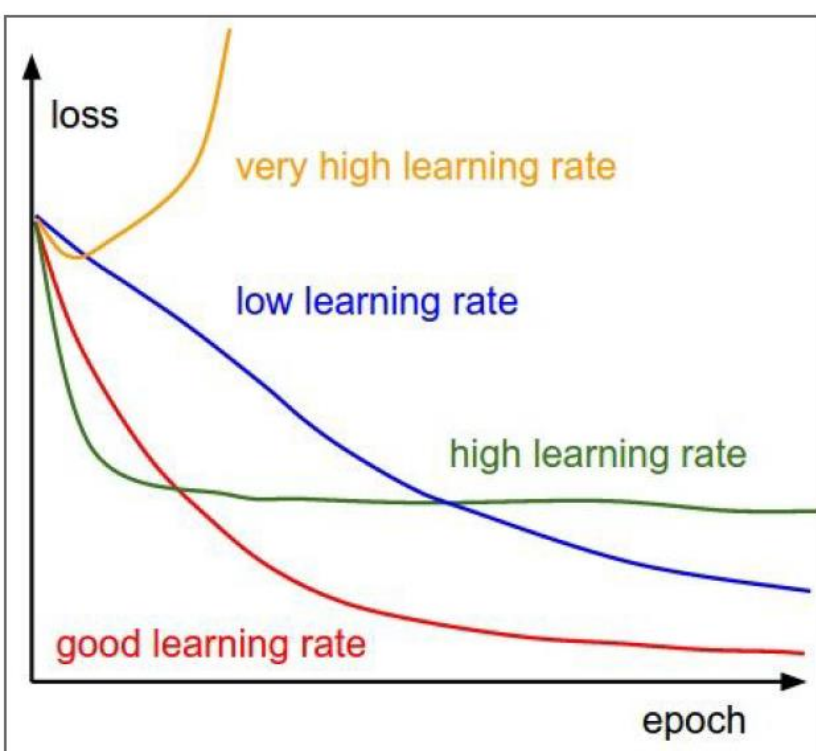
SGD, SGD+Momentum, Adagrad, RMSProp, Adam all have **learning rate** as a hyperparameter.



Q: Which one of these learning rates is best to use?

Learning Rate

SGD, SGD+Momentum, Adagrad, RMSProp, Adam all have **learning rate** as a hyperparameter.



=> **Learning rate decay over time!**

step decay:

e.g. decay learning rate by half every few epochs.

exponential decay:

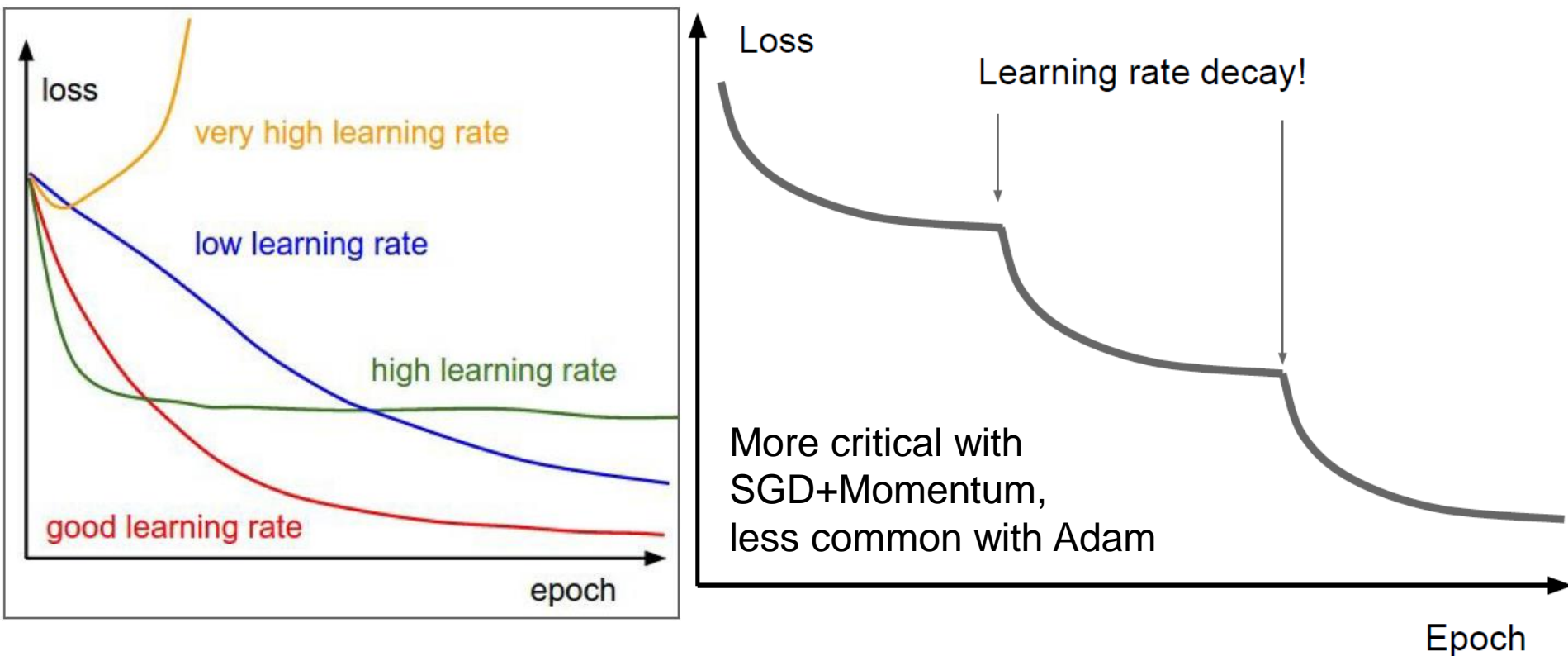
$$\alpha = \alpha_0 e^{-kt}$$

1/t decay:

$$\alpha = \alpha_0 / (1 + kt)$$

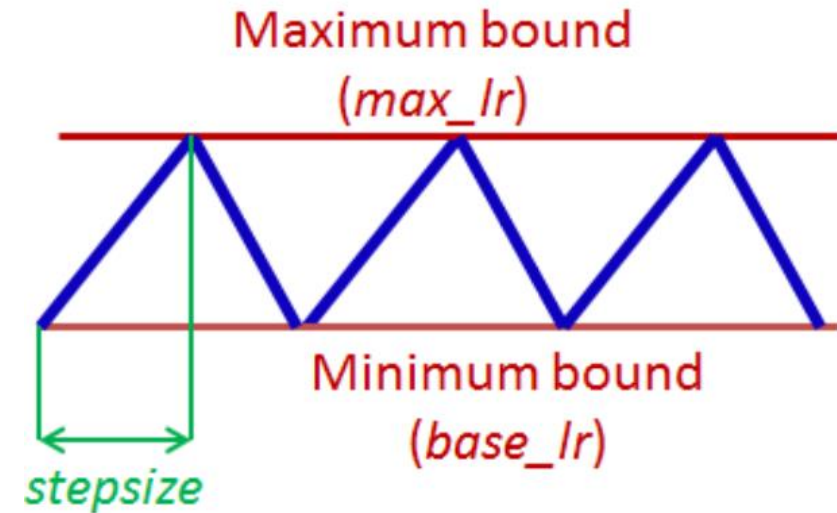
Learning Rate

SGD, SGD+Momentum, Adagrad, RMSProp, Adam all have **learning rate** as a hyperparameter.



Learning Rate

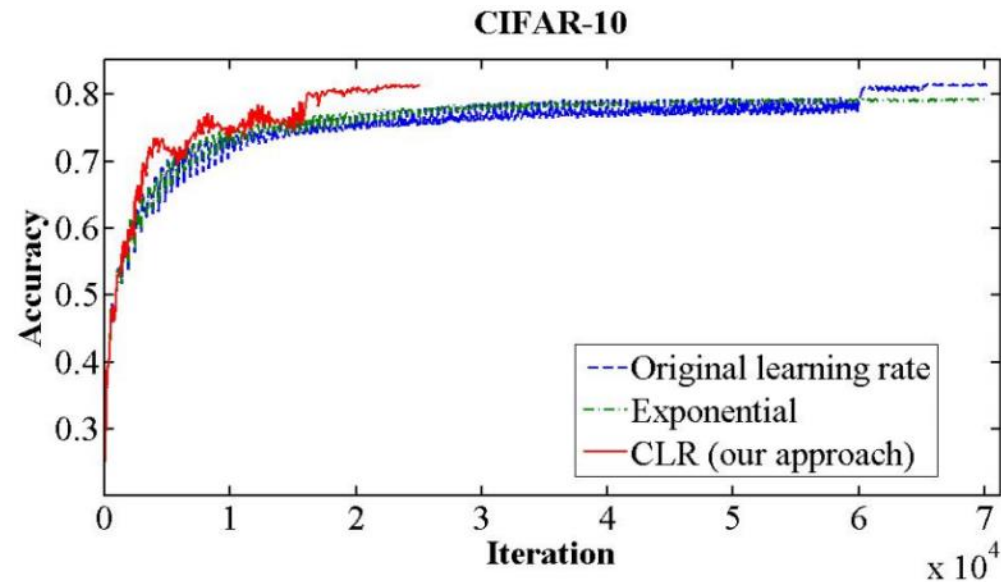
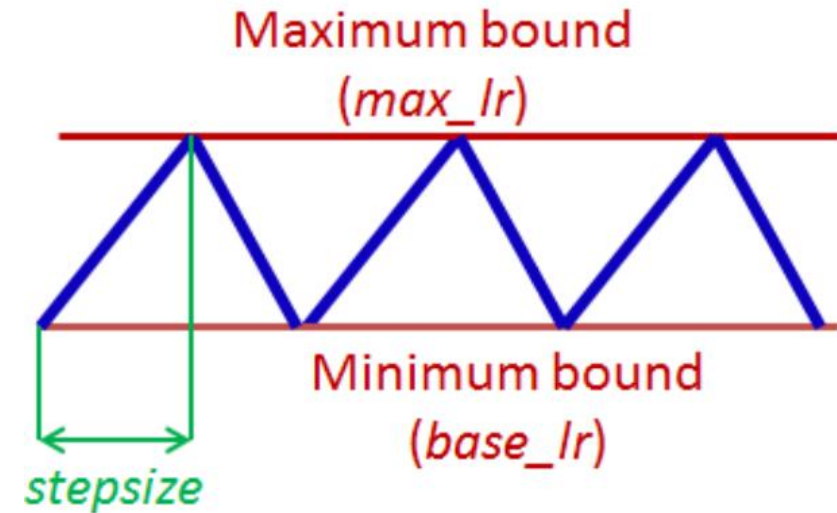
Cyclic Learning Rate



Smith, Leslie N. "Cyclical learning rates for training neural networks." *WACV 2017*.

Learning Rate

Cyclic Learning Rate



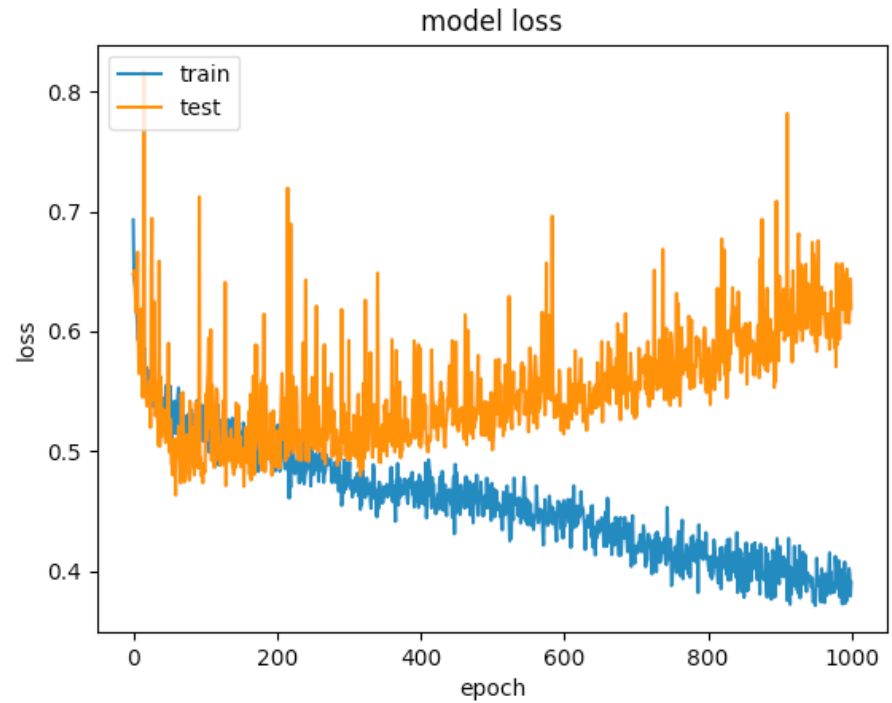
Smith, Leslie N. "Cyclical learning rates for training neural networks." *WACV 2017*.

Optimizer and Learning Rate

In Practice:

- **Adam** is a good default choice in most cases
- **Learning rate** with step decay is commonly used

More Optimizer: <http://ruder.io/optimizing-gradient-descent/>



Regularization

Image Source: <https://stackoverflow.com/questions/44909134/how-to-avoid-overfitting-on-a-simple-feed-forward-network/44985765>

Regularization

$$L(W) = \underbrace{\frac{1}{N} \sum_{i=1}^N L_i(f(x_i, W), y_i)}$$

Data loss: Model predictions
should match training data

Regularization

$$L(W) = \underbrace{\frac{1}{N} \sum_{i=1}^N L_i(f(x_i, W), y_i)}_{\text{Data loss}} + \underbrace{\lambda R(W)}_{\text{Regularization}}$$

Data loss: Model predictions should match training data

Regularization: Prevent the model from doing *too* well on training data

Regularization

λ = regularization strength
(hyperparameter)

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Simple examples

L2 regularization: $R(W) = \sum_k \sum_l W_{k,l}^2$

L1 regularization: $R(W) = \sum_k \sum_l |W_{k,l}|$

Elastic net (L1 + L2): $R(W) = \sum_k \sum_l \beta W_{k,l}^2 + |W_{k,l}|$

Regularization

λ = regularization strength
(hyperparameter)

$$L(W) = \underbrace{\frac{1}{N} \sum_{i=1}^N L_i(f(x_i, W), y_i)}_{\text{Data loss}} + \underbrace{\lambda R(W)}_{\text{Regularization}}$$

Data loss: Model predictions should match training data

Regularization: Prevent the model from doing *too* well on training data

Why regularize?

- Express preferences over weights
- Make the model *simple* so it works on test data
- Improve optimization by adding curvature

Regularization

$$x = [1, 1, 1, 1]$$

$$w_1 = [1, 0, 0, 0]$$

$$w_2 = [0.25, 0.25, 0.25, 0.25]$$

Regularization

$$x = [1, 1, 1, 1]$$

$$w_1 = [1, 0, 0, 0]$$

$$w_2 = [0.25, 0.25, 0.25, 0.25]$$

$$w_1 \cdot x = w_2 \cdot x = 1$$

Regularization

$$x = [1, 1, 1, 1]$$

$$w_1 = [1, 0, 0, 0]$$

$$w_2 = [0.25, 0.25, 0.25, 0.25]$$

$$w_1 \cdot x = w_2 \cdot x = 1$$

Which W to consider?

Regularization

$$x = [1, 1, 1, 1]$$

$$w_1 = [1, 0, 0, 0]$$

$$w_2 = [0.25, 0.25, 0.25, 0.25]$$

$$w_1 \cdot x = w_2 \cdot x = 1$$

L2 Regularization

$$R(W) = \sum_k \sum_l W_{k,l}^2$$

Regularization

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$$w_1 = [1,0,0,0]$$

$$w_2 = [0.25,0.25,0.25,0.25]$$

$$w_1 \cdot x = w_2 \cdot x = 1$$

L2 regularization likes to
“spread out” the weights

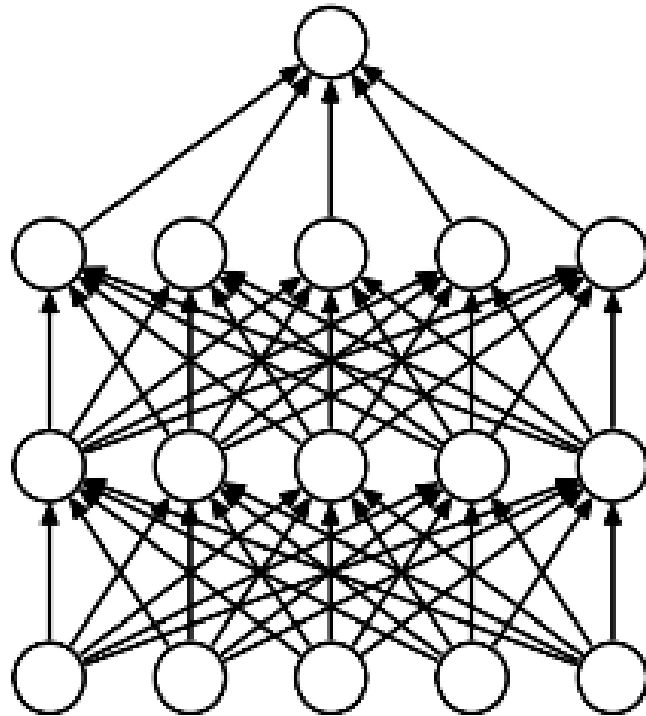
L2 Regularization

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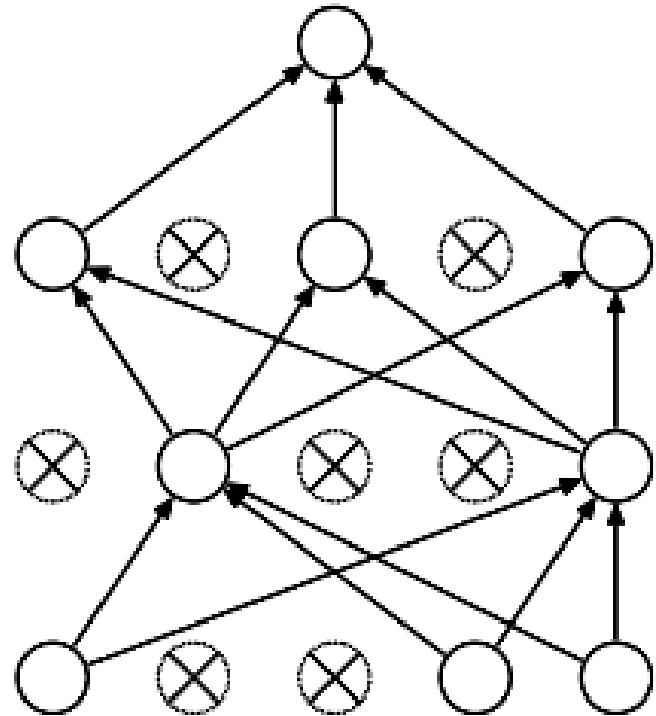
Dropout

Dropout

In each forward pass, randomly set some neurons to zero
Probability of dropping is a hyperparameter; 0.5 is common



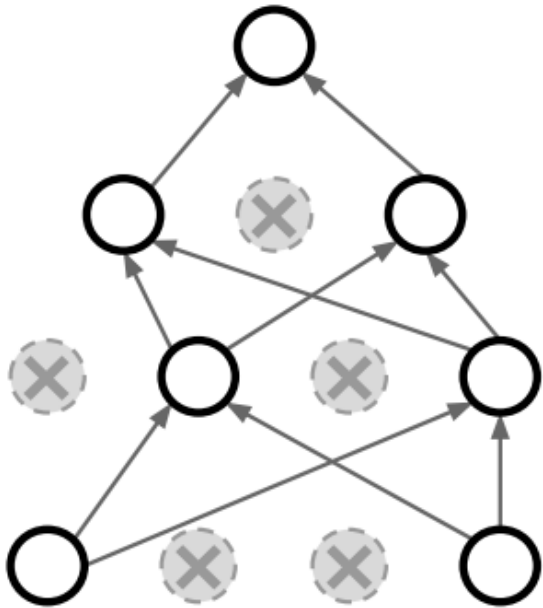
(a) Standard Neural Net



(b) After applying dropout.

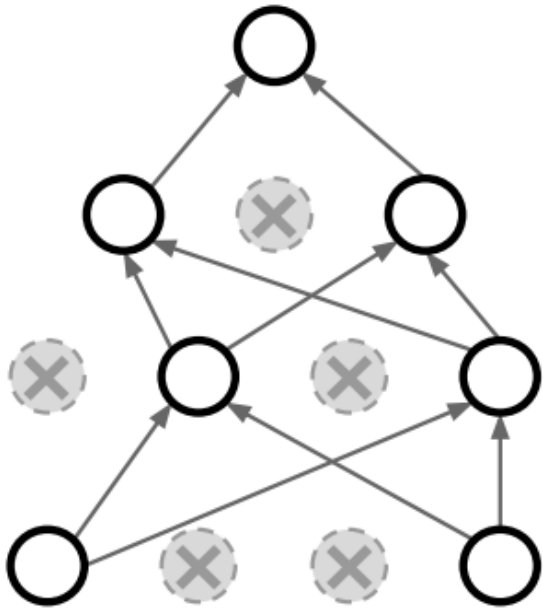
Dropout

How can this possibly be a good idea?

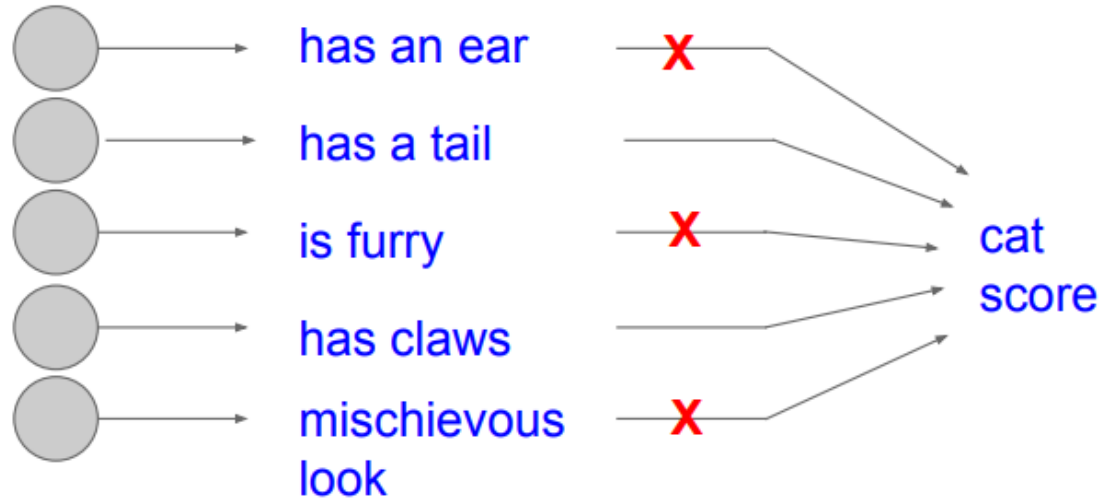


Dropout

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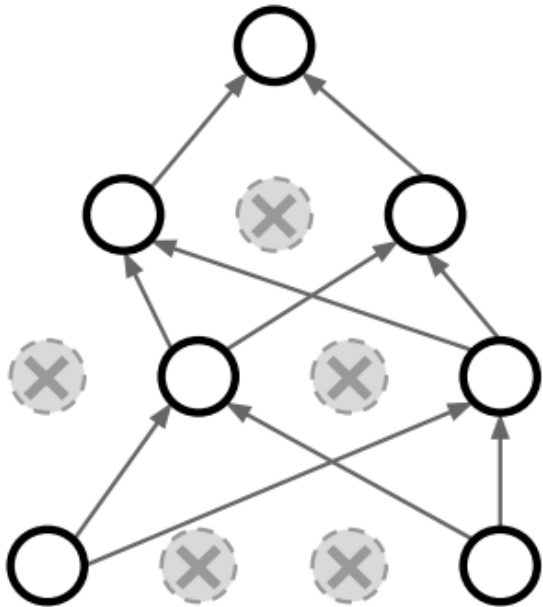
Forces the network to have a redundant representation;
Prevents co-adaptation of features



Dropout

How can this possibly be a good idea?

Dropout is training a large ensemble of models (that share parameters).



Intuition: successful conspiracies

- 50 people planning a conspiracy
- Strategy A: plan a big conspiracy involving 50 people
 - Likely to fail. 50 people need to play their parts correctly.
- Strategy B: plan 10 conspiracies each involving 5 people
 - Likely to succeed!

Dropout: Test Time

```
def predict(X):  
    # ensembled forward pass  
    H1 = np.maximum(0, np.dot(W1, X) + b1) * p # NOTE: scale the activations  
    H2 = np.maximum(0, np.dot(W2, H1) + b2) * p # NOTE: scale the activations  
    out = np.dot(W3, H2) + b3
```

At test time all neurons are active always
=> We must scale the activations so that for each neuron:
output at test time = expected output at training time

More common: “Inverted dropout”

Dropout: More common: “Inverted dropout”

We drop and scale at train time and don't do anything at test time.

```
p = 0.5 # probability of keeping a unit active. higher = less dropout

def train_step(X):
    # forward pass for example 3-layer neural network
    H1 = np.maximum(0, np.dot(W1, X) + b1)
    U1 = (np.random.rand(*H1.shape) < p) / p # first dropout mask. Notice /p!
    H1 *= U1 # drop!
    H2 = np.maximum(0, np.dot(W2, H1) + b2)
    U2 = (np.random.rand(*H2.shape) < p) / p # second dropout mask. Notice /p!
    H2 *= U2 # drop!
    out = np.dot(W3, H2) + b3

    # backward pass: compute gradients... (not shown)
    # perform parameter update... (not shown)

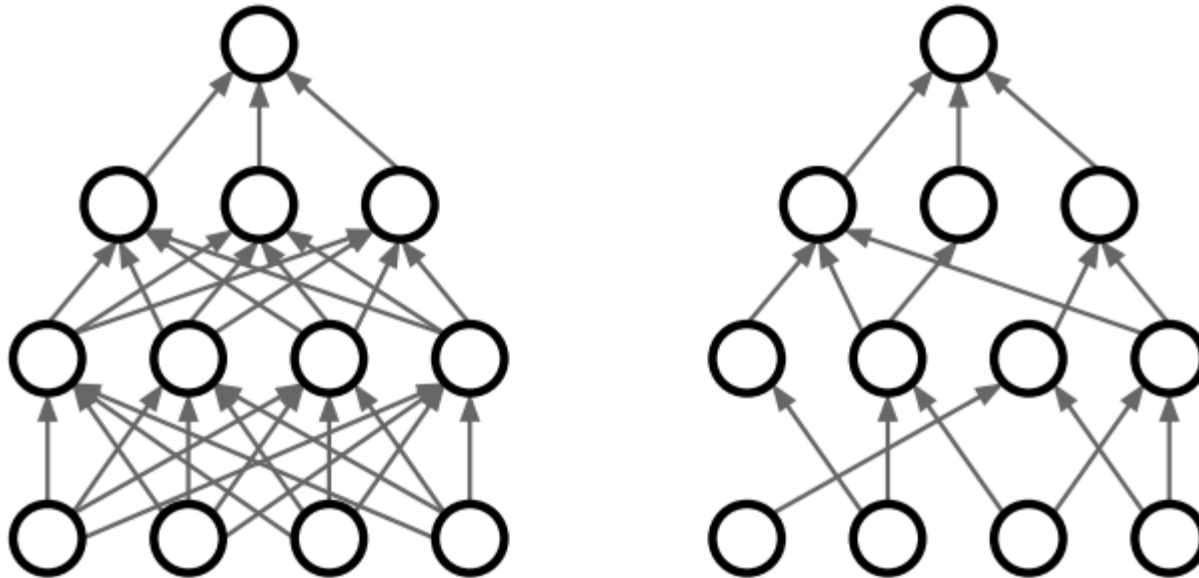
def predict(X):
    # ensembled forward pass
    H1 = np.maximum(0, np.dot(W1, X) + b1) # no scaling necessary
    H2 = np.maximum(0, np.dot(W2, H1) + b2)
    out = np.dot(W3, H2) + b3
```

test time is unchanged!



DropConnect

Dropping some connections



Wan et al, "Regularization of Neural Networks using DropConnect", ICML 2013

Source: cs231n

Batch Normalization

Batch Normalization

“We want zero-mean unit-variance activations? lets make them so.”

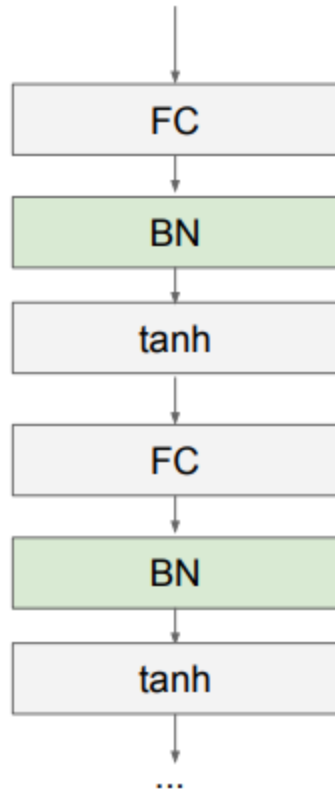
Batch Normalization

“We want zero-mean unit-variance activations? lets make them so.”

consider a batch of activations at some layer. To make each dimension zero-mean unit-variance, apply:

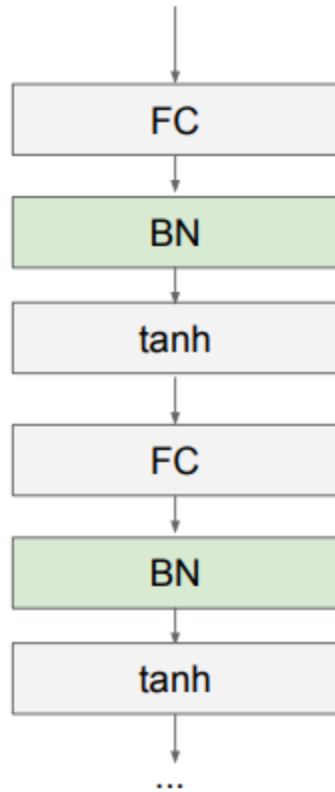
$$\hat{x}^{(k)} = \frac{x^{(k)} - \mathbb{E}[x^{(k)}]}{\sqrt{\text{Var}[x^{(k)}]}}$$

Batch Normalization



Usually inserted after Fully Connected or Convolutional layers, and before nonlinearity.

Batch Normalization



Usually inserted after Fully Connected or Convolutional layers, and before nonlinearity.

Problem:
do we necessarily want a zero-mean unit-variance input?

Batch Normalization

Normalize:

$$\hat{x}^{(k)} = \frac{x^{(k)} - \mathbb{E}[x^{(k)}]}{\sqrt{\text{Var}[x^{(k)}]}}$$

And then allow the network to squash the range if it wants to:

$$y^{(k)} = \gamma^{(k)} \hat{x}^{(k)} + \beta^{(k)}$$

Batch Normalization

Normalize:

$$\hat{x}^{(k)} = \frac{x^{(k)} - \mathbb{E}[x^{(k)}]}{\sqrt{\text{Var}[x^{(k)}]}}$$

And then allow the network to squash the range if it wants to:

$$y^{(k)} = \gamma^{(k)} \hat{x}^{(k)} + \beta^{(k)}$$

Note, the network can learn:

$$\gamma^{(k)} = \sqrt{\text{Var}[x^{(k)}]}$$

$$\beta^{(k)} = \mathbb{E}[x^{(k)}]$$

to recover the identity mapping.

Batch Normalization

Input: Values of x over a mini-batch: $\mathcal{B} = \{x_1 \dots x_m\}$;

Parameters to be learned: γ, β

Output: $\{y_i = \text{BN}_{\gamma, \beta}(x_i)\}$

$$\mu_{\mathcal{B}} \leftarrow \frac{1}{m} \sum_{i=1}^m x_i \quad // \text{ mini-batch mean}$$

$$\sigma_{\mathcal{B}}^2 \leftarrow \frac{1}{m} \sum_{i=1}^m (x_i - \mu_{\mathcal{B}})^2 \quad // \text{ mini-batch variance}$$

$$\hat{x}_i \leftarrow \frac{x_i - \mu_{\mathcal{B}}}{\sqrt{\sigma_{\mathcal{B}}^2 + \epsilon}} \quad // \text{ normalize}$$

$$y_i \leftarrow \gamma \hat{x}_i + \beta \equiv \text{BN}_{\gamma, \beta}(x_i) \quad // \text{ scale and shift}$$

Batch Normalization

- Improves gradient flow through the network
- Allows higher learning rates
- Reduces the strong dependence on initialization
- Acts as a form of regularization

Batch Normalization

Note: at test time BatchNorm layer functions differently:

The mean/std are not computed based on the batch.

Instead, a single fixed empirical mean of activations during training is used.

(e.g. can be estimated during training with running averages)

Batch Normalization: Recent Trends

Layer Normalization:

Ba, Kiros, and Hinton, “Layer Normalization”, arXiv 2016

Instance Normalization:

Ulyanov et al, Improved Texture Networks: Maximizing Quality and Diversity in Feed-forward Stylization and Texture Synthesis, CVPR 2017

Group Normalization:

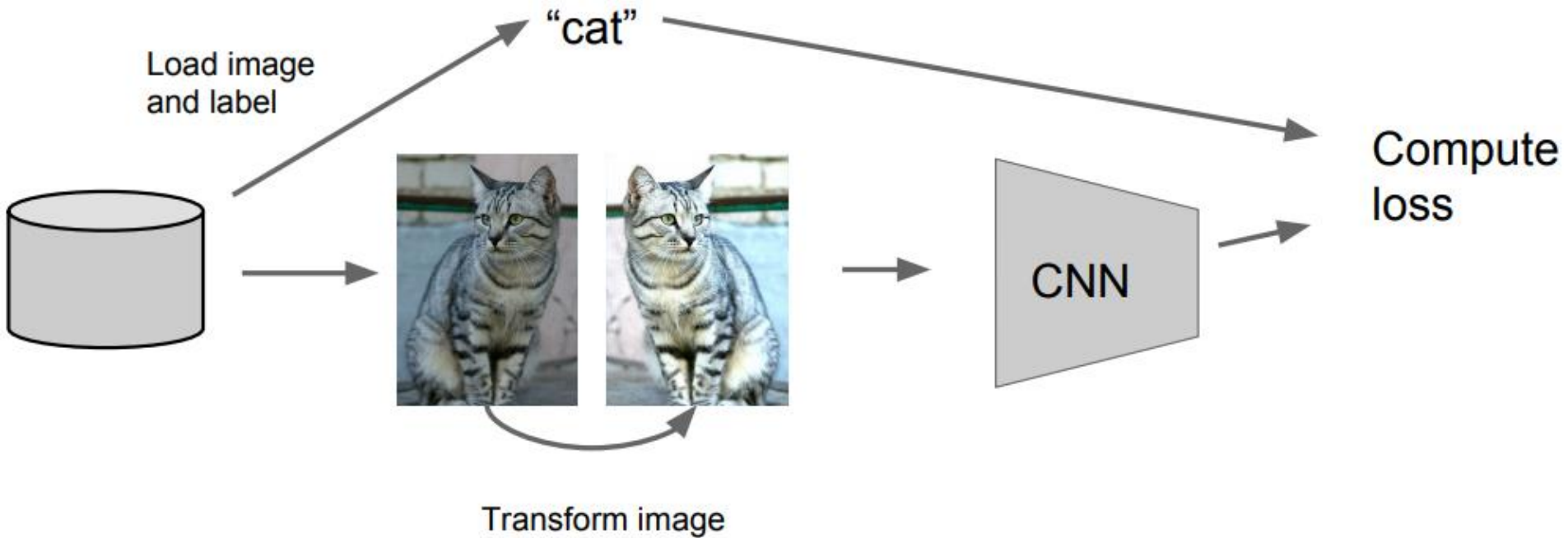
Wu and He, “Group Normalization”, arXiv 2018
(Appeared 3/22/2018)

Decorrelated Normalization:

Huang et al, “Decorrelated Batch Normalization”, arXiv 2018
(Appeared 4/23/2018)

Data Augmentation

Data Augmentation (Jittering)



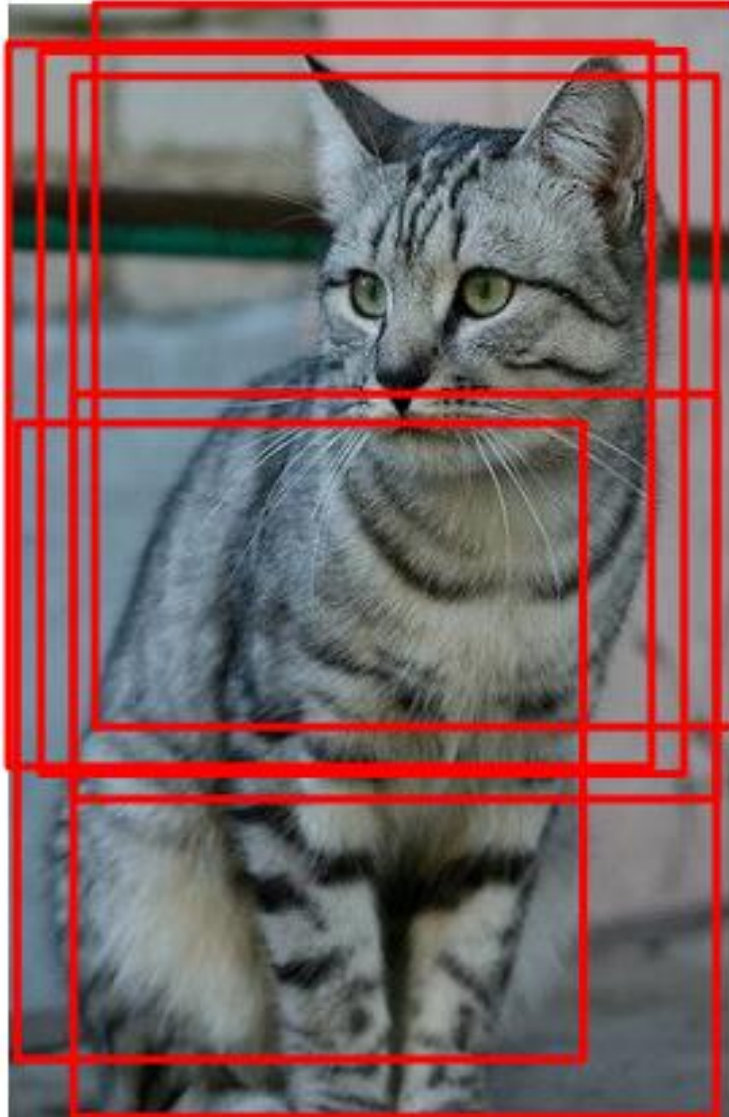
Data Augmentation (Jittering)

Horizontal Flips



Data Augmentation (Jittering)

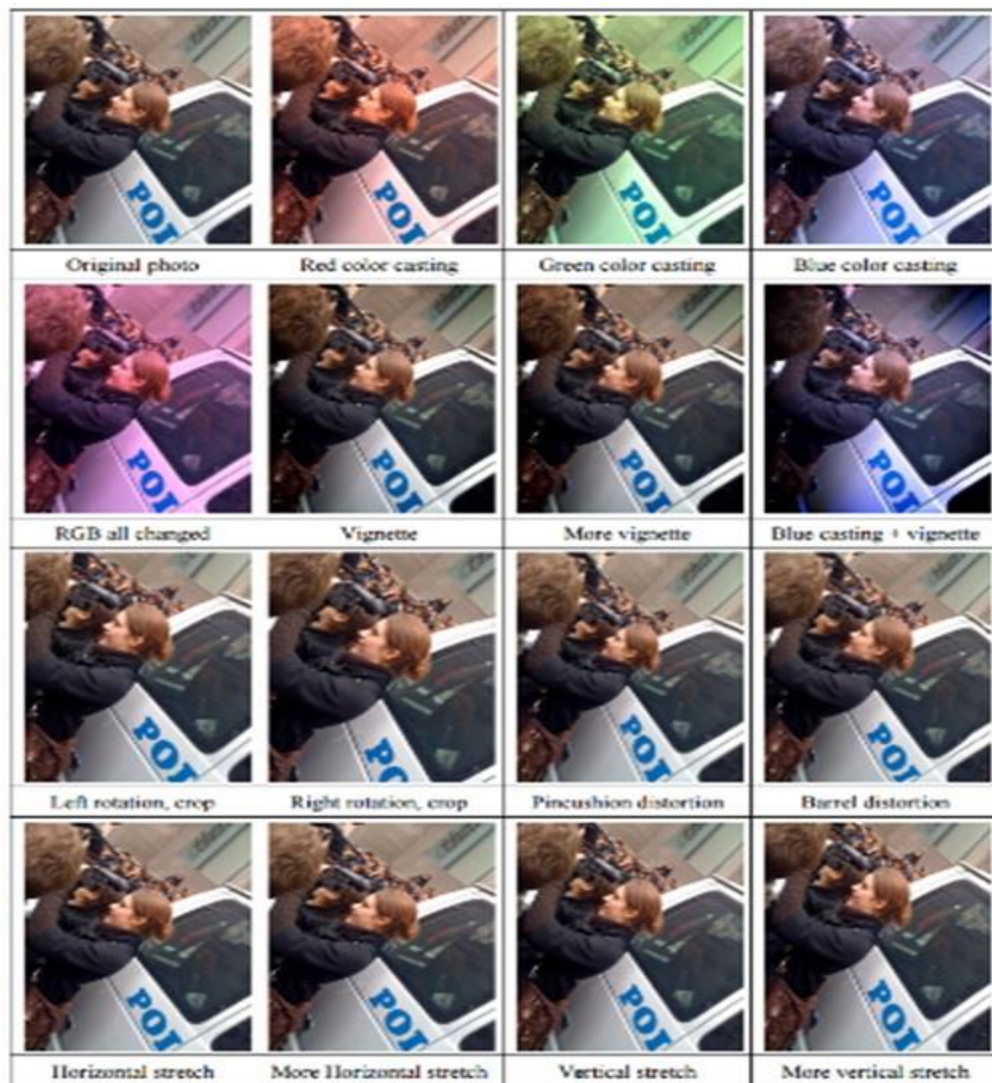
Random crops and scales



Data Augmentation (Jittering)

- Create *virtual* training samples
- Get creative for your problem!

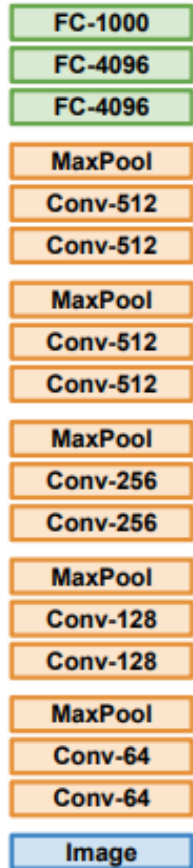
- Horizontal flip
- Random crop
- Color casting
- Randomize contrast
- Randomize brightness
- Geometric distortion
- Rotation
- Photometric changes



Transfer Learning

Transfer Learning with CNNs

1. Train on Imagenet



Donahue et al, “DeCAF: A Deep Convolutional Activation Feature for Generic Visual Recognition”, ICML 2014

Razavian et al, “CNN Features Off-the-Shelf: An Astounding Baseline for Recognition”, CVPR Workshops 2014

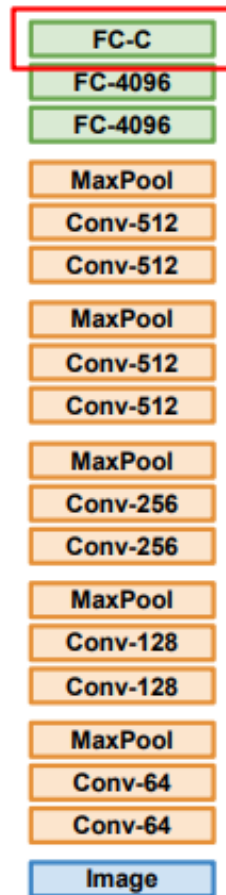
Source: cs231n

Transfer Learning with CNNs

1. Train on Imagenet



2. Small Dataset (C classes)



Reinitialize
this and train

Freeze these

Donahue et al, "DeCAF: A Deep Convolutional Activation Feature for Generic Visual Recognition", ICML 2014

Razavian et al, "CNN Features Off-the-Shelf: An Astounding Baseline for Recognition", CVPR Workshops 2014

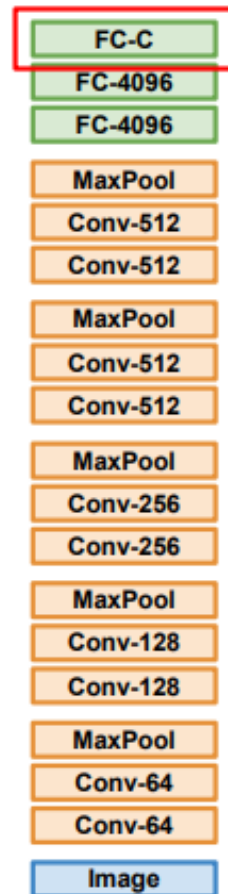
Source: cs231n

Transfer Learning with CNNs

1. Train on Imagenet



2. Small Dataset (C classes)



Reinitialize
this and train

Freeze these

3. Bigger dataset



Train these

With bigger
dataset, train
more layers

Freeze these

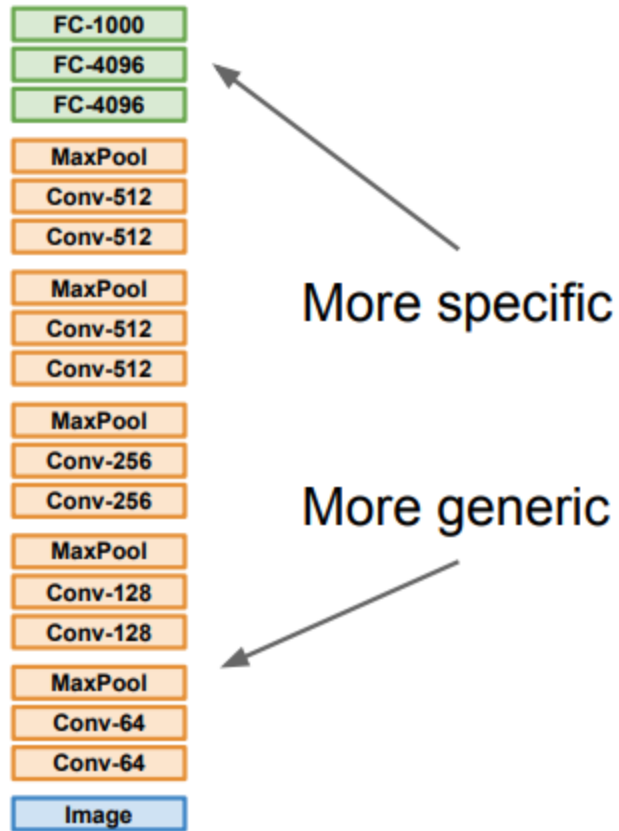
Lower learning rate
when finetuning;
1/10 of original LR
is good starting
point

Donahue et al, "DeCAF: A Deep Convolutional Activation Feature for Generic Visual Recognition", ICML 2014

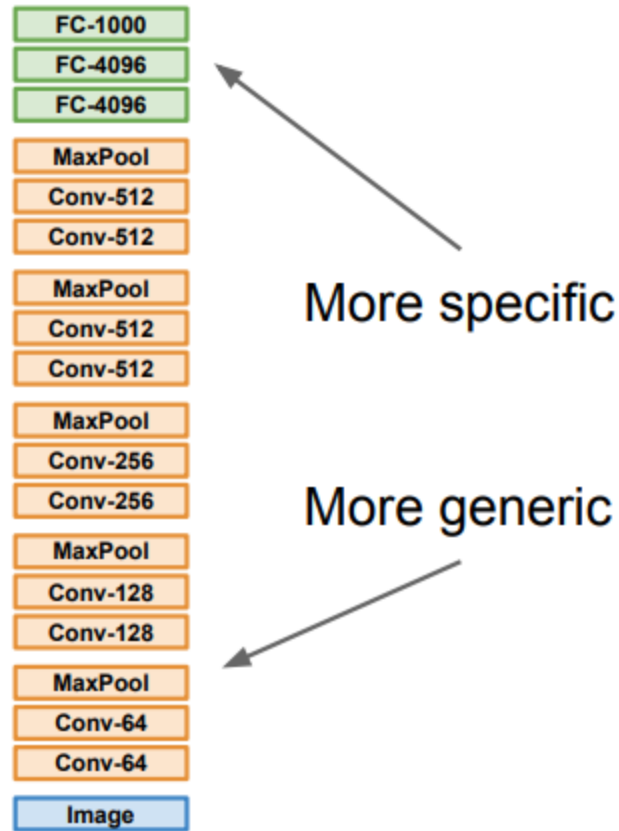
Razavian et al, "CNN Features Off-the-Shelf: An Astounding Baseline for Recognition", CVPR Workshops 2014

Source: cs231n

Transfer Learning with CNNs

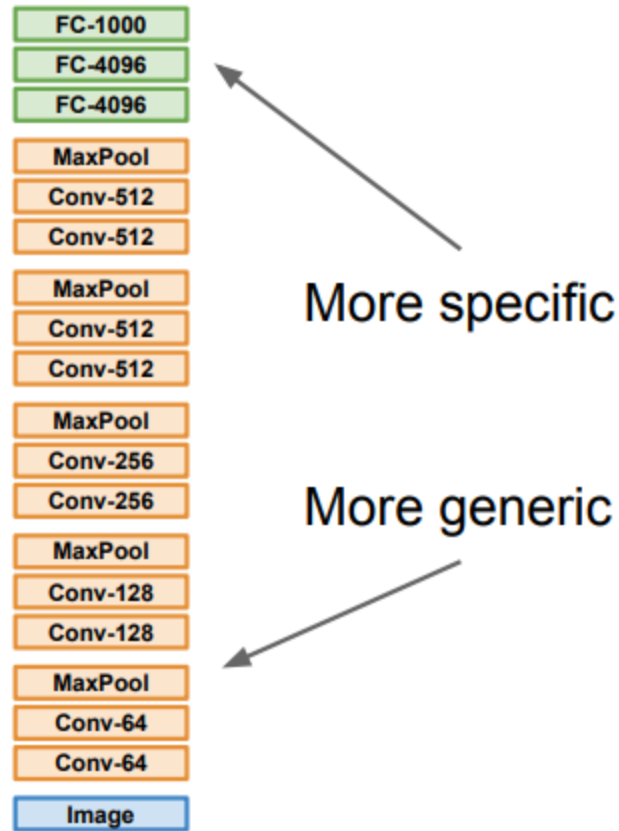


Transfer Learning with CNNs



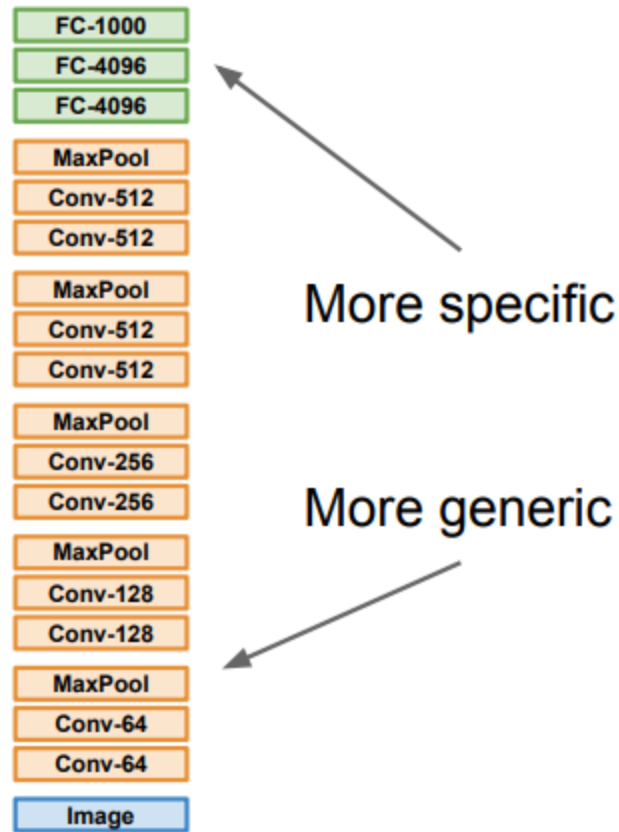
	very similar dataset	very different dataset
very little data	Use Linear Classifier on top layer	
quite a lot of data		

Transfer Learning with CNNs



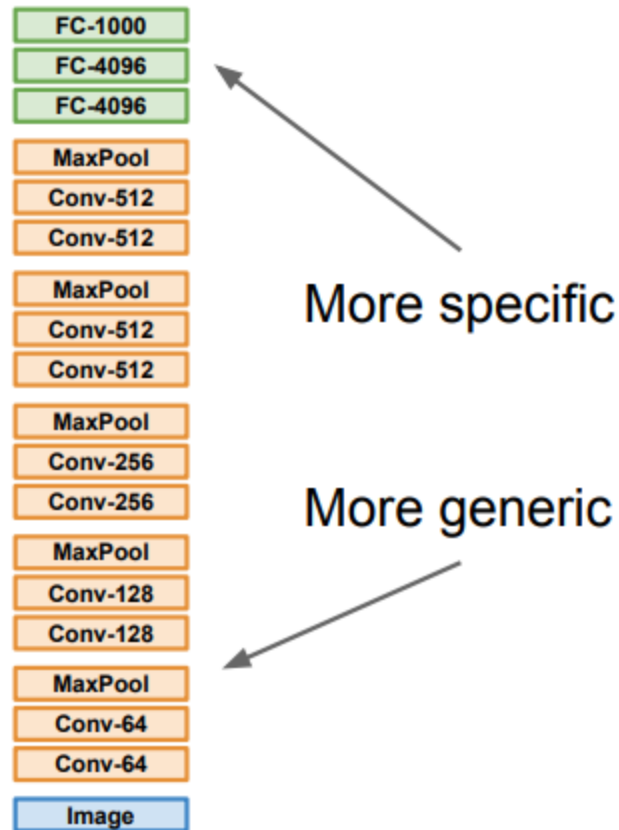
	very similar dataset	very different dataset
very little data	Use Linear Classifier on top layer	
quite a lot of data	Finetune a few layers	

Transfer Learning with CNNs



	very similar dataset	very different dataset
very little data	Use Linear Classifier on top layer	
quite a lot of data	Finetune a few layers	Finetune a larger number of layers

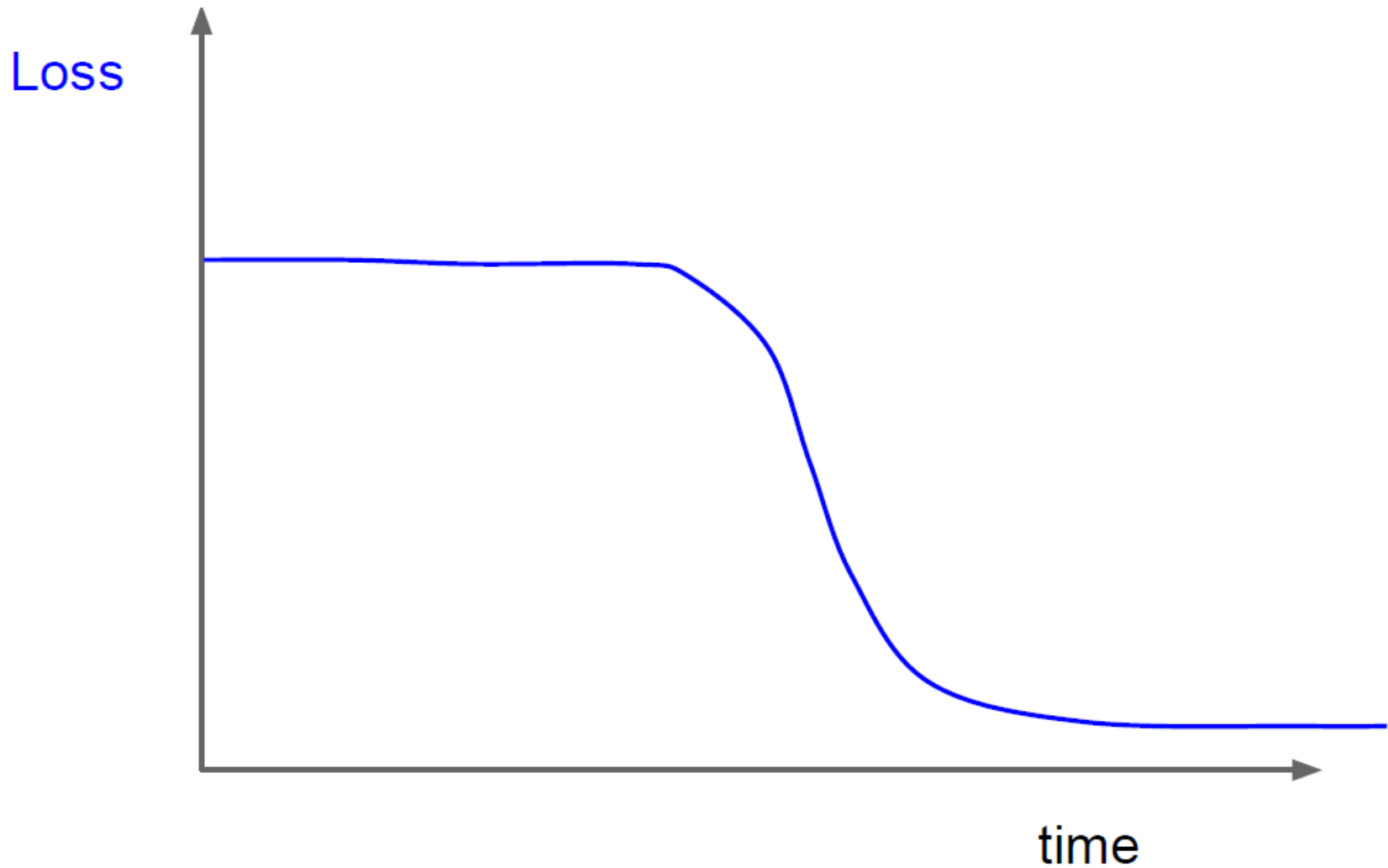
Transfer Learning with CNNs



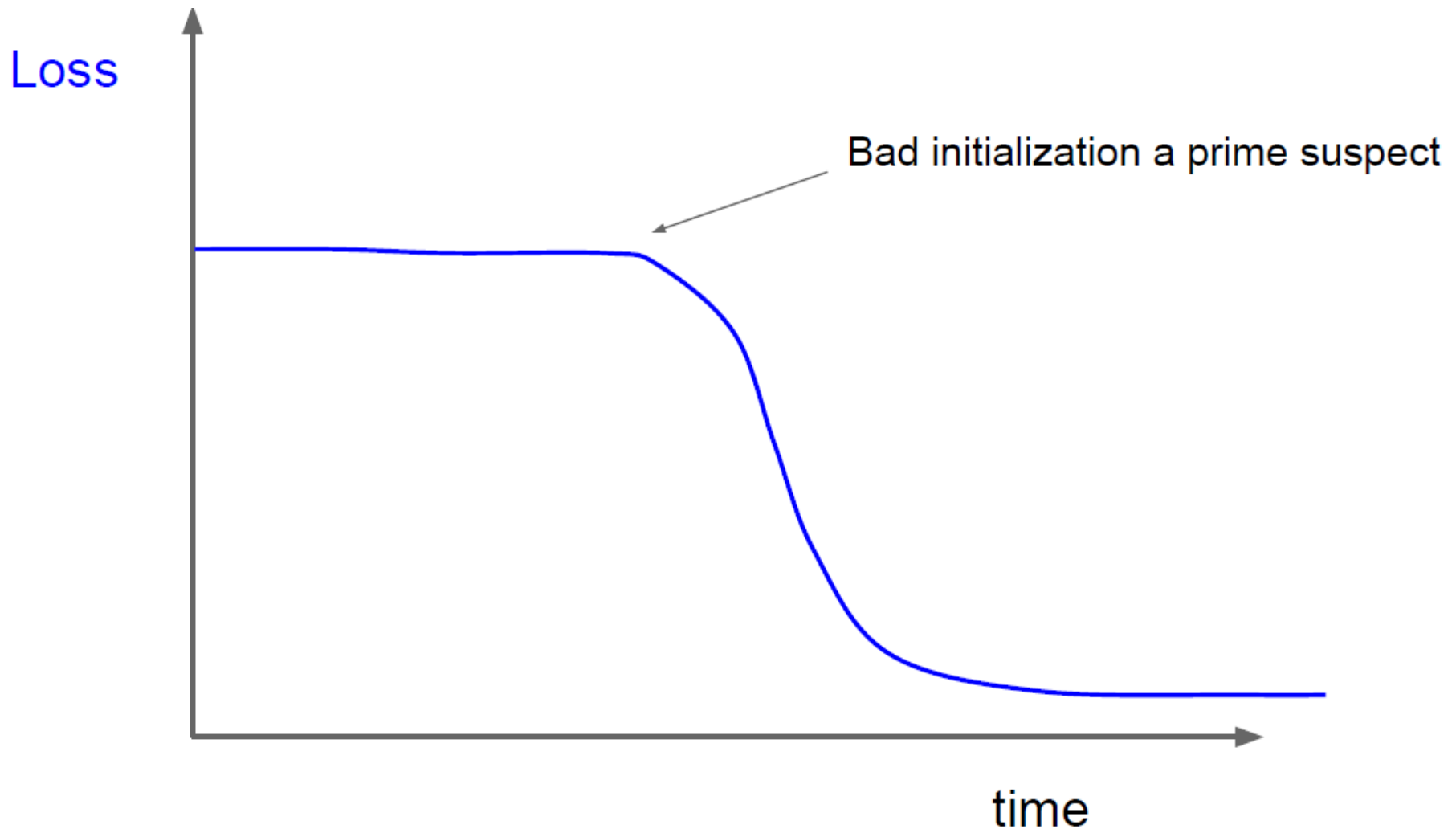
	very similar dataset	very different dataset
very little data	Use Linear Classifier on top layer	You're in trouble... Try linear classifier from different stages
quite a lot of data	Finetune a few layers	Finetune a larger number of layers

Monitor and Visualize the Loss Curve

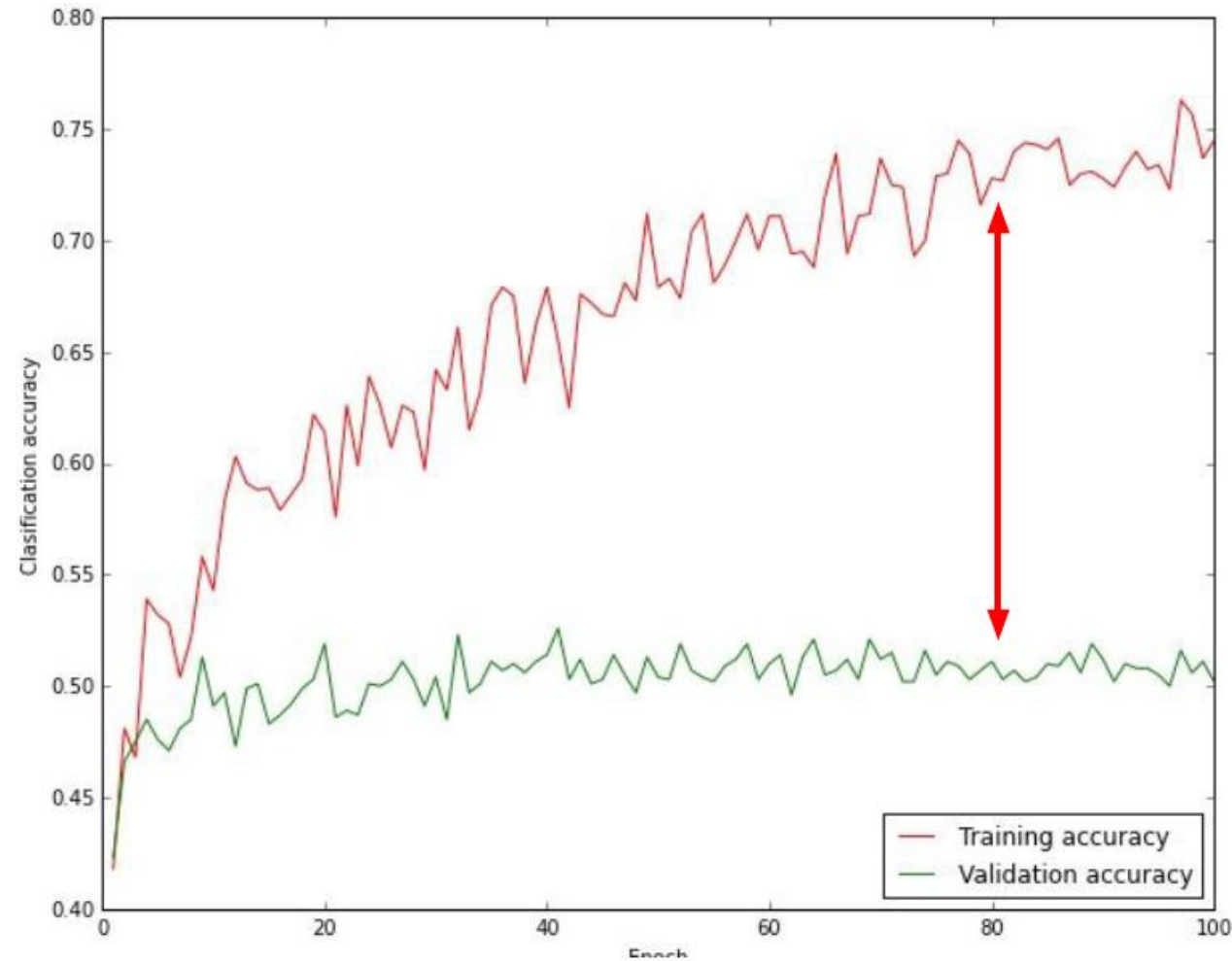
Monitor and visualize the loss curve



Monitor and visualize the loss curve



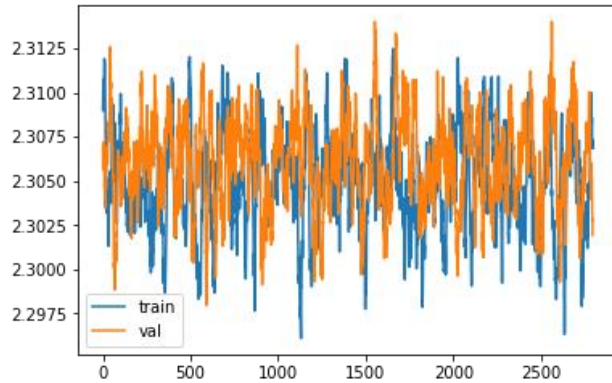
Monitor and visualize the loss curve



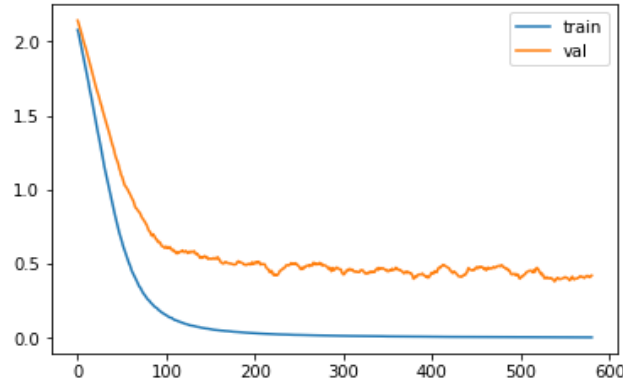
big gap = overfitting
=> increase
regularization
strength?

no gap
=> increase model
capacity?

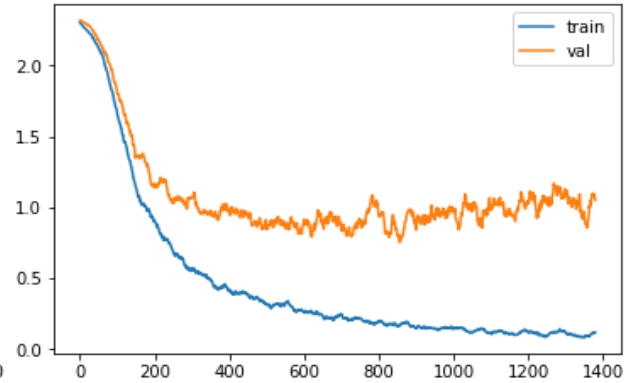
Monitor and visualize the loss curve



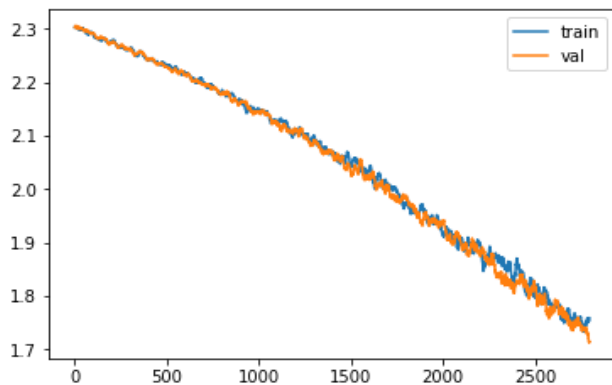
Not learning: gradients not applied to weights



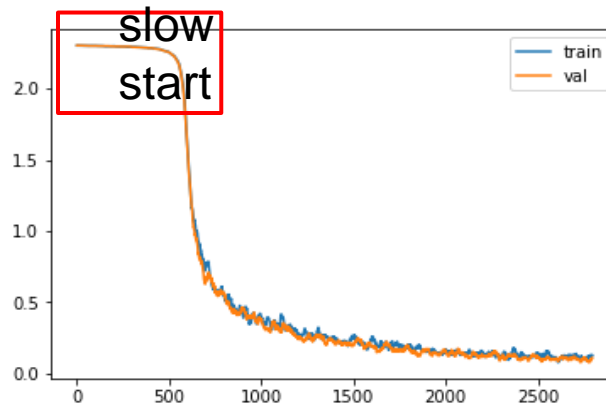
Overfit: model too large/dataset too small



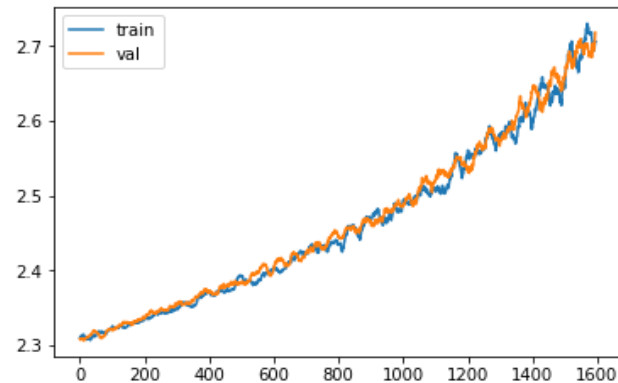
More extreme case of overfitting



Not converged yet: need longer training

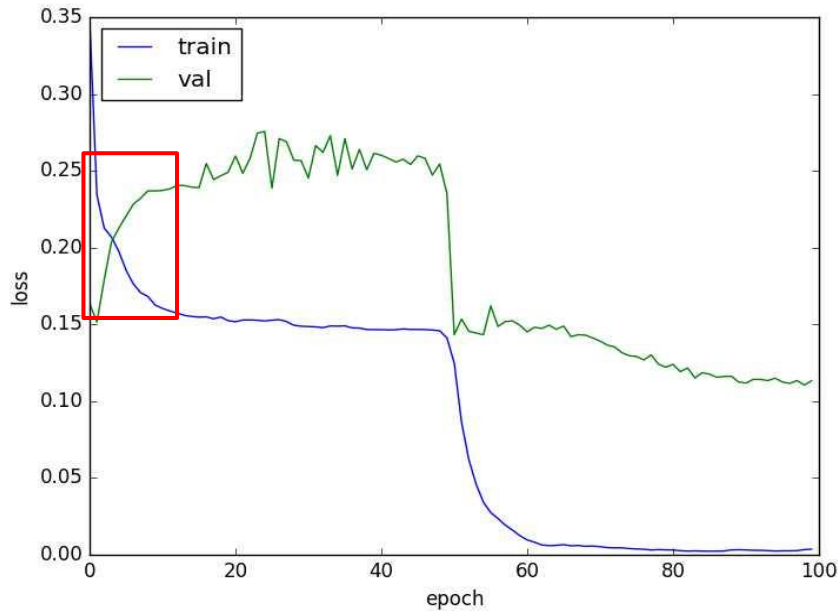


Slow start: initialization weights too small

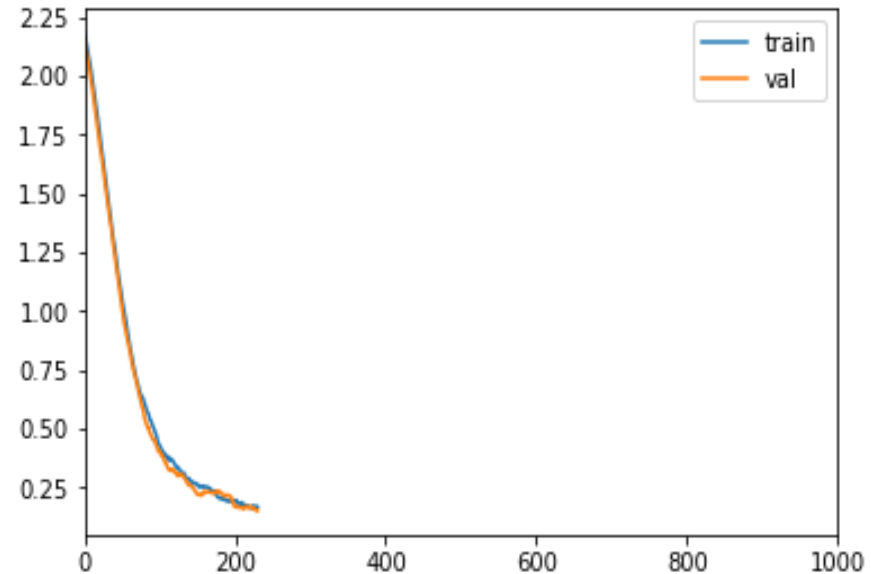


Applied the negative of gradients

Monitor and visualize the loss curve



Problem: val set too small,
statistics not meaningful



Get nans in the loss after a number of
iterations: caused by high learning rate
and numerical instability in models

Things to remember

- **Training CNN**
 - Adam is common (AMSGrad can be tried)
 - Learning rate: Step decay, Cyclic learning rate
 - Transfer learning, Fine tuning
- **Regularization**
 - L2/L1/Elastic regularization
 - Dropout and Dropconnect
 - Batch Norm
 - Data Augmentation: Flip, Crop, Contrast, etc.
- **Interpreting Loss**
 - Bad initialization
 - Overfitting
 - Slow/High learning rates
 - Update in wrong direction
 - Etc.

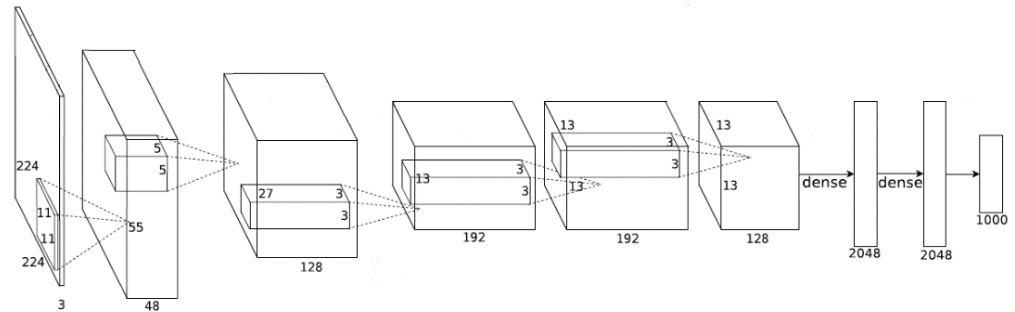
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 - Forsyth
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 - Derek Hoiem
 - D. Lowe
 - A. Bobick
 - S. Lazebnik
 - K. Grauman
 - R. Zaleski
 - Antonio Torralba
 - Rob Fergus
 - Leibe
 - And many more

Next Class

CNN Architectures: Plain Models

- LeNet
- AlexNet
- ZFNet
- VggNet
- Network in Network



CNN Architectures: DAG Models

- GoogLeNet
- ResNet
- Pre-act ResNet
- SENet
- DenseNet
- ResNetXt
- Etc.

